TOWARDS CLIMATE NEUTRALITY

ECONOMIC IMPACTS, OPPORTUNITIES AND RISKS

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Case studies of transition-related fields

Dr. Angela Wilkinson
Secretary General & CEO World Energy Council

Foreword

This is the most significant moment in the relationship between society and energy in 100 years. In the decade, which is decisive in terms of collaborative energy actions worldwide, societies everywhere are reeling from multiple energy price crises and grappling with the interconnected challenges of energy and climate security.

Better energy for people and planet, whilst not forgetting peace and prosperity, has been the enduring mission of the World Energy Council for 100 years.

The urgency to decarbonise without destabilising societies now involves rethinking the connections between energy and climate security in a new context of affordability and global justice movements.

Net zero is a tough and essential milestone for all countries: it is not enough to decarbonise energy supplies. We need to secure a safe operating space for humanity to flourish.

For decades to come, the world will need more energy for sustainable development. Renewable energy solutions will depend on global supply chains and other clean energy friends to get to scale. Net negative strategies will involve demand management and nature-based solutions. New models of human and economic development are emerging.

Clean and just energy transitions are pathways to a new paradigm of shared, circular and regenerative global development.

Energy is not a single-issue agenda. Diversity in energy is increasing in the broadest sense. There is no 'one-size-fits-all' approach. Managing the complex process of energy transition is not a simple technology substitution problem, it is a systemic leadership challenge. Getting ahead of globally connected challenges involves local actions.

The European energy security crisis has prompted a rethink of regional resilience. Lest we forget, Covid-19 extended resilience to people, communities, and supply chains. How Europe deals with its energy security crisis has cascading impacts on other regions and systems. Interdependence is not a choice.

As the world's locally deep and globally connected energy community network, we exist to support diverse regions, countries, and communities to lead with and learn from each other. Compounding crises have redirected leadership attention to managing all three dimensions of the World Energy Trilemma framework – energy security, energy affordability and environmental sustainability. In the Council, we do not just talk about the energy trilemma, we invented the concept and have been tracking performance of 120 countries for two decades.

Throwing money and technology at global climate and energy security challenges does not guarantee success. We have convened and facilitated collaboration between public, private and civil sectors for a century. More people and diverse communities need to be actively engaged in all regions.

Our strategic leadership agenda is focussed on the inclusive implementation gap: humanising energy to mobilise clean energy transitions and transformations at pace and scale in all regions. Our bold ambition is to achieve a step-change in global energy literacy by 2030, helping billions of people understand their roles, make better informed choices, and hold their leaders and each other to account for progressive energy actions.

As the world moves to COP28 and the 26th World Energy Congress, the challenges of inclusive implementation will remain front and centre of our humanising energy breakthrough impact action agenda. We believe we are heading in the right direction. We can and need to go faster, more fairly and further forward together. We are pulling world energy leadership together to avoid the climate emergency tearing societies apart.

In view of these challenges and opportunities, the publication of the current monograph, containing interdisciplinary reflections on navigating the bumpy road ahead is very timely. There is no silver – or green – technology bullet. All levers will be needed.

I am pleased to see that an entire section is dedicated to the World Energy Trilemma and how energy security AND affordability and equity AND environmental sustainability can be better managed in Latvia, and with reference to the new context of European and global energy developments. Whilst this is not a World Energy Council publication, many of our members have contributed their experiences and insights, including our vibrant Future Energy Leaders communities in Latvia, Portugal and Uruguay. We are proud to have established our first Future Energy Leaders programme over 40 years ago. Inclusive implementation is best achieved with the active involvement of NextGen leadership and talent.

I hope the rich content of this monograph will help make a meaningful difference in our everyday focus on progressing inclusive, clean and just energy transitions.

Andris Piebalgs
European Commissioner for Energy (2004–2010),
Professor at the European University Institute

Foreword

The invasion of Ukraine by the Russian Federation in late February 2022 has had a deep impact on Europe's energy sector. It has enormously increased uncertainty about international energy flows and prolonged the surge in wholesale gas and electricity prices, which was originally expected to decrease with the end of winter. Furthermore, the war has driven up the surge in prices of oil and its derivatives.

Beyond Europe, a price explosion of several raw materials, disruption of many supply chains and increasing tensions between global powers have exacerbated problems in international cooperation and suggest a broader shift towards a more complicated global order. This development has several implications for the energy transition, including a need to extend the notion of 'energy security' to include critical raw materials and intermediate goods. The world is facing an energy shock of unprecedented breadth and complexity.

Russia's invasion of Ukraine and the escalation of the energy crisis have shifted the focus of European and national policymakers to new short-term policy priorities and strategies, such as containing the impact of increasing energy prices on consumers and identifying alternative gas supplies. Implementation of strategies and policy priorities adopted before the outbreak of the war may not seem feasible at the moment. However, it remains essential for the current national emergency strategies and priorities not to undermine the important achievements of the past, such as the internal energy market, and not to forfeit long-term policy goals such as reaching net zero carbon emissions.

Accelerating the transition towards a low-carbon economy in Europe is the key to addressing the causes of the crisis the European Union is experiencing, and to supporting its energy security in the medium and long term.

In the short term, the European Union and its Member States have to urgently address the shock caused by the dramatic surge in energy prices. They should support those segments of society and the economy that have been hurt the most by the increase in energy prices and their volatility, and those that will continue to suffer until the end of the most acute phase of the crisis. Support measures should ideally be targeted and aim at the minimum possible distortion of the signalling of the resource cost by market prices.

Once the most acute phase of the current crisis is over, the EU and its Member States will have to consider the actions and perspectives in the decades up to 2050. This vision will have to be promptly translated into a roadmap based on no-regret options consistent with the strategy for 2030 and on all the major decarbonised technologies. In this roadmap, energy security will continue to score high on the list of priorities but will no longer focus on fossil fuels.

The monograph “Towards Climate Neutrality: Economic Impacts, Opportunities and Risks” provides valuable input for designing an efficient pathway to address European and global energy challenges. On the basis of a robust analysis of current trends, successes and failures, it proposes various scenarios for creating efficient energy policies moving towards climate neutrality. Notably, the monograph identifies two prerequisites for successfully rebuilding the existing energy systems: energy policies should be consistent, transparent and stable; and the development of new green energy technologies should be part of the backbone of industrial policies. The transition should also strike a careful balance between the clean and fossil energy systems. Both are required to deliver affordable energy services to consumers. The energy crisis we are facing now is a strong reminder that the transition to climate neutrality should be inclusive and affordable for all.

Prof. Inna Šteinbuka
Chair of Latvian Fiscal Discipline Council,
Professor at the University of Latvia

Introduction

The idea of this monograph is to present a set of interdisciplinary studies of the researchers from different countries to help creating a comprehensive roadmap towards climate neutrality.

The overall driving force behind the monograph is to contribute to reaching the EU climate neutrality by 2050. The findings and conclusions will support the implementation of the Paris Agreement[1], the European Green Deal[2], strategic vision "A Clean Planet for All"[3] and other EU priorities[4] in the areas of climate change mitigation,

1 UNCC (2015). Paris Agreement on Climate Change. Available: https://unfccc.int/process-and-meetings/the-paris-agreement

2 EU responses to climate change. Available: https://www.europarl.europa.eu/news/en/headlines/society/20180703STO07129/eu-responses-to-climate-change

3 A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX-%3A52018DC0773

4 2030 climate & energy framework. Available: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2030-climate-energy-framework_en

energy, environmental sustainability, and mobility[5]. In response to pandemic crisis and global energy market disruption caused by Russia's invasion in Ukraine, the authors' recommendations can serve well in implementation of the EU's Recovery Plan for Europe[6] and REPowerEU plan[7].

The research corresponds to the strategy of Latvia for Achieving Climate Neutrality until 2050[8] and the National Energy and Climate Plan of Latvia 2021–2030[9], which highlight a transition process to sustainable energy system, as well as the high importance of secure and affordable energy.

The negative effects of the fossil fuel dependency are reflected in the post-Covid-19 lockdown period with unprecedented high electricity price levels. The situation acutely deteriorated after Ukraine invasion, challenging the EU to undertake initiatives, such as the reduction on Russian gas by two thirds before the end of 2022[10], oil embargo and oil price cap. Therefore, the required level of security of supply has been designated, while the end-users mistrust the ability of market mechanisms to provide sufficient energy supply at reasonable prices. Moreover, decarbonisation, cost-effectiveness and affordability, security of supply and grid stability as well as other objectives[11] of the clean energy transformation depend on an efficient and effective network management and optimisation.

The monograph consists of four chapters. The first chapter gives the floor to two distinguished politicians for scene setting in Latvia and the European Union. In response to the new economic reality, at the end of 2022 the Latvian government has established a Climate and Energy Ministry. **Raimods Čudars, Minister of Climate and Energy**, kindly agreed to give an interview to co-editor of the monograph, **Dr. Olga Bogdanova.** By answering a number of questions, he has described his ambitious plans and priorities in navigating Latvia towards climate neutrality. **Valdis Dombrovskis, Executive Vice-President of the European**

5 REPowerEU Plan. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

6 Europe's moment: Repair and prepare for the next generation. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_940

7 REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

8 Latvijas stratēģija klimatneitralitātes sasniegšanai līdz 2050. gadam. Available: https://ec.europa.eu/clima/sites/lts/lts_lv_lv.pdf

9 Par Latvijas Nacionālo enerģētikas un klimata plānu 2021.–2030. gadam. Available: https://likumi.lv/ta/id/312423-par-latvijas-nacionalo-energetikas-un-klimata-planu-20212030-gadam

10 REPowerEU: Joint European action for more affordable, secure and sustainable energy. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511

11 Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2002&from=EN

Commission provides an analytical overview of the European Union's energy policy in the medium and long term, as well as the short-term measures. He concludes that the surge in energy prices and Russia's aggression towards Ukraine have forced the European Union to fundamentally rethink its energy policy. Clearly, the policy actions described in the paper do not cover all the EU's proposals and initiatives in the energy sector. However, even the already implemented EU energy instruments help continue the EU development towards achieving energy neutrality goal and sustainable economic growth.

The second chapter is aimed at the energy policy and its economic impact. **Oļegs Barānovs, Jānis Salmiņš, Irina Skribāne** have elaborated on the long-term macroeconomic trends affecting the Latvian energy sector. The authors argue that the future development of the Latvian economy and the energy sector will be significantly affected by the structural transformation of the economy. The crisis caused by the Covid-19 pandemic and the war in Ukraine are strong catalysts for transformation. The expected structural change is closely linked to the overall level of productivity in the economy. The scenarios developed by the authors suggest that the growth rate in the medium to long term will be determined by the ability to restructure the economy, to increase productivity based on improved production efficiency and innovation, to a lesser extent – on cheap labour and low resource prices.

How the way towards climate neutrality goal will affect production costs? **Olga Bogdanova and Kārlis Piģēns** are trying to find an answer. To this end, the authors are analysing determinant factors of energy prices, global energy transition policy scenarios and underlying assumptions. The three basic assumptions of the majority of scenarios are: 1) reducing energy demand by increasing efficiency; 2) end-consuming electrification and 3) decarbonisation of electricity generation. The implementation of sustainable transition scenarios based on these assumptions require massive investments. The risk assessment is crucial to prevent a potential skyrocketing of energy costs.

Ahmad Humbatov argues that the role of natural gas in the global energy transition for simultaneous achievement of climate neutrality, strong economic growth, and energy security remains high.

The timely decarbonisation of the global energy system is necessary to avoid the negative implications of climate change. **Konstantinos Fragkiadakis, Dimitris Fragkiadakis and Leonidas Paroussos** conclude that dynamics of the energy system and its interaction with the economy are quite complex and require an adequate quantitative assessment. The authors contribute to the empirical literature by providing new quantitative estimations on the energy – capital substitution elasticity accounting for structural breaks. The estimations are based on the statistics available from the WIOD database and cover the entire EU – 27 Member States and UK.

Smart energy policy planning calls for a clearly dedicated aim reflecting a well-balanced targets of Energy Trilemma dimensions highlighted by the World Energy Council (WEC) methodology: sustainability, security, and affordability. The third chapter of the monograph is aimed at finding the best balance of Energy Trilemma.

Edgars Groza, Kārlis Gičevskis, Edgars Smiltāns, Inese Karpoviča and Gunārs Valdmanis analyse one of the WEC's Energy Trilemma Index dimensions, namely, energy security. The paper provides a review of the most important criteria that are impacting the energy security dimensions score. This review focuses on the current state of the energy system, the current and future challenges, possible solutions and suggestions for maintaining and increasing of the energy security dimension's score.

Karīna Viskuba, Anrijs Tukulis, Tomass Liepnieks and Haralds Millers use the concept of the WEC's Trilemma Index to analyse Latvia's Environmental Sustainability and Green Energy Development. The study aims at scrutinizing Latvia's performance in WEC's Trilemma Index environmental sustainability pillar. The research focus on the environmental sustainability pillar's components of Trilemma Index – resource productivity, decarbonisation, emissions and pollution.

Romāns Oļekšijs, Fēlikss Zajecs, Egons Rozenfelds in a 'story-teller' manner present the issue of Energy Equity. The story starts with WEC Energy Trilemma methodology, which allows to assess the performance of more than 100 countries in terms of their ability to provide universal and affordable access to energy for both households and commercial enterprises. The WEC has made also significant work in rating and comparison of different country success in the Energy Equity. Despite achievements, some issues remain open for a more profound research. The aim of the study is to propose additional indicators that would allow the deeper analysis and better comparison of the energy situation in the countries with similar climatic conditions, population or gross domestic product (GDP).

FELPT (the group of authors) present a Portuguese case study of the life cycle assessment of renewable energy sources. The energy sector produces around 70% of greenhouse gas (GHG) emissions. Consequently, its decarbonisation is very relevant and can be achieved through renewable sources. The authors stress the importance of a life cycle assessment to evaluate the environmental impacts of the different electricity production technologies. They argue that strategic policies in the energy sector should aim at minimizing negative impacts, promoting the rational and efficient use of electricity. The authors recommend extending the analysis by using socio-economic sustainability indicators, which would allow an in-depth quantification of the impacts of the electrical production technologies on speeding up the transition to an effective green, sustainable, and fair economy.

The fourth chapter presents case studies of Uruguay, India and Latvia focussed on different transition-related fields.

Felipe Bastarrica et al. describe the emerging green hydrogen economy globally and in Uruguay. Like many economies around the world, Uruguay is trying to diversify its energy needs away from fossil fuels in the context of the Paris Agreement. Green hydrogen has gained momentum as a key decarbonisation enabler. This is particularly true, for instance, regarding the heavy industry and long-distance transport (air, maritime and land), where electrification is not possible. The case of Uruguay, where the first energy transition has been successfully completed, and the share of wind and solar energy in the electricity mix is second highest in the world, can serve as an encouraging example for many other countries.

Kaushal Kishore shares the experience of India in energy transition and emergence of electric vehicles. The study successfully illustrates the ways how the Indian economy has met the challenges of adopting renewable energy and EVs to support the energy transition.

Contrary to papers presenting the experience and expertise of developing countries (Uruguay and India), the focus of **Olegs Krasnopjorovs'** paper is capital city of Latvia. The research is aimed at measuring a perceived quality of the environment in Riga compared to other European cities. The author notes a lack of progress with perceived quality of urban environment in Riga over the recent years, and discusses the links between the urban environmental quality and people's health, economic development and the overall life satisfaction.

I hope that the monograph will help policy makers to meet challenges and avoid risks on the way towards climate neutrality. The monograph is also a useful source of information and inspiration for academic and business community, students and young researchers. Enjoy the reading!

Part I

Scene setting

Assoc. Prof. Olga Bogdanova,
President of the Latvian National Committee of the World Energy Council

Raimonds Čudars
Minister for Climate and Energy

Interview with Raimonds Čudars, Minister for Climate and Energy

2022 was the year which heralded major changes in society's perception of the energy sector. The previously understood urgency for fighting climate change processes supplemented with the socio-economic consequences of Covid-19 crisis was overtaken by the geopolitical shock of Russia's war in Ukraine, causing energy security and affordability tension in Europe. The fact that the energy sector of the Baltic states is still considerably interrelated with its eastern neighbour has had a significant impact on the energy sector's resilience and sustainability in Latvia during the geopolitical turbulence and in the long run. In the autumn of 2022, politicians of Latvia recognized the unquestionable need to speed up the transition to net zero emissions policy, substantially eliminating energy import dependency. The decision was taken to prioritize energy and climate issues under the competence of a separate ministry – the Climate and Energy Ministry. In December 2022, Mr. Raimonds Čudars joined the Cabinet of Ministers, taking on the ambitious position of Climate and Energy Minister.

Assoc. Prof. Olga Bogdanova had an honour of talking to Mr. Raimonds Čudars, the Minister of the newly created the Climate and Energy Ministry, discussing the challenges of Latvia on its way to climate neutrality. The opinion of the Minister regarding the vision and perspectives of the energy sector in Latvia, as well as the intentions and plans for the Climate and Energy Ministry are reflected here for the readers of this monograph.

How do you see Latvian energy sector in perspective of years 2035 and 2050? What is the strategic aim you would define for the newly created Climate and Energy Ministry?

Latvia is one of the European leaders in the use of renewable sources of energy. The capacities of the hydro power plants of the Daugava River cascade, as well as the use of biomass in the production of thermal energy have enabled the amount of our renewable energy resources as the proportion of total energy consumption to exceed 40%, and in the production of electricity – 50%. We are currently in the midst of an energy revolution. Our common goals of climate neutrality can be achieved by significantly increasing the share of RES and becoming a green energy exporting country.

What will be the main focus of the newly created Climate and Energy Ministry, and which steps should be taken to achieve the desired aim in a long-term and in medium-term?

We will focus on attracting investments to increase wind and solar power generation, as well as strengthening power transmission and distribution systems; it is also important to boost the capacity of Latvian interconnections on a European scale. Regarding thermal energy, our long-term goal is to ensure that directly available and affordable electricity becomes the main source of heat – the mass introduction of heat pumps and photovoltaic technologies in households is the way forward. The spread of centralized heat supply systems is Latvia's advantage, which should be developed further.

In addition to the energy sector, transport and agriculture play an equally important role in reducing GHG emissions. Eliminating the use of internal combustion engines, as well as the introduction of environmentally friendly agricultural technologies is a prerequisite on our way to climate neutrality.

Which challenges you expect to require the most efforts on the way to the desired aim?

The challenges caused by the effects of climate change have been supplemented by the geopolitical consequences of Russia's criminal war against Ukraine. Altogether, this has determined the need for a much faster economic and, of course, energy transformation. The concern is our ability to cover the costs of such rapid changes. Stable and affordable prices will constitute the main challenge in this swift phase of transformation. Maintaining and facilitating the competitiveness of the national economy, protecting households from the excessive burden of utility payments – these are our main goals.

Who should be the main actors involved in making the sustainable energy policy transition process successful?

First of all, our people! It is in our own hands to change our daily habits and to introduce general energy efficiency into our lives. The consumption of fossil natural gas in Latvia in the month of November 2022 fell by more than 40% compared to the previous year. No doubt, this was largely due to the extraordinary prices; however, it also made us realize that the past situation will no longer be the case in the future! In addition, individual households have an important function in generation of solar energy. Even now, by installing solar panels on the roofs of houses, Latvia as a whole creates a large distributed solar park.

Secondly, the readiness and ability of energy producing companies to invest in the development of RES capacities will be crucial. It should be highlighted that the significant amount of RES electricity can be generated in a relatively short time by the joint project of the Latvian state forests and JSC Latvenergo – Latvian wind farms.

Thirdly, in this transitional phase, power transmission and distribution capacity, as well as connection availability are more important than ever. The ability of the state-governed transmission and distribution system companies to adjust to the changes will be a decisive factor.

And, of course, the policy makers. We cannot afford delays, ill-considered decisions, unreasonable bureaucratic hinderance, or lobbying of specific interests that are not focused on the common benefit.

How Climate and Energy Ministry as a separate institution particularly focused on the energy sector could facilitate the transition process? What was missing in the previous approach governing energy policy together with other sectors of economy?

It is important that we duly respond to today's challenges with common and well-coordinated policy-making in both climate change and energy. These sectors are comprehensive, covering the entire economy.

What would be your message to the readers of the monograph regarding our challenge of achieving secure, affordable and sustainable energy in the future?

Insecurity and doubts about the future are always overcome only by participating in the creation of that future. Latvia does not have abundant mineral deposits, oil or gas. However, Latvia does have much more – a huge potential of renewable energy and nature!

On behalf of the editors and the authors of the monograph we would like to thank Minister Raimonds Čudars for the interview and to wish him success in leading Latvia through the transition process of climate and energy policy towards sustainable, affordable and secure energy system facilitating economic growth of Latvia.

Valdis Dombrovskis
Executive Vice-President of the European Commission

Europe’s energy policy – from short-term solutions to the crisis to the long-term outlook

This paper gives an overview of the European Union’s energy policy in the medium and long term, as well as the short-term measures to stabilise the energy market against a backdrop of rapidly rising energy prices and gas supply problems.

The European Union’s main challenges in the energy sector are currently related to factors such as its dependence on imported energy, limited geographic availability of energy supply sources, high and volatile energy prices and the growing global demand for energy. At the same time, we see increasing geopolitical security threats that affect both producer and transit countries, slow progress in energy efficiency and the ever-increasing impact of climate change on our planet. Challenges also include the need for a greater transparency in the energy sector and further integration of Europe’s energy market.

1. Europe's Energy Union strategy

The EU's energy policy is based on measures which aim to bring about an integrated energy market, increase the security of energy supply and establish a sustainable energy sector.

The European Union's energy policy is now based on the Energy Union strategy, which was adopted in February 2015, and on the related Regulation on the governance of Europe's Energy Union, adopted in December 2018[1]. The strategy aims to establish an energy union for European consumers – households and businesses alike – to have access to safe, sustainable and competitive energy at affordable prices.

Its main objectives are:

- to diversify Europe's energy sources and ensure security of supply, drawing on solidarity and cooperation between EU Member States;
- to safeguard the functioning of a fully integrated internal market in energy and guarantee the free flow of energy in the European Union by creating the relevant infrastructure and removing technical and regulatory barriers to energy flows;
- to improve energy efficiency and reduce dependence on imported energy, reduce emissions and promote employment and growth;
- to decarbonise the economy and transition towards a low-emissions economy in line with the Paris Agreement;
- to promote research and innovation in low emissions and clean energy technologies in a bid to drive energy transformation forward and improve competitiveness.

2. The European Green Deal

When the new European Commission began its work in 2019, the European Green Deal became one of its flagship policies. This is a new and ambitious EU climate policy which aims to reduce greenhouse gas emissions by 55% by 2030 (compared with 1990 levels) and reach climate neutrality by 2050.

The main ways of achieving the European Green Deal objectives are, for instance, investing in environmentally friendly technologies, decarbonising the energy sector, ensuring that buildings are energy efficient and introducing cleaner means of private and public transport.

The Energy Union is still the main policy instrument for decarbonising our energy system. To make sure that policies and measures tie in with each other

1 European Commission (2015) COM/2015/080 and 2018/1999.

at various levels, and to make sure that they are mutually complementary and with sufficient ambition, governance of the Energy Union is based on integrated national energy and climate plans.

For example, Latvia's climate and energy plan for 2021–2030[2] sets out 12 lines of action. The first six relate directly to the energy sector, while the remaining six relate to other policy areas – agriculture, taxation and communicating with the public. The ones addressing the energy transition are the following:

- raising the energy efficiency of buildings;
- boosting energy efficiency and promoting the use of renewable energy technologies for heating and cooling and in industry;
- promoting the use of zero-emission technologies in the electricity production sector;
- promoting own-generation and own-consumption of economically viable energy;
- increasing energy efficiency and encouraging the use of alternative fuels and renewable energy technologies in the transport sector;
- energy security, reducing energy dependence, full integration of energy markets and modernisation of infrastructure.

Latvia's plan was drawn up in close conjunction with the Energy Union objectives, whose details are shown in Table 1.

As for the European Green Deal, a major reform package designed to implement the green transition was published in June 2021 – known as 'Fit for 55' plan[3]. The package includes a raft of energy-related measures including the reform of the Emissions Trading System (ETS), a Carbon Border Adjustment Mechanism (CBAM) and emission standards for vehicles. It also includes long-term measures in the energy sector, namely:

- increasing the renewable energy target from 32% to 40%, with the simplification of licensing procedures and the removal of other obstacles;
- new energy efficiency targets for 2030, i.e. 36% of final consumption and 39% of primary energy consumption, and a public sector's obligation to renovate 3% of its buildings each year;
- overhaul of the taxation system for electricity and energy resources based on energy content and ecological characteristics.

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2 Par Latvijas Nacionālo enerģētikas un klimata plānu 2021.–2030. gadam (likumi.lv). Available: https://likumi.lv/ta/id/312423-par-latvijas-nacionalo-energetikas-un-klimata-planu-20212030-gadam

3 Fit for 55 – The EU's plan for a green transition – Consilium (europa.eu). Available: https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/

Table 1. **The objectives set by Latvia for the 2021–2030 climate and energy plan**

Policy outcome in each dimension of the Plan	EU		Latvia		
	Target value		Actual value	Target value	
	2020	2030	2017	2020	2030
1.1. GHG emission reduction target (% compared to 1990)	–20	–40	–57	–	–65
1.1.1. Non-ETS activities (% compared to 2005)	–10	–30	+7	+17	–6
1.1.2. LULUCF accounting categories (million t)[4, 5]	–	0	–	0	–3.1
1.1.3. Transport energy life-cycle GHG emission intensity reduction (%)	6	6	0.8	6	≥6
1.2. Share of energy produced from RES in gross final energy consumption (%)	20	32	39	40	50
1.3. Share of energy produced from RES in gross final energy consumption in transport (%)	10	14	2.5	10	7[12]
1.4. Share of advanced biofuels & biogas[6] in gross final energy consumption in transport (%)	–	3.5	0	–	3.5
2.1. Mandatory national target – cumulated final energy savings (Mtoe)	–	–	0.45	0.85	1.76
2.2. Building renovation target (total renovated m^2)	–	–	398.707	678.460	500.000
3. Share of imports in gross national energy consumption (incl. bunkering) (%)	–	–	44.1	44.1	30–40
4. Interconnection capacity (% of total generation capacity)	10	15	60	10	60
5.1. Investment in R&D (% of GDP)	3	–	0.51	0.7	>2
5.2. Global Competitiveness Index (position in the world)	–	–	42	–	higher than 42

4 GHG emission reduction and CO_2 removal target in LULUCF accounting categories in 2030.

5 The target can be reached by setting an obligation for fuel suppliers, within whose scope it is allowed to use advanced biofuel and/or biogas, produced from the raw materials listed in Annex IX to Directive 2018/2001, electricity obtained from RES, hydrogen obtained from RES, processed carbon fuels, as well as other biofuels or biomass fuels which are not produced from food or animal feed crops.

6 Advanced biofuel & biogas should be produced from the raw materials listed in Part A of Annex IX to Directive 2018/2001, for example, animal manure, sewage sludge, straw, different waste, etc.

3. Surge in energy prices

Against this backdrop of medium- and long-term measures, the surge in energy prices is one of the most pressing problems that the European Commission had to deal with over the course of 2022. This began with the global economic recovery from the Covid-19 pandemic and the related surge in energy demand, which outstripped supply. Energy supply problems were the result of insufficient investment in the exploitation of energy resources during the previous years. The situation was also exacerbated by the unfavourable climate conditions in 2021, which created additional demand for energy while restricting the supply of renewable energy at the same time, particularly wind and hydropower. Overall, it can be said that the surge in energy prices was not caused by a single factor or circumstance but by a whole range of factors[7]. Restrictions of gas supplies from Russia created more problems in the European Union, and the energy market situation deteriorated further with the Russian invasion of Ukraine in February 2022. Russia's aggression caused an additional rise in energy and food prices, increasing the overall inflationary pressure and reducing the purchasing power of households. Further supply problems came as Russia reduced gas supplies to a number of EU Member States or cut them off altogether. Figure 1 shows the sharp fall in supplies of Russian gas between January and August 2022 compared to the corresponding period in the previous year. The volume of gas supplies from Russia fell further still in the autumn of 2022.

In addition, the EU sanctions on Russia are set to ban imports of Russian coal and, to a large extent, oil. 2022 has therefore been characterised by high and extremely unstable prices on the energy market.

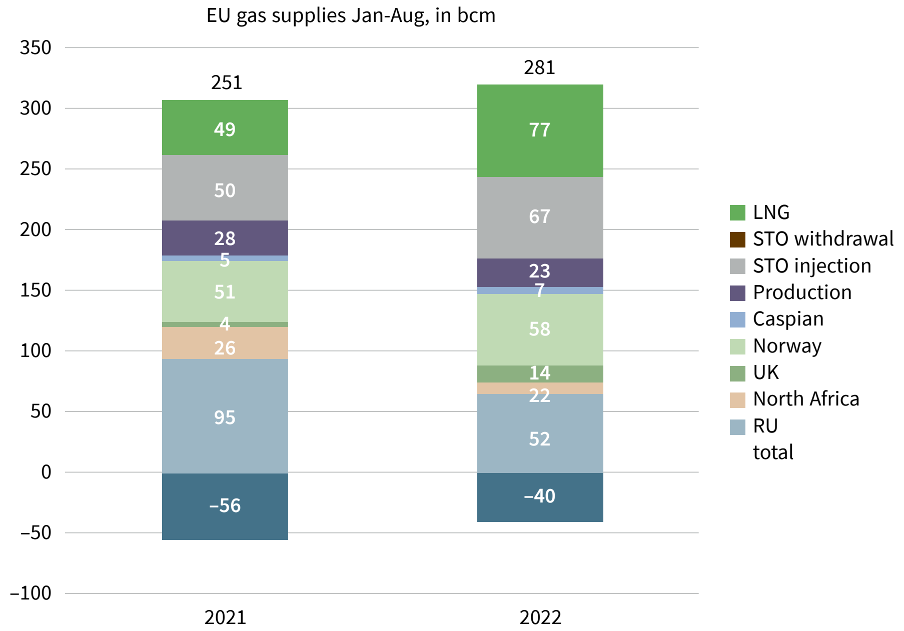
It is clear that the EU is faced with a complex problem. Solving it will require a complex solution including measures such as ensuring security of energy supplies and diversifying supply sources, along with social measures to protect the population, support measures for businesses and energy saving measures.

Table 2 shows that a significant share of the EU Member States' energy resources is still made up of fossil fuel.

As one can see, the European Union is still characterized by its dependence on imports of fossil fuel. The level of its dependence can be gauged from the fact that fossil fuel accounted for 57–60% of total energy consumption over the past five years. Even though intra-EU production of renewable energy resources has increased considerably over the last few years, the EU is still dependent on imports of gas (90% of gas consumption), oil (97%) and coal (70%). In 2021, Russia provided

7 Fernández Alvarez, C., Molnar, G. (2021). What is behind soaring energy prices and what happens next? iea.org. Available: https://www.iea.org/commentaries/what-is-behind-soaring-energy-prices-and-what-happens-next

Figure 1. Supplies of natural gas to the European Union in January–August 2021 and 2022



around 45% of the EU's total gas imports (either via pipelines or in the form of liquefied gas). Other major gas suppliers to the European Union were Norway (23%), Algeria (12%), the US (6%) and Qatar (5%). In the oil sector, the main supplier was Russia (27%), followed by Norway (8%), Kazakhstan (8%) and the US (8%). In 2021, the leading supplier of coal was also Russia (46%), although import volumes were down on previous years, followed by the US (15%) and Australia (13%).[8]

As can be seen from Table 3, many EU Member States have seen major – even several times – increases in the price of gas in recent years. Given that electricity prices are to a large extent linked to gas prices on the EU market, similar trends have also been observed in electricity prices.

8 EC working paper. EU Action to Address the Energy Crisis. Last update: 20 September 2022

Table 2. Structure of energy resources in EU Member States 2019 (%)

Energy mix 2019	EU27	BE	BG	CZ	DK	DE	EE	IE	GR	ES	FR	HR	IT	CY
Solid fossil fuels	11.3	4.7	27.7	33.1	4.8	17.5	0.3	2.5	12.3	3.7	2.9	4.7	4.1	0.6
Natural gas	22.4	23.4	12.9	16.7	14.2	24.6	8.0	30.2	17.2	23.1	14.8	27.3	38.6	0.0
Oil and petroleum products	36.4	46.4	25.5	23.0	42.5	36.3	4.3	50.2	54.9	47.2	31.2	37.4	35.9	89.9
Renewables and biofuels	15.3	6.7	13.1	11.4	33.4	14.8	23.5	10.8	12.2	14.1	11.2	24.2	18.7	8.5
Non-renewable waste	0.9	1.0	0.4	0.8.	2.4	1.4	0.8	1.0	0.2	0.2	0.7	0.3	0.7	1.1
Nuclear heat	13.1	17.5	22.7	17.6	0.0	6.3	0.0	0.0	0.0	11.3	41.1	0.0	0.0	0.0
Energy mix 2019	**LV**	**LT**	**LU**	**HU**	**MT**	**NL**	**AT**	**PL**	**PT**	**RO**	**SI**	**SK**	**FI**	**SE**
Solid fossil fuels	0.8	2.1	0.9	6.8	0.0	7.3	8.1	42.1	5.0	14.8	15.4	16.0	6.2	3.6
Natural gas	22.3	23.3	15.1	31.7	9.7	36.5	22.1	16.2	21.3	27.9	10.6	24.0	6.2	1.9
Oil and petroleum products	37.2	40.1	65.0	30.6	87.0	47.6	37.3	30.3	47.4	29.7	37.0	21.1	25.7	24.5
Renewables and biofuels	36.9	19.9	7.1	10.6	1.6	6.2	29.8	9.5	24.4	18.1	16.5	12.9	35.4	41.1
Non-renewable waste	0.9	0.4	0.8	0.8	0.0	0.9	2.0	1.0	0.8	0.5	0.9	1.2	0.9	1.6
Nuclear heat	0.0	0.0	0.0	15.4	0.0	1.0	0.0	0.0	0.0	8.6	19.9	23.8	16.4	31.4

Table 3. Changes in the prices of gas and electricity between 2019 and 2021 (%)

	BE	BG	CZ	DK	DE	EE	IE	EL	ES	FR	HR	IT	CY	LV
Wholesale gas	592	159	565	554	559	264	100	11	370	562	N/A	406	N/A	271
Retail gas	38	23	7	51	5	–12	0	28	4	25	5	14	N/A	25
Wholesale electricity	306	122	227	245	259	151	343	121	271	281	153	210	N/A	153
Retail electricity	21	8	15	16	5	23	14	19	8	5	3	–2	–2	4
	LT	**LU**	**HU**	**MT**	**NL**	**AT**	**PL**	**PT**	**RO**	**SI**	**SK**	**FI**	**SE**	**EU**
Wholesale gas	283	572	410	N/A	572	463	504	0	–41	52	37	289	7	429
Retail gas	8	17	–6	N/A	29	19	–2	–4	103	–1	–8	N/A	6	14
Wholesale electricity	154	259	143	171	273	258	83	271	121	151	206	83	135	230
Retail electricity	17	7	–5	0	–20	14	3	–4	48	5	9	5	17	7

9 DG ENER, European Commission.

In view of the current situation and its negative impact on household purchasing power and business competitiveness, the EU Member States, including Latvia, are providing significant support to households and businesses. At the same time, the EU is working on common measures to overcome the crisis.

4. Measures to stabilize the energy market and regularize prices

4.1. Supply-side measures

As regards the measures which the European institutions have adopted to cope with the energy crisis, most of them simultaneously address several of the challenges described above.

The first instrument, which the European Commission adopted in October 2021, was the energy prices toolbox[10]. This was complemented the following spring by the Communication on short-term market interventions and long-term structural adjustment of the energy market[11] and the REPowerEU plan.

4.2. The energy prices toolbox

The energy prices toolbox features measures designed to mitigate the effects of sudden price volatility on the energy market. These include both short-term measures to protect consumers and medium-term structural measures to bolster energy systems. Figure 2 shows the progress made with implementing the toolbox recommendations in the EU Member States.

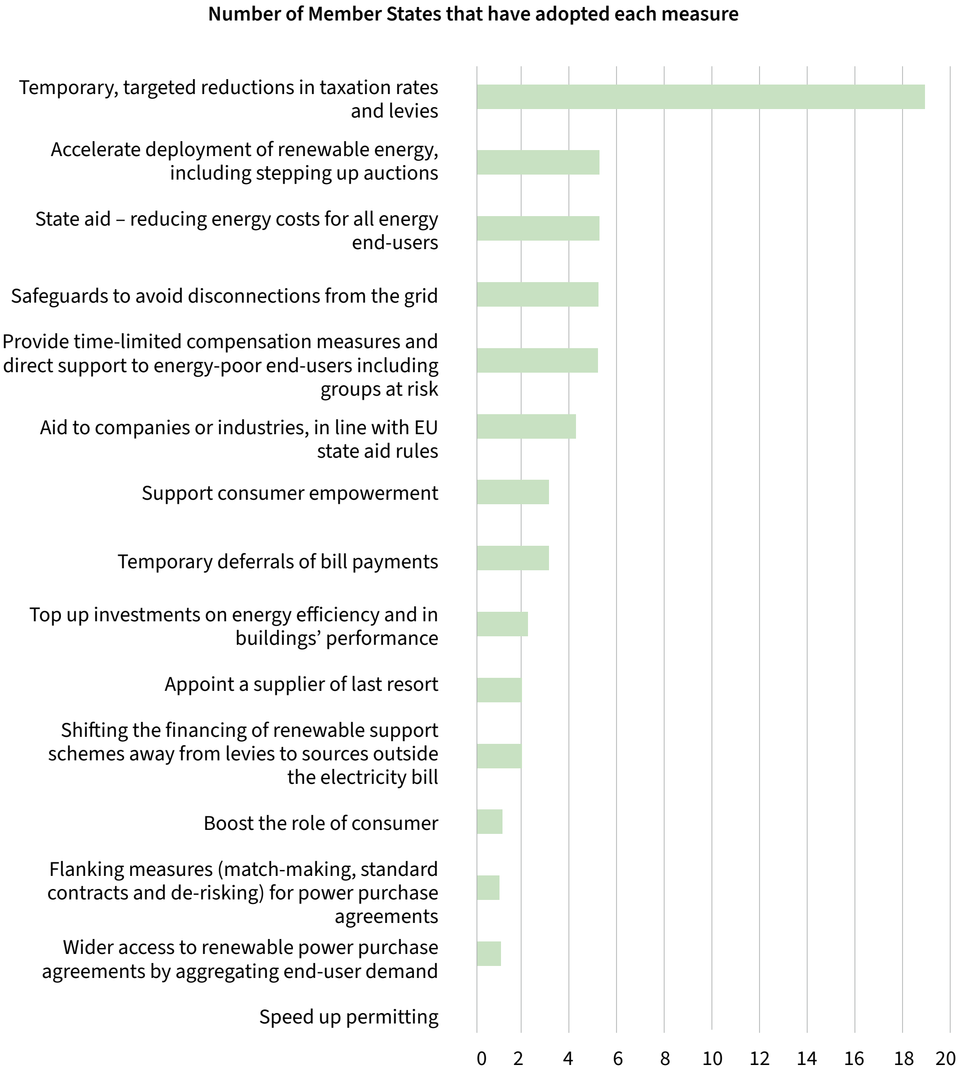
REPowerEU

Against this backdrop and almost immediately after Russia's invasion of Ukraine, in March 2022 the European Commission adopted the REPowerEU communication[12], and proposed the REPowerEU plan in May[13].

REPowerEU was Europe's answer both to Russia's aggression against Ukraine and to its ongoing policy of energy blackmail against the EU Member States. These measures aim to achieve full independence from Russian fossil fuel whilst simultaneously expediting the transition to cleaner energy. They come in addition

10 EUR-Lex - 52021DC0660 - EN - EUR-Lex (europa.eu)
11 EUR-Lex - 52022DC0236 - EN - EUR-Lex (europa.eu)
12 EUR-Lex - 52022DC0108 - EN - EUR-Lex (europa.eu)
13 EUR-Lex - 52022DC0230 - EN - EUR-Lex (europa.eu)

Figure 2. **Implementation of energy prices toolbox measures**



to the sanctions against Russia adopted in a number of areas, including the energy sector. I will return to sanctions a little later on.

The REPowerEU communication identifies the following workstreams:

- to create new energy partnerships or consolidate existing ones with a view to securing reliable suppliers throughout the world;
- to ensure that the EU is ready for future decrease in Russian gas supplies, including by making sure that the EU's natural gas storage facilities are filled up to the legally required levels before winter;
- to expedite the transition to clean energy by implementing the recommendations in the 'Fit for 55' European Green Deal package and launching new initiatives for the deployment of renewable energy resources, energy efficiency and energy saving measures.

The REPowerEU plan aims to expedite the phasing out of energy resources imported from Russia, reduce the EU's dependence on fossil fuels, reinforce the energy market against price volatility and accelerate implementation of the Green Deal. It features the measures geared to four main strategic objectives – saving energy, diversifying energy supplies, accelerating the replacement of fossil fuels with clean energy sources and mutually streamlined reforms and investments.

REPowerEU aims to boost energy efficiency by increasing efficiency targets to 13% compared with the previous target of 9% set out in the 'Fit for 55' package. It also includes the EU 'Save Energy' Communication[14] which recommends short-term changes in consumer behaviour that could reduce the demand for gas and oil products by 5%. Member States are also encouraged to launch public awareness campaigns as soon as possible.

Regarding diversification of gas supplies, and based on the European Council's mandate of March 2022, the European Commission and the EU Member States are voluntarily setting up an EU energy platform. Here, the idea is to pool Member State demand for different types of energy, as well as organising and negotiating the joint procurement of gas, liquefied gas and potentially hydrogen with international suppliers. As far as possible, this will be coordinated with more efficient use of the existing energy sector infrastructure. The first Member States groups have already been set up, and negotiations are starting with third-country suppliers. Agreements have been signed with Norway, the US, Canada, Egypt, Israel and Azerbaijan, and in October 2022 energy discussions resumed with Algeria. As a result, gas supplies from Norway, the US and other countries have increased significantly in a short space of time, largely replacing Russian gas supplies. In the autumn of 2022, Norway became the EU's leading gas supplier. In the run-up to winter we have managed to fill gas storage facilities – more than 90% of the capacity by October.

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14 EUR-Lex - 52022DC0240 - EN - EUR-Lex (europa.eu)

The plan envisages accelerating the deployment of renewable energy sources (solar, wind, hydrogen) with a higher renewables target of 45% in the EU's energy mix by 2030 (compared with the previous target of 40%). It simplifies and expedites licensing procedures for investments in renewable energy projects whilst minimizing potential environmental risks. It also identifies 'go-to' areas that are particularly suited to the construction of renewable energy infrastructure: construction permits will be issued for entire areas instead of individually.

Solar energy

The plan also sets out the EU's first solar energy strategy, which aims to double solar photovoltaic capacity in the European Union by 2025 and install 600 gigawatts by 2030.

Under the 'solar roof' initiative, a legal obligation would be gradually introduced for installing roof solar panels in all new public and commercial buildings and new residential housing from 2026.

Other areas identified include the wider use of heat pumps, and doubling their deployment rate; and measures to integrate geothermal and solar thermal energy into state-of-the art district and communal heating systems.

Hydrogen

One of the most promising future carriers of energy is hydrogen. The EU is focusing on developing its production and creating a European hydrogen market, paying particular attention to 'green' hydrogen. The REPowerEU plan has a target of producing 10 million tonnes of local renewable hydrogen by 2030 and importing 10 million tonnes of hydrogen to replace gas, coal and oil in production sectors that are difficult to decarbonise, and also in the transport sector. This will entail developing standards for hydrogen infrastructure, and for production and end-use installations.

Establishing a new European hydrogen bank will be a major boost to the creation of a European hydrogen market. This will help to guarantee the supply of hydrogen, with 3 billion euros invested from the Innovation Fund to provide support for procuring hydrogen to help overcome the current problem of insufficient investment in Europe's hydrogen sector.

It should be noted that the 'Fit for 55' package also provides for setting up European Network for Network Operators of Hydrogen to build more hydrogen infrastructure and promote cross-border coordination and interconnections.

Energy security and the filling of gas storage facilities

Gas storage plays a crucial role in the EU's energy security. With a view to increasing the EU's preparedness and its ability to react to risks to the security of gas supply, REPowerEU calls on Member States to grant sufficient support – including financially – to projects that will boost storage and withdrawal capacities. It is estimated that around 10 billion euros in investments will be needed by 2030 to secure imports of LNG and piped gas.

The EU Member States are already working intensively on raising their gas storage capacities. According to the Gas Storage Regulation adopted in June 2022[15], a minimum filling level was set for gas storage facilities – 80% by 1 November 2022 and 90% for subsequent years. As mentioned before, the 2022 objective has already been exceeded.

Investment and infrastructure

In addition to funding already earmarked under the Green Deal, the EU is likely to need another 210 billion euros to reach the REPowerEU objectives, in the period up to 2027.

Furthermore, a regional assessment of gas infrastructure needs shows that reduced demand combined with the accelerated domestic production of biogas and hydrogen and limited extensions of gas infrastructure will fully compensate imports of Russian gas. Substantial infrastructure extensions will be needed in central and eastern Europe and northern Germany, and the capacity of the southern gas corridor will also need to be expanded. This additional infrastructure should meet the gas needs of the next decade without creating a fossil fuel 'trap' or stranded assets that are not needed for the long-term transition to a climate-neutral economy.

The REPowerEU plan promotes the construction of new gas pipelines and interconnections, where work is already underway. For example, in May 2022 a gas interconnection between Poland and Lithuania was opened, in August an interconnection between Poland and Slovakia, in September the Baltic pipe from Norway to Denmark and Poland, and in October a pipeline between Greece and Bulgaria. In May, a new floating liquefied gas terminal entered into operation in Alexandropoulis in Greece. Estonia is building a liquefied gas terminal in Paldiski and work is underway on the Skulte liquefied gas terminal project in Latvia.

External energy strategy

In parallel, the EU's external energy strategy aims to promote the diversification of energy supplies and long-term partnership with suppliers. This includes working together on hydrogen and other green technologies.

It calls for the EU energy sector to support Ukraine, Moldova, Georgia and the countries of the Western Balkans, along with other partners – given Russia's ongoing aggressive policy.

15 European Union (2022). Regulation of the European Parliament and of the Council amending Regulations (EU) 2017/1938 and (EC) No 715/2009 with regard to gas storage. Available: https://data.consilium.europa.eu/doc/document/PE-24-2022-INIT/en/pdf

Cooperation with Ukraine will continue: strengthening of supply security and a functioning energy sector; the simultaneous drafting of preconditions for the continued trading of electrical energy and potentially renewable hydrogen; rebuilding and upgrading of the energy systems as part of the REPowerUkraine initiative.

4.3. Demand-side measures

Along with measures to expand and diversify the supply of energy resources, some of the more effective short-term policy instruments include the measures designed to restrict demand, initially – for electricity and gas.

The 'Save gas for a safe winter' plan and Regulation

In August 2022, the EU advanced with a new law to reduce gas demand. The Regulation on coordinated measures to reduce gas demand sets a target for all Member States to reduce their gas demand by 15% between 1 August 2022 and 31 March 2023. It authorises the European Commission to issue a 'Union warning' on supply security, obliging all Member States to reduce demand for gas. Provision is also made for the possibility, where necessary, of optimising gas distribution to cover critical supplies for the Member States.

4.4. Emergency market intervention

In September 2022, the European Commission proposed a new regulation on emergency intervention[16] with a view to reducing the energy bills of households and businesses. It includes measures to reduce demand for electricity, including at peak hours, which will help reduce costs for consumers. It also proposes a temporary cap on revenues for electricity producers who use technologies with lower marginal costs – such as renewables and nuclear energy. The Commission proposes setting a revenue cap for so-called 'infra-marginal' producers at EUR 180/MWh. The third measure is a temporary solidarity contribution on surplus profits in the fossil sector. EU Member States would collect this contribution for 2022 and/or 2023 profits that are at least 120% of the average of the previous three years, and the proceeds of the contribution would be passed onto energy consumers.

16 European Commission, Directorate-General for Energy (2022). Proposal for a Council Regulation on an emergency intervention to address high energy prices. COM/2022/473. Available: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2022:473:FIN

Further, in October 2022 the European Commission presented a proposal for a regulation[17] for coordinating gas purchases, exchanges of gas across borders and reliable price benchmarks. Its aims are to guarantee the security of gas supplies in the European Union, promote Member State solidarity on the gas market and restrict excessive price volatility on the gas markets.

The proposed measures will allow to collect data on gas demand in the Member States, to organize joint purchases of gas, to set the price caps and stabilisation mechanisms on the gas markets, to promote transparent use of infrastructure and to strengthen solidarity between Member States when gas supply is being disrupted.

The Regulation also allows Member States to make use of European Structural and Cohesion Funds that are still available from the 2014–2020 programming period to support households and businesses affected by the energy crisis.

Financial markets

High gas and electricity prices also have a negative impact on financial markets. Due to the surge in energy prices and market volatility, energy producers and traders have faced very high margin calls to keep their futures positions open. In turn, this requires large sums of money that can be difficult to secure in the short term, creating credit risks in respect of margin calls and the solvency of the companies concerned.

Consequently, in September 2022, the European Commission presented a number of measures to address the liquidity problem for energy companies facing increased margin calls. The measures being considered include, for instance, the use of blocking systems in the event of excessive intra-day market volatility and the possibility of extending the list of eligible assets that energy companies may submit as collateral, thus solving their liquidity problems. The European Commission is also reviewing the State aid temporary crisis framework to ensure that Member States can continue to provide necessary and proportionate support to energy companies with high safety reserve requirements by making use of, among other things, State guarantees.

At the same time, as the share of liquefied gas in imports grows, the current Title Transfer Facility (TTF) index, which is based on pipeline gas, no longer accurately reflects the gas price structure on the European market and may lead to a mark-up of as much as 30%[18]. Work is now underway on a new EU gas price index to better reflect the realities of the European energy market.

17 COM (2022) 549: Proposal for a Council Regulation Enhancing solidarity through better coordination of gas purchases, exchanges of gas across borders and reliable price benchmarks. COM/2022/549. Available: https://eur-lex.europa.eu/legal-content/EN/HIS/?uri=COM:2022:549:FIN

18 DG ENER, European Commission.

High gas prices also lead to high electricity prices, since the latter are now largely linked to the former in the EU market. In addition to short-term market intervention measures, therefore, a long-term solution that decouples gas prices from electricity prices is needed. This will be one of the elements for the structural reform of the electricity market, which the European Commission will present by the end of 2022[19].

4.5. Funding

4.5.1. The EU Green Deal

To achieve the targets laid down in the European Green Deal, the European Commission has committed to mobilize over one trillion euros in long-term investments within 10 years.

Much of this funding will come from the EU's Multiannual Financial Framework 2021–2027 and the European economic recovery plan NextGenerationEU with a total amount of 2.018 trillion euros. 30% of the EU's Multiannual Financial Framework (MFF) and the NextGenerationEU plan financing is dedicated to the green investment, including investment in energy transition related projects. Table 4 shows climate mainstreaming targets for different EU-financed programmes. The largest part of the NextGenerationEU plan is the recovery and resilience facility with 672.5 billion euros. Member States in their national recovery and resilience plans have to dedicate at least 37% to climate related investments and reforms. This means that up to 248.8 billion euros will be available for climate related investment, making the recovery and resilience facility the single most important instrument for green transition (assuming full uptake of its loan component). In addition, the investments and reforms that are eligible for financing must not significantly harm the EU's other environmental objectives ("Do no significant harm" principle).

4.5.2. The EU cohesion policy

The European Union's cohesion policy helps Member States and regions to implement investments which also contribute to the objectives of the European Green Deal. At least 30% of the 226 billion euros coming from the European Regional Development Fund must be dedicated to investments of this type. In addition, 37% of the 48 billion euros from the Cohesion Fund goes towards climate neutrality objectives, including energy measures.

19 From Ursula von der Leyen's letter to the European Council of 5 October 2022.

Table 4. **Climate mainstreaming in Multiannual Financial Framework 2021–2027**

Climate contribution figures in million EUR at 2018 prices	Climate coefficient in the legal basis	Total Climate contribution
Horizon Europe (research)	35%	28 315
ITER (International Thermonuclear Experimental Reactor)	100%	5000
InvestEU Fund	30%	2520
Connecting Europe Facility	60%	11 038
ERDF (European Regional Development Fund)	30%	60 108
Cohesion Fund	37%	15 746
REACT EU (Recovery assistance for cohesion & the territories)	25%	11 875
Recovery and Resilience Facility	37%	248 825
CAP (Common Agricultural Policy) 2021–2022	26%	26 468
CAP 2023–2027	40%	96 857
EMFF (European Maritime and Fisheries Fund)	30%	1629
LIFE (environmental projects)	61%	2935
Just Transition Mechanism	100%	19 000
NDICI (Neighbourhood, Development and International Cooperation Instrument)	25%	17 700
OCT (Overseas Countries and Territories)	25%	111
Pre-Accession Assistance	16%	2010
Total		550 137

Another 17.5 billion euros are available for a number of European regions under the Just Transition Fund to support the transition from fossil fuel to renewables and other climate-related investment[20].

4.5.3. REPowerEU funding

To achieve the REPowerEU targets, additional funding will be needed (on top of the one to meet the ‘Fit for 55’ objectives) – around 210 billion euros by 2027, and around 300 billion euros by 2030. To implement the REPowerEU plan, there are plans to use the 225 billion euros still available as of October 2022 under the loans part of the recovery and resilience facility. Additional 20 billion euros are being earmarked in form of grants.

20 The prices of 2018.

4. Sanctions against Russia

Since the Russian invasion of Ukraine, the European Union is exerting pressure on Russia (and its ally Belarus) by applying strict and broad-ranging sanctions. As of October 2022, eight packages of sanctions have been adopted.

The packages include personal sanctions against Russian officials and oligarchs, and economic sanctions. Economic sanctions are applied in a wide range of sectors such as finance, high-tech, military and dual use technology, transport and energy.

The sanctions aim to negatively impact the Russian economy, thus restricting its resources for funding war operations in Ukraine. Sanctions in the energy sector are particularly important, as the revenue from the oil and gas export is estimated to fund around 40% of Russia's budget[21].

The main sanctions in the energy sector include:

- a ban on new European investment in the Russian energy sector, and a ban on the export of oil processing/refining technologies to Russia, in addition to the 2014 ban on the export of oil equipment, which will hamper modernisation of the Russian oil processing industry and make it more costly;
- a ban on oil imports of Russian crude oil and petroleum products transported by sea, covering 90% of our current oil imports from Russia. The ban is subject to certain transitional periods, six months in the case of oil and eight months for petroleum products, to allow industry and global markets to adapt. Member States which are particularly dependent on imports of oil by pipeline from Russia are granted a temporary exemption in order to ensure that supplies are phased out gradually;
- the EU operators banned from providing and funding the transport of oil to third countries, including transport by sea;
- At G7 level, there is a conceptual agreement to introduce a price cap on Russian oil. This price cap will also be implemented by the EU. An exemption from the ban on the provision of services for the transport of Russian oil to third countries is thus being introduced, allowing shipping and related technical assistance, financing and insurance for the transport of Russian oil, provided that it is sold at a price not exceeding the price cap set by the G7;
- a ban on the import of Russian coal.

21 Reuters (2022). Revenue from Russian oil and gas exports rise in June y/y: Vedomosti. Available: https://energy.economictimes.indiatimes.com/news/oil-and-gas/revenue-from-russian-oil-and-gas-exports-rise-in-june-y/y-vedomosti/93132493?redirect=1

Negotiations are also underway on price cap on Russian gas imports, though agreement has yet to be reached by the Member States. Russia has responded by restricting gas supplies to several EU Member States or cutting off supplies altogether. Moreover, in September 2022 the Nord Stream I and II pipelines between Russia and Germany were damaged, likely as a result of charges being detonated.

Conclusion

The surge in energy prices and Russia's aggression towards Ukraine have forced the European Union to fundamentally rethink its energy policy.

In the current context, the European Union cannot rely on supplies of Russian energy, so the EU must make sure that its energy strategy is not dependent on Russia by diversifying towards deliveries from reliable suppliers. Consequently, as of 2021, and particularly since the Russian invasion of Ukraine, the European Commission has presented a series of initiatives to enhance the EU's energy security, restrict energy prices and mitigate their negative impact on the economy. At the time of writing, October 2022, some of these proposals are already being implemented, while others are still in the legislative process. This paper does not cover all proposals and initiatives in the energy sector, instead outlining the main thrust of work and initiatives. Work on these issues will continue in the coming months, and we can expect new proposals and initiatives to come.

However, in the medium- and long-term, consistent implementation of the European Green Deal will play a crucial role in securing Europe's energy independence, with major investments in renewable energy production, adjustment of our energy systems and energy efficiency measures.

Part II

Energy policy and economy

Oļegs Barānovs, Jānis Salmiņš, Irina Skribāne

Long-term macroeconomic trends affecting the Latvian energy sector

Sustainable economic development is based on the ability to adapt to new circumstances and global challenges. Several studies have shown that economic and non-economic factors may lead to significant changes in the current state of the global economy, and the crisis caused by the Covid-19 pandemic and the war in Ukraine are strong catalysts for this change. The future development of the Latvian economy, including the energy sector, will also be affected by demographic processes, the structural transformation of the economy, as well as the European Green Deal policy initiatives. Climate change and the move towards climate neutrality will lead to serious structural changes, the positive and negative aspects of which on the Latvian economy are not yet fully understood. The directions of structural transformation have already been marked, but there may be several scenarios for their impact on the Latvian economy. Future changes in the structure of the potential economy are not clearly identifiable and therefore pose a challenge to maintaining the country's competitiveness. This will largely depend on the ability of businesses to increase productivity adapting to new conditions.

The paper analyses global development trends, Latvia's demographic processes and structural changes in the economy, which will affect the overall growth in the future, including the energy sector. Section 1 analyses global technological change, European Green Deal initiative and the move towards climate neutrality, the changes caused by the Covid-19 pandemic and the war in Ukraine. Section 2 examines the role of investment in Latvia's economic development. Section 3 is devoted to the analysis of Latvia's long-term demographic forecasts and assessments of economic development opportunities in publicly available publications. In Section 4, based on the modelling tool developed by the authors, possible macroeconomic development scenarios are modelled.

1. Global development trends

1.1. Global technological change

The global economy is undergoing rapid and comprehensive change, and the development of technological and innovation is accelerating. The digitalisation of processes and new technologies are playing an increasing role, as well as the effects of global climate change are exacerbating. As a result of the aforementioned changes, the production process and structure are transformed, which at the same time both escalates the threat and opens new opportunities for the development of the Latvian economy. The country's ability to adapt its economy to future needs will become increasingly important, reaping the full benefits of new production opportunities and market niches, while minimizing risks and maintaining the ability to respond flexibly to new challenges.

A study by the World Economic Forum[1] has hypothesized that the most important drivers of future readiness are technology and innovation, human capital, institutional framework and global trade and investment. These drivers have the strongest correlation with economic complexity.

The main global technology trends are mainly related to information technology development, digitalisation and mobile internet – artificial intelligence and machine learning, internet of things, big data and advanced analysis, smart cities, blockchain technology, cloud computing, digitally enhanced reality, digital digitization and processing, voice interfaces, computer vision and facial recognition, robots, autonomous vehicles, 5G technologies, genetics and gene sequencing, machine creativity and design, digital platforms, drones, 3D and 4D printers, cybersecurity, quantum computing. Almost all the things and devices around will be connected, which will change both business models, while this connectivity will support more efficient and sustainable use and management of resources. The structure of demand will also change, for example, people will increasingly use binding/appropriate services based on the analysis of large amounts of data. Digitalisation is an important set of factors that play a key role in rising the productivity.

In Latvia, too, new technologies will affect virtually all sectors of the economy. This will include the use of new technologies to improve existing business processes, the physical replacement of manual labour with smart devices, the use of big data to make decisions and meet demand. In addition, the development of digital technologies is creating new niches for products and services. There are already significant achievements in certain areas of technology in Latvia,

1 World Economic Forum (2018). Readiness for the Future of Production Report 2018. Available: http://www3.weforum.org/docs/FOP_Readiness_Report_2018.pdf

such as 5G, drones, smart city, gene sequencing, language digitization, big data. In the field of artificial intelligence and quantum computing, on the other hand, there is a basis for incorporation and science.

Rapid technological development will step up the pace of change and create new opportunities, but it will exacerbate the divide between winners and losers. Automation and artificial intelligence threaten to change industries faster than the economic system will be able to adapt by shifting resources appropriately and absorbing the unintended consequences of these changes for society.

1.2. The European Green Deal

The development of the Latvian economy is significantly influenced by the common European policy. The EU aims to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions.

To deliver the European Green Deal, there is a need to rethink policies for clean energy supply across the economy, industry, production and consumption, large-scale infrastructure, transport, food and agriculture, construction, taxation and social benefits. To achieve these aims, it is essential to increase the value given to protecting and restoring natural ecosystems, to the sustainable use of resources and to improving human health. This is where transformational change is most needed and potentially most beneficial for the EU economy, society and natural environment. The EU should also promote and invest in the necessary digital transformation and tools as these are essential enablers of the changes[2].

The biggest challenge in the energy sector is decarbonisation. Much more emphasis will have to be placed on renewable and alternative energy sources in energy production. In turn, replacing fossil fuels in the European Green Deal concept will mean a significant reduction in the consumption of oil, natural gas and coal throughout the EU. On the one hand, it solves the expected energy deficit caused by the depletion of oil resources, but on the other hand, it will significantly affect the classic Latvian transit industry.

The introduction of cleaner modes of private and public transport in terms of pollution will affect the existing supply chain for internal combustion engine manufacturers. At the same time, such a transition could create new business niches in the alternative fuel vehicle production chains. The transformation of the transport sector will necessitate the development of smart infrastructure for

2 European Commission (2019). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal. Available: https://eur-lex.europa.eu/legal-content/LV/TXT/?qid=1588580774040&uri=CELEX:52019DC0640

alternative fuels, such as smart grids, hydrogen grids or carbon capture, storage and use, as well as the development of energy storage solutions.

Renovation and insulation of buildings is an important way to reduce energy consumption and costs. Renovation of buildings means an increase in the production of building materials, opportunities for the development of innovative products, as well as additional demand for the construction industry.

A major reorientation awaits the agricultural sector, which includes activities such as carbon management and storage in the soil, better management of fertilizers, and innovative ways to replace existing plant protection chemicals.

The transition to climate neutrality is also having a major impact on industry. Increasing attention will need to be paid to innovation to help companies transform their existing operations and to replace old ones with newer, more energy-efficient ones, which in turn will have a positive effect on productivity. This is particularly the case for cement production, which has received special attention due to its high energy intensity.

The concept of the circular economy, which allows consumers to choose products that are reusable, durable, and repairable, will have an impact on the electronics and electrical equipment industry. The model of a sustainable economy could reduce waste, while new business niches could be created to recycle the remaining waste.

The priorities of the European Green Deal in the industrial sector are areas such as clean hydrogen technologies, fuel cells and other alternative fuels, energy storage and carbon capture, storage and use. Although Latvia has not developed production in these areas, in the future, together with the support of science, they have the potential to become a new development niche. Digitalisation opportunities also play an important role in the context of industrial development, especially in the areas of artificial intelligence, 5G, cloud computing and the Internet of Things.

Achieving a climate neutral and circular economy requires the full mobilisation of industry. It takes 25 years – a generation – to transform an industrial sector and all the value chains. To be ready in 2050, decisions and actions need to be taken in the next five years[3]. Therefore, industries must already consider the potential effects of climate change when planning their long-term development. The European Green Deal will require a large financial investment and will be a labour-intensive process, while it can create new business opportunities.

To achieve the ambition set by the European Green Deal, there are significant investment needs. The Commission has estimated that achieving the current

3 European Commission (2019). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal, p. 7. Available: https://eur-lex.europa.eu/legal-content/LV/TXT/?qid=1588580774040&uri=CELEX:52019DC0640

2030 climate and energy targets will require €260 billion of additional annual investment, about 1.5% of 2018 GDP. This flow of investment will need to be sustained over time. The magnitude of the investment challenge requires mobilising both the public and private sector[4].

Latvia's recovery and resilience plan identifies Climate Change and Environmental Sustainability as the most important components. The main goal in this area is to reduce greenhouse gas (GHG) emissions and increase CO_2 sequestration by facilitating the transition to renewable energy sources by investing in sustainable transport solutions to improve the accessibility of services, incl. in the context of administrative-territorial reform, as well as improving energy efficiency in housing and business and promoting disaster management measures and adaptation to climate change[5].

1.3. Changes caused by the Covid-19 pandemic

The Covid-19 crisis has hit the industries connecting with gathering and serving people particularly hard. These industries are mainly retail, accommodation and catering, transport and storage, arts, entertainment and leisure, as well as personal services such as hairdressing, beauty care, etc. In Latvia, such industries make up 1/5 of the total economy, and in 2020 these industries will also see the largest decline in activity. In the case of the prevalence and impact of Covid-19, optimistic assessments and forecasts of V-shaped or U-shaped economic recovery scenarios have not materialized. Further developments are likely to be wavy, with governments having to impose tighter restrictions from time to time, at least in the short term. Consequently, companies must be able to objectively assess the continuation of existing businesses in the face of prolonged restrictive conditions.

The changes brought about by the pandemic will be felt for a long time. The Covid-19 crisis is accelerating the global digital transformation process. Countries and companies that have not previously implemented digital solutions will suffer the most, but by introducing digital solutions, they can significantly increase productivity and stay in business even under strict restrictive measures. Online commerce is growing and developing. Many consumers will become accustomed to online shopping solutions and may not want to return to retail

4 European Commission (2019). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal, p. 16. Available: https://eur-lex.europa.eu/legal-content/LV/TXT/?qid=1588580774040&uri=CELEX:52019DC0640

5 Cabinet of Ministers (2021). Eiropas Savienības atveseļošanas un noturības mehānisma plāns Latvija 2021–2026, p. 55. Available: www.esfondi.lv/upload/anm /01_anm_plans_04062021.pdf

stores after the pandemic, and some customers will continue to use these channels after the store opens.

The changes will also create new forms of work, including teleworking opportunities are expanding. Some companies will switch to remote work (in areas where this is possible, such as IT), but there are also many companies that will not be able to do so because some industries are not yet fully digitally transformed. Telework will reduce demand (and prices) for office space and transport services.

Even before the Covid-19 crisis, global value chains faced a variety of challenges related to rapid technological development. In developed countries, for example, robots have replaced cheaper workers in third world countries. This facilitates the transition to shorter value chains and localization[6]. Localization can boost investment in the medium term.

1.4. The changes brought about by the war in Ukraine

With the Russian invasion of Ukraine, the geopolitical situation has deteriorated and there is a great deal of uncertainty about how the war and the associated sanctions and disruptions in the supply chain will affect economic development. The high level of uncertainty will affect both consumer consumption and business investment and foreign trade. At the same time, the extent of the economic impact of the conflict is very uncertain and will depend on the length of the war and political reactions. However, the war will significantly stifle growth and increase inflationary pressures.

In 2021, Latvia's exports of goods to Russia, Belarus and Ukraine accounted for 9.5%, while imports from these three countries accounted for 12.7%. There are several groups of goods that make up almost one third of Latvia's total imports from these countries – mostly raw materials (e.g., metals, wood, fertilizers) and energy resources (mainly natural gas). The conflict in Ukraine will not affect all companies equally, but more those that export or import and find it more difficult to change or find new partners and markets. New and diversified markets for the supply of raw materials, the strengthening of the country's energy independence and the reorientation from Russia to more solvent Western markets will raise the future potential of the Latvian economy.

In response to the hardships and global energy market disruption caused by Russia's invasion of Ukraine, the European Commission on 18 May 2022 has

6 Fortunato, P. (2020, September 2). How Covid-19 is changing global value chains. UNCTAD. Available: https://unctad.org/news/how-COVID-19-changing-global-value-chains

published the REPowerEU Plan[7]. The REPowerEU plan sets out a series of measures to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition, while strengthening the resilience of the EU-wide energy system.

2. The role of investments in Latvia's macroeconomic development

2.1. Investment dynamics and level in Latvia

Investment is important for improving productivity and enhancing the competitiveness of an economy and therefore facilitating higher rates of growth. The empirical evidence for a large sample of countries at different stages of development since 1960 to the present shows that an increase of 10 percentage points in the ratio of private investment to GDP corresponds to an increase of 3.1 points in the long-term growth rate of per capita income, higher than the elasticity of 2.7 obtained between total investment and growth[8]. Therefore, good public policies that encourage permanent increases in private investment rates lead to increases in long-term economic growth and welfare.

Investment (gross fixed capital formation) activities in the Latvian economy are volatile, sensitively responding to geopolitical changes, the EU structural fund planning periods, external and internal shocks. Since Latvia's accession to the EU, investment has risen sharply (by an average of 21.4% per year in 2004–2007), driven significantly by foreign capital inflows. Investment growth continued to pick up until 2007, reaching almost 36% of GDP, a major factor in productivity growth.

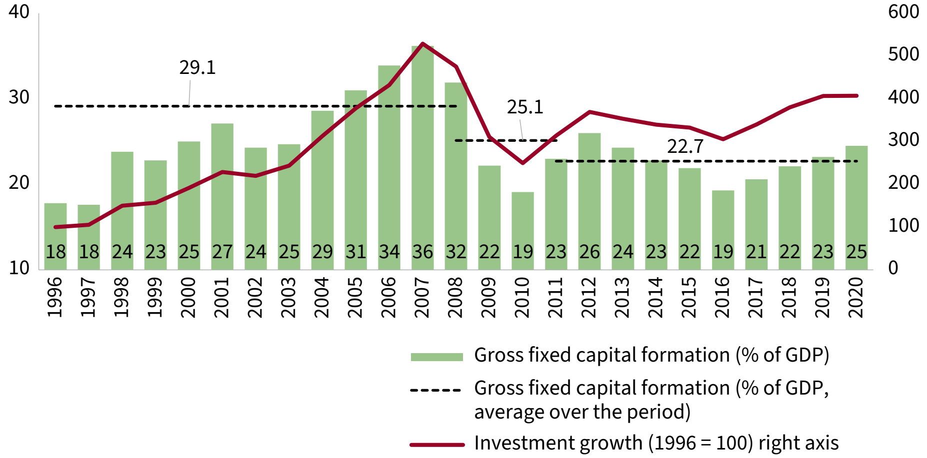
As a result of the global financial crisis, investment has been hit hard. Investment fell by more than half in three years (2008–2010). The level of investment in 2010 was only 19% of GDP, the lowest level since 1998. Prolonged credit contraction, high indebtedness and low demand following the financial crisis have dampened investment activity in the post-crisis period.

Investment trends in the Latvian economy over the past decade have been very weak with unsustainable dynamics. Investment grew by an average of 5% per year to 22.7% of GDP, well below the pre-global financial crisis. The weak

7 European Commission (2022). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions REPowerEU Plan. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

8 Doménech, R. and Sicilia, J. (2021, April 14). Private investment as the engine of economic growth and social welfare. *Economic Watch*, p. 1. Available: https://www.bbvaresearch.com/en/publicaciones/global-private-investment-as-the-engine-of-economic-growth-and-social-welfare

Figure 1. Investment dynamics and level in Latvia (%)



Source: Eurostat, authors' calculation

investment trend has been exacerbated by the Covid-19 crisis, given the high level of uncertainty that has reduced private investment. The level of private investment fluctuates between 16–20% of GDP, which is almost 10 percentage points lower than in the boom years. The investment gap could be estimated at around 10% of cumulative investment over the last ten years. Compared to 2005–2007, the private investment gap for the period 2007–2013 is estimated at 2.4 billion euro, which also largely contributes to slower productivity growth in recent years. It also contributed significantly to the weakening of productivity dynamics, which grew by an average of 2.2% per year between 2010 and 2020.

As the analysis shows, the investment dynamics in the Latvian energy sector are less subject to cyclical fluctuations. This is largely due to the important role of the public investment projects in the energy sector. Between 1997 and 2007, investment in the energy sector grew by an average of 15% annually. As in the economy as a whole, investment in the energy sector declined during the economic downturn (2008–2010) and was on average 12% lower than in the boom years (2004–2007). However, since 2011 investments have increased significantly and in 2012 reached a historically high level – 619 million euros, i.e., 11% of total investments in the Latvian economy. In the coming years, investment dynamics show a downward trend. In the last three years (2018–2020), an average of almost 300 million euros (approximately 4.5% of total investments) has been invested in the energy sector. However, considering the fact that the capital productivity indicator of the Latvian energy sector is one of the lowest in the EU countries, such an amount of investment is insufficient. Achieving the common climate and energy efficiency goals will require significant investment in the energy sector over the next decade.

2.2. Public funding available to Latvia for economic modernization

According authors' calculation in the period from 2020 to 2027, approximately 17.5 billion euros are available to Latvia for investments to strengthen the potential of the national economy. Finances include both the resources available to overcome the Covid-19 crisis and the state budget investments marked in the medium-term planning documents, as well as the financing provided for in the EU multi-annual budget.

Within the framework of Next Generation EU funding, significant funding is also provided for the Latvia's recovery and resilience plan. The plan includes reforms and investments with a maximum indicative funding of 1.82 billion euro. This is a significant amount for Latvia – 10% of all available public funds in the next 7–8 years or 6.2% of the 2020 GDP. The plan provides support in six areas: achieving climate goals (676.2 million euro), digital transformation (365.2 million euro), reducing inequalities (370 million euro), economic transformation and productivity reforms (196 million euro); in the health sector (181.5 million euro), strengthening the rule of law (37 million euro).

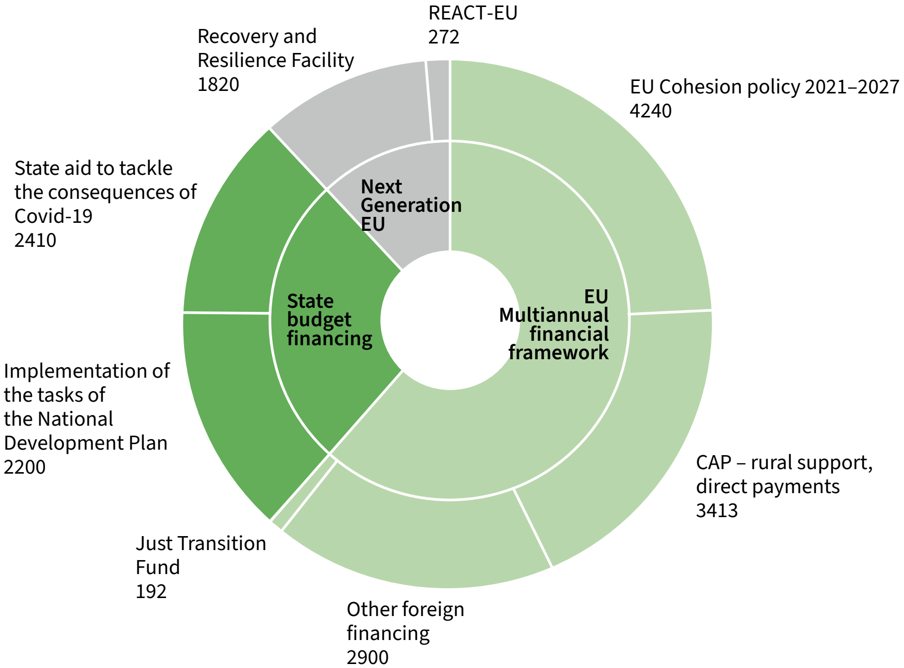
In turn, the REACT-EU programme, or Recovery Assistance for Cohesion and European Territories, will have an indicative amount of 272 million euro, which is intended as additional funding for 2014–2020 annual programming period. Funding will be provided mainly for job retention, support for the self-employed, youth employment measures, support for health care systems, etc. activities in various sectors, including tourism and culture. The additional support will also be used to invest in European green courses and digital transformation.

192 million euro available under the Just Transition Fund, which is intended to invest in the economic diversification of areas most affected by climate change.

In the next programming period (2021–2027) in the framework of the EU multiannual budget Cohesion policy instruments will be available to Latvia in the amount of 4.24 billion euro.

In addition, funding for research and innovation projects can be obtained from the instruments offered by Horizon Europe. For its part, the European Commission will devote at least 30% of the InvestEU fund to the fight against climate change. The InvestEU will give Member States the opportunity to use the EU budget guarantee, for example, to achieve climate-related cohesion policy objectives on their territory and in their regions.

Figure 2. Indicative public funding available for the modernization of the Latvian economy in 2020–2027 (million euro)



Source: Authors' calculation based on European Commission, Ministry of Finance, Cross-Sectoral Coordination Centre data

In order to accelerate productivity growth and ensure stable economic growth, it is vital not only to invest available public finances in a sustainable way, but also to stimulate private investment by stimulating credit growth, capital market development and the use of financial instruments.

The Commission's analysis indicates that REPowerEU[9] entails additional investment of 210 billion euro between now and 2027, on top of what is needed to realise the objectives of the Fit for 55 proposals. To mobilise finance for covering the short term REPowerEU investment needs, the Commission proposes a targeted and swift amendment of the Recovery and Facility Regulation. The amendment foresees allocating additional funding from the auctioning of allowances of the Emissions Trading System, in a limited amount. It also proposes that Member States benefit from a higher flexibility to transfer resources allocated to them both

9 The official website of the European Union EUR-Lex. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/DOC/?uri=CELEX:52022DC0230&from=EN

under the Common Provisions Regulation (EU 2021/1060) and the Regulation on CAP strategic plans (EU 2021/2115). These grants will complement the remaining 225 billion euro of loans under the RRF, resulting in a total amount close to 300 billion euro.

3. Evaluation of Latvia's demographic forecasts and economic development opportunities in publicly available publications

Latvia's demographic processes and structural changes in the economy will affect overall economic growth in the future, including the energy sector.

Latvia's demographic trends and economic development opportunities have been assessed in a number of publicly available publications, such as the European Commission's EU Reference Scenario 2020 and the 2021 Ageing Report, the United Nations World Population Prospects 2019, and the Ministry of Economics' 2020 long-term forecasts, University of Latvia think tank LV PEAK Latvian Productivity Report 2020.

3.1. The EU Reference Scenario

The EU Reference Scenario[10] projects the impact of macro-economic, fuel price and technology trends and policies on the evolution of the EU energy system, on transport, and on their greenhouse gas (GHG) emissions in the 27 EU Member States individually and altogether by 2050. As the authors of this publication note, the Reference Scenario presents a projection, not a forecast, of the evolution of the EU energy system, transport system and GHG emissions. It does not predict how these will look in the future, but provides a model-based simulation of a possible future outlook, given the current policy context, based on certain framework conditions, assumptions, and historical trends, notably in the light of the most recent statistical data on energy system, transport and GHG emissions.

The macroeconomic scenario of the Reference Scenario (population and GDP projections) is the starting point for further modelling of the development of energy and transport systems and related GHG emissions. It should be noted that GHG emissions are modelled using a variety of sophisticated models that cover economic sectors, emission sources and mitigation options.

10 European Commission (2020). *EU Reference Scenario 2020*. Energy, transport and GHG emissions – Trends to 2050. Directorate-General for Energy, Directorate-General for Climate Action, Directorate-General for Mobility and Transport. Luxembourg: Publications Office of the European Union, July 2021, EU reference scenario 2020, Publications Office of the EU (europa.eu).

The macroeconomic outlook used in the Reference Scenario provides a basic forecast of how the European economy as a whole and each EU Member State will develop in the coming decades. The macroeconomic scenario is based on the latest demographic and economic forecasts for EU countries, developed jointly by Eurostat, the Council's Economic Policy Committee (EPC), and the European Commission, and described in the European Commission's 2021 Ageing Report[11].

Among other things, the above-mentioned EU Reference Scenario 2020 also describes Latvia's macroeconomic perspective. As it is taken from 2021 Ageing Report, the Latvian population and GDP forecasts are described below under the relevant section.

3.2. European Commission Ageing Report

The 2021 Ageing Report states that the long-term projections are based on commonly agreed methodologies and assumptions. They take as starting point Eurostat's population projections for the period 2019 to 2070. In addition, the EPC, on the basis of proposals prepared by the Commission services and the Ageing Working Group of the EPC, agreed upon assumptions and methodologies common for all Member States to project a set of key macroeconomic variables covering the labour force (participation, employment and unemployment rates), labour productivity, and the interest rate. This set of variables allowed deriving GDP for all Member States up to 2070[12].

The long-term projections include a broad range of alternative scenarios and sensitivity tests, reflecting the uncertainty surrounding the baseline scenario. The baseline projections (or reference scenario) are made under a 'no-policy-change' assumption, generally illustrating the evolution of age-related expenditure if current policies remain unchanged. However, there is uncertainty surrounding these projections, and the results are strongly influenced by the underlying assumptions. The macroeconomic assumptions on which this report is based were agreed upon in the first half of 2020 and published in November 2020[13].

11 European Commission (2021, May). The 2021 Ageing Report Economic and Budgetary Projections for the EU Member States (2019–2070). Institutional Paper 148. Luxembourg: Publications Office of the European Union. The 2021 Ageing Report. Economic and Budgetary Projections for the EU Member States (2019–2070) (europa.eu).

12 Ibid., p. 1.

13 European Commission (DG ECFIN) and Economic Policy Committee (AWG) (2020, November). 2021 Ageing Report: Underlying assumptions and projection methodologies. European Commission, European Economy, Institutional papers, No. 142. Available: https://ec.europa.eu/info/sites/default/files/economy-finance/ip142_en.pdf

Eurostat forecasts a decrease in the population of Latvia from 1.9 million in 2019 to 1.7 million in 2030 and 1.4 million in 2050, including the continuation of negative migration. In turn, GDP in the period from 2019 to 2030 will increase by an average of 2% annually, from 2031 to 2040 by 1.3% and from 2041 to 2050 – by 0.7%[14] each year.

3.3. United Nations World Population Prospects Report

The current United Nations (UN) edition of World Population Prospects 2019[15] reflects the latest global demographic projections developed by the UN Department of Economic and Social Affairs since 1951. For each country, the publication provides a brief description of the data sources and demographic methods used to derive the base year estimates of the population and components of demographic change (births, children, adults and overall mortality, international migration). The UN predicts a reduction in Latvia's population to 1.72 million in 2030 and 1.5 million in 2050. According to estimates, net migration in the period from 2025 to 2030 – minus 20 thousand people and from 2045 to 2050 – minus 5 thousand people.

3.4. Ministry of Economics Report on Medium and Long-Term Labour Market Forecasts

The 2020 report of the Ministry of Economics[16] describes the current situation in the labour market, medium-term labour market forecasts for the period up to 2027 and long-term labour market forecasts until 2040. For the modelling of labour market, the system dynamic approach is employed. The forecasting methodology is based on partial balance principles, where labour market demand stimuli are determined and arise from the set economic growth targets, but labour supply in the long term adapts to labour market demand and relative wage changes.

14 European Commission (DG ECFIN) and Economic Policy Committee (AWG) (2020, November). 2021 Ageing Report: Underlying assumptions and projection methodologies. European Commission, European Economy, Institutional papers, No. 142, p. 67. Available: https://ec.europa.eu/info/sites/default/files/economy-finance/ip142_en.pdf

15 United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Volume II: Demographic Profiles (ST/ESA/SER.A/427). Available: https://population.un.org/wpp/Publications/Files/WPP2019_Volume-II-Demographic-Profiles.pdf

16 Ekonomikas ministrija (2020). Informatīvais ziņojums par darba tirgus vidēja un ilgtermiņa prognozēm. Available: https://www.em.gov.lv/lv/darba-tirgus-zinojums

The labour market forecasts of the Ministry of Economics are based on the target scenario of the economic growth and the corresponding macroeconomic forecast. The target scenario has been drafted according to settings of the Latvian structural policy defined in policy documents – Sustainable Development Strategy of Latvia until 2030, draft National Development Plan of Latvia for 2021–2027. The impact of the Covid-19 pandemic was also taken into account and the processes defining the development of the national economy were analysed.

From the forecasts of the Ministry of Economics it can be concluded that the population of Latvia will decrease by almost 134 thousand to about 1786 thousand by 2040[17]. In both the medium and long term, the main reason for population decline will be the ageing population, which will rise the impact of negative natural increase (the gap between births and deaths) on demographic trends. The decline in the working age population will generally have a negative impact on the overall labour supply, leading to a decline in the economically active population in both the medium and long term.

In the medium term (until 2027) the target scenario envisaged GDP growth by about 4.6% per year, while in the long term (until 2040) annual economic growth rates will become slower and will be within 2.8%. The fundamental precondition for growth in the medium and long term is to support economic competitive advantages by technological factors, manufacturing efficiency and innovation, as well as the ability to adapt and use the opportunities provided by global changes[18].

3.5. Productivity Report of the Scientific Institute for Productivity at the University of Latvia

Latvia's 2020 Productivity Report[19] examines two development scenarios – the trend and the acceleration scenario. It models the overall development of the economy and the key sectors of the economy up to 2030.

In the trend scenario, if the current trends continue, GDP growth in the coming years (2021–2024) could reach an average of 3.9% per year, while in the following years (2025–2030) the annual growth rate of the economy will slow down to 2.5%. In the acceleration scenario, which bases its competitive advantage

17 Ekonomikas ministrija (2020). Informatīvais ziņojums par darba tirgus vidēja un ilgtermiņa prognozēm, p. 91. Available: https://www.em.gov.lv/lv/darba-tirgus-zinojums

18 Ibid., p. 90.

19 Latvijas Universitātes Biznesa, vadības un ekonomikas fakultātes Produktivitātes zinātniskais institūts "Latvijas Universitātes domnīca LV PEAK" (2020, decembris). Latvijas produktivitātes ziņojums 2020. Rīga. Available: https://www.lvpeak.lu.lv/fileadmin/user_upload/lu_portal/lvpeak.lu.lv/LU_domnica_LV_PEAK/Latvijas_produktivitates_zinojums_2020/LPZ_2020_.pdf

on technological factors, production efficiency, innovation, digitalisation, investment in human capital, and the ability to adapt to and seize the opportunities of global change, economic annual growth will average 5.3% from 2021 to 2024, but from 2025 to 2030 – 3.7% per year.

Overall, the calculations show that the deployment of newer technologies, the development of innovative products and services and the broader use of digital solutions and improved process efficiency have a significant impact on the faster growth of sectors and of the economy as a whole. Under both development scenarios, productivity is the main driver of growth. However, a significant factor in ensuring faster growth is also solving labour supply problems. Investment in human capital has a key role to play[20].

3.6. Key findings

- The demographic situation in Latvia will continue to deteriorate both in the medium and long term. The main reason for the declining population is the ageing population, which will rise the impact of negative natural increase (the gap between births and deaths) on demographic trends. The impact of migration is assessed differently. Eurostat and the UN forecast a negative migration balance until 2050, while the Ministry of Economics believes that the gap between the number of emigrants and immigrants could narrow significantly in the coming years, and a positive migration balance is expected from 2023 onwards.
- The differences in demographic projections can be largely explained by the fact that Eurostat and the UN projections are made under a ‘no-policy-change’ assumption. In turn, the forecasts of the Ministry of Economics are based on the assumption that the target scenario will be implemented, i.e., Latvia will be able to adapt and seize the opportunities created by global change and change the structure of the economy in favour of higher value-added sectors, which will ultimately ensure accelerated economic growth.
- The growth rate in both the medium and long term will be determined by the ability to restructure the economy, increase productivity based on improved production efficiency and innovation, to a lesser extent on cheap labour and low resource prices.

20 Latvijas Universitātes Biznesa, vadības un ekonomikas fakultātes Produktivitātes zinātniskais institūts “Latvijas Universitātes domnīca LV PEAK” (2020, decembris). Latvijas produktivitātes ziņojums 2020. Rīga, p. 97. Available: https://www.lvpeak.lu.lv/fileadmin/user_upload/lu_portal/lvpeak.lu.lv/LU_domnica_LV_PEAK/Latvijas_produktivitates_zinojums_2020/LPZ_2020_.pdf

4. Latvia's medium and long-term development scenarios

Based on the assessment of global development trends (changes caused by the Covid-19 pandemic, changes caused by the geopolitical consequences of the Russian invasion of Ukraine, global technological changes, the European Green Deal and progress towards climate neutrality, etc.), Latvia's strategic policy documents and planned investment assessments and economic development opportunities, and given the high level of uncertainty, the authors have developed medium (until 2030) and long-term (until 2050) 3 development scenarios (pessimistic, optimistic, baseline).

Hermin's medium-term model adapted to the Latvian economy, which is based on the traditional Keynesian mechanism of action, was used to develop economic development forecasts – output depends on both internal and external demand. However, the model also has the properties of neoclassical theory. Thus, for example, production volumes in the manufacturing sector depend not only on demand but also on price and cost competitiveness. In addition, the demand for factors of production is determined by the CES (Constant elasticity of substitution) function, where the capital-labour ratio depends on the relative costs of the factors of production. The wage setting mechanism also includes the properties of the Philip curve, as wage dynamics are also related to changes in the unemployment rate. It also provides an opportunity to analyse the impact of relative factor costs.

In total, the model consists of more than 200 equations. Many equations are included in the model to increase the transparency and connectivity of the model, and a large proportion of identity equations are common practice in systems of simultaneous equations, as identities link national accounts variables into a single system. The model is based on a smaller number of equations, where more than 20 equations are exactly the behavioural equations of economic entities.

With the help of the model, the impact of each development scenario on the development trends and structural changes of the sectors was assessed. The baseline scenario envisages that in the medium term, Latvia's economic growth will return to the growth trend of the previous decade (2011–2019). The optimistic scenario envisages faster economic development, driven by economic transformation, with productivity growth playing a key role in growth. The pessimistic development scenario is based on the 2020 reference scenario developed by the European Commission. According to each development scenario, the expected changes in the population have also been modelled.

Although the restrictions imposed by Covid-19 and the geopolitical consequences of the Russian invasion of Ukraine are having a negative impact on the economy today, the medium-term economic development challenges already identified in policy planning documents, such as the need to increase exports and productivity of goods and services, remain unchanged. Initiatives previously launched by the European Commission, such as the European Green Deal and digitalisation, also remain.

The developed scenarios until 2050 are not considered to be economic development forecasts, but various future development opportunities that may be fulfilled because of different conditions and factors. Scenarios do not cover the full range of uncertainties about the future, which may be outside the range of scenarios. The basic assumptions for each of the scenarios are given in Table 1.

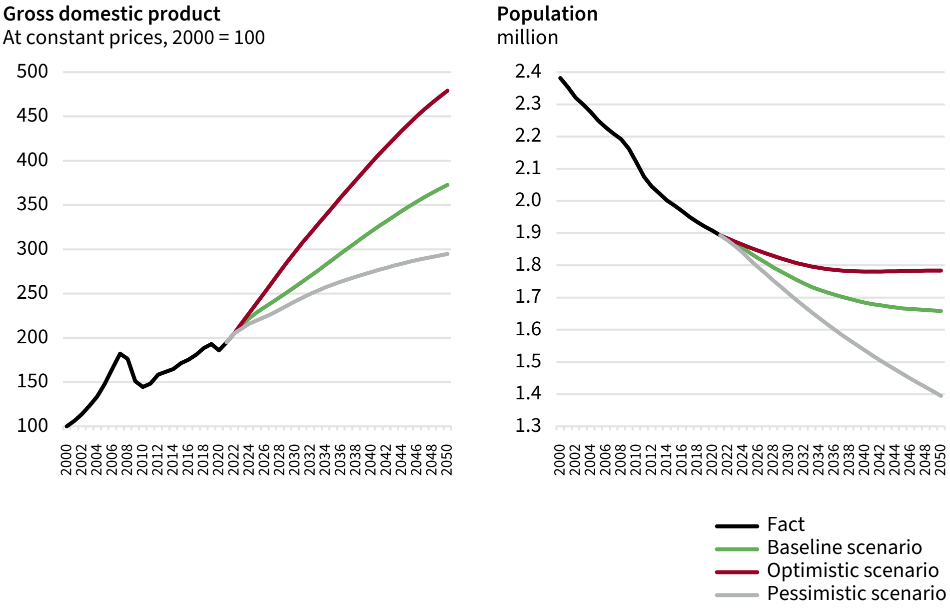
Table 1. Basic assumptions for forecast scenarios

FACTOR	BASELINE SCENARIO investment and public support facilitate transition to higher productivity levels	OPTIMISTIC SCENARIO investment and public support facilitate faster transition to higher productivity levels	PESIMISTIC SCENARIO productivity is growing slowly, limited by negative demographic trends
EXTERNAL ENVIRONMENT	The geopolitical situation is not more escalated. The hardest hit sectors are recovering slowly. Achieving pre-crisis levels in industries related to Russian markets may take 1–2 years. Problems in supply chains are gradually decreasing.	The geopolitical situation is not more escalated. Companies are looking for solutions to shift their focus from the hardest hit areas to new business niches and new markets. Supply chains are adapting to new conditions relatively quickly.	The geopolitical situation is deteriorating. The hardest hit sectors are recovering slowly. Achieving pre-crisis levels in sectors related to Russian markets is taking a long time. Problems in supply chains persist.
IMPACT OF COVID-19	The distribution of Covid-19 remains fluctuating. The hardest hit sectors are recovering slowly. It may take several years to reach pre-crisis levels. The process of economic transformation is slow.	The distribution of Covid-19 remains wavy. As a result of vaccination, the situation will return to normal in 2022. Companies are looking for solutions to reorient their operations from the hardest hit areas to new business niches. E-commerce practices are evolving in commerce. Flexible forms of work remain in operation.	The distribution of Covid-19 remains wavy. New strict restrictions are possible. The hardest hit sectors are recovering slowly.
INVESTMENT, TECHNOLOGIES	Investments mainly in maintaining existing business models.	The available financial resources are mainly investing in bridging the productivity gap with technologically advanced countries. Investments not only in technological novelties, but also in the improvement of production process management. Significant increase in private investment.	Investment activities are moderate. Investments in maintaining existing business models.

INNOVATION, RESEARCH	Investment in research and development continues to grow, albeit at a moderate pace.	Funding for research and development will increase significantly. Business investment in research and innovation is growing.	Investment in research and development is growing slowly. Latvia has long maintained its weakest position among the EU Member States.
DIGITALIZATION	The initiatives of individual companies (5G, smart city) continue, but the differences between companies that are leaders in digital technologies and companies that use digital solutions remain present.	The Covid-19 crisis will exacerbate the current upward trend in digital services. According to the degree of digital maturity of each company, there is a continuous process of introduction of digital technologies. New products and niche markets are emerging.	The uptake of digital solutions, especially for SMEs, is slow. Latvia has long maintained a weak position in the EU in the use of various digital solutions.
GREEN COURSE	To comply with environmental requirements, Latvia mostly imports green technologies.	Timely reorientation and preparation for change. Finding new business niches for developing and exporting green technologies.	The move towards climate neutrality and additional costs has a negative impact on the competitiveness of Latvian companies in the global market.
HUMAN CAPITAL	In the medium term, labour supply and demand mismatches persist. Public participation in adult education remains at the level of 7–8%. The market is dominated by relatively short training to improve general competencies.	Public and private investment in skills development is significantly increasing. State-subsidized training programs for retraining the workforce into sectors with the greatest growth potential. Offering adult education in the context of new digital technologies to all sections of society, thus reducing the risks of growing inequality. Active involvement of employers in raising the competencies of existing employees, as well as the creation of new skill sets so that people can qualify for new professions in the conditions of economic transformation and robotization.	The mismatch between labour and skills supply and demand is gradually growing. Lack of appropriate skills hampers the growth of knowledge- and technology-oriented industries and companies.

A summary of scenarios for changes in gross domestic product and population is given in Figure 3. As can be seen, the demographic situation in the country is closely related to economic development trends and the growth of total income. In the pessimistic scenario, the population will continue to decline for the next 30 years and could shrink below 1.4 million in 2050. In contrast, in

Figure 3. **Latvia's medium and long-term development scenarios**



Source: Authors' calculation based on EC, Eurostat and CSB data

a faster growth scenario, the population could stop declining over the next decade. The main reason is the positive migration balance, which is driven by overall income growth. It should be noted that in all scenarios, the overall demographic situation is characterized by an ageing population and a declining working age population.

Overall, estimates suggest that structural transformation of the economy has the potential to have a greater impact on future welfare growth. The changes caused by Covid-19, global technological development trends and the European Green Deal open new opportunities for increasing the productivity level of the Latvian economy by investing in new technologies, digitalisation and innovation. The introduction of the latest technologies, the development of new products and services, as well as the wider use of digital solutions and the improvement of process efficiency, have a significant impact on the faster growth of industries and the economy as a whole. In the optimistic scenario, productivity is the biggest contributor to growth. However, the calculations show that solutions to the problem of labour supply are also a more important factor in ensuring faster growth. Investment in human capital is very important. Providing a growing and productive sector with a workforce is critical, which means reviewing existing adult education programs and encouraging a shift of labour from less productive to productive sectors.

Given the growing use of digital solutions and the structure of the Latvian labour market, investment in human capital at all levels of education is important. Motivate employees to move from low-wage companies / industries to higher-income jobs, provide retraining support tools, and support exporting companies with growth potential.

Conclusion

The future development of the Latvian economy and the energy sector will be significantly affected by demographic processes, the structural transformation of the economy, the global technological trends, climate change and new European Union policy initiatives. The crisis caused by the Covid-19 pandemic and the war in Ukraine are also strong catalysts for transformation. The expected structural change is closely linked to the productivity-enhancing aspect, as it is important to promote a redistribution of resources in favour of productive areas, thus also increasing the overall level of productivity in the economy.

The analysis of various literature sources shows that the demographic situation in Latvia will continue to deteriorate both in long term. The main reason for the declining population is the ageing population, which will rise the impact of negative natural increase (the gap between births and deaths) on demographic trends.

Given the above mentioned, it is necessary to invest wisely in maintaining economic capacity in the short term and in the economic transformation measures in the medium and long term. Currently, approximately 17.5 billion euro public funding are provisionally available to Latvia for the next 7 years. In addition to public investment, private investment will also play an important role. In order to accelerate productivity growth and ensure stable economic growth, it is vital not only to invest available public finances in a sustainable way, but also to stimulate private investment by stimulating credit growth, capital market development and the use of financial instruments.

Based on the assessment of global development trends, Latvia's strategic policy documents and planned investments, as well as assessing Latvia's demographic development trends and economic development opportunities, and taking into account the high level of uncertainty, the authors have developed three development scenarios (pessimistic, optimistic, baseline), viewing them in medium term (until 2030) and long term (2050) perspectives.

The baseline scenario envisages a return to overall economic growth in the medium term in 2010–2019. at the level of the average trend over the period.

Between 2023 and 2030, GDP growth could average 3.2% per year, but the annual growth rates of the economy will slow in the coming years. The baseline scenario until 2050 does not envisage a very significant change in the structure of economic sectors compared to the current situation.

The optimistic scenario envisages GDP growth of 4.8% per year on average in the medium term (until 2030), based on technological factors, production efficiency, innovation and the ability to adapt to and take advantage of global change. Options. In the long run (until 2040 and 2050), the annual growth rates of the economy will slow to between 3% and 1.9% per year, respectively.

Overall, estimates show that the growth rate in both the medium and long term will be determined by the ability to restructure the economy, to increase productivity based on improved production efficiency and innovation, to a lesser extent on cheap labour and low resource prices.

Olga Bogdanova, Kārlis Piģēns

Factors affecting energy costs: Green deal impact

One of the European Union's energy policy objectives is to promote renewable energy sources. The growing use of the energy obtained from renewable energy sources is important precondition to reduce greenhouse gases and to comply with the 2015 Paris Agreement on Climate Change[1], as well as the EU Climate and energy policy framework for the period from 2020 to 2030, as well as to 2050. In 2018, the remastered Renewable Energy Directive[2] together with the revised Energy Efficiency Directive[3] and a new Governance regulation[4] as a part of the package of Clean Energy in Europe for everyone was adopted.[5] It aims to provide new, comprehensive rules on energy regulation for the coming decade. In July 2021, the European Commission came up with a new package "Prepared for target result 55%" (Fit for 55) initiative. On its way to achieve climate neutrality, the European Commission as an intermediate step has offered to speed up the EU 2030 commitments to the climate progress, proposing to reduce emissions by at least 55% by 2030. The EU is currently working on the evaluation of its policies

1 UNCC (2015). Paris Agreement on Climate Change. Available: https://unfccc.int/process-and-meetings/the-paris-agreement

2 Energy Efficiency Directive. Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency (OJ L 328, 21.12.2018, pp. 210–230).

3 Ibid.

4 Management regulation. 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 (OJ L 328, 21.12.2018, pp. 1–77).

5 European Commission (2017). Clean energy for all Europeans package. Available: https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en

due to the ambitious goals in the climate, energy and transport areas set by 2030 and 2050.[6]

In 2022, energy security became a major issue due to the war in Ukraine. Russia has demonstrated that it is an unreliable supplier of energy to Europe through unjustified and unacceptable actions such as halting natural gas exports to Poland and Bulgaria, and threatening similar actions against other European nations, terminating supply of electricity and natural gas to Finland, and others. On 24 May 2022, in the joint statement the European Commission and the United States condemned Russia's use of energy blackmail and reaffirmed the commitment to strengthening Europe's energy security.[7]

Commitment to Green Deal and the new agenda of energy security solutions undoubtfully have an impact on energy costs. The task for the policy makers is to find the most cost-efficient solution.

1. How is the energy price being determined?

Net Zero Carbon targets and possible energy policy measures to achieve them is a broadly discussed topic in professional and scientific literature. Economists are applying different approaches and develop policy measures, as well as justified scenarios how to reach the climate commitment. One of the most important challenges for economies is to indicate the approach ensuring the green transition in the most cost-efficient way.

United States National Broker Organization[8] has compiled the following main factors affecting the daily **energy wholesale price**: *delivery* (energy from nuclear power, coal, gas, oil and renewable sources has rapid response to demand; as a result, prices range every hour), *demand* (demand for heating, cooling, light and processes varies according to activity in economics, technology and efficiency measures), *gas storage* (an energy 'warehouse'; it could be reflected as the difference between supply and demand of energy sources), *weather forecast* (the main factor affecting immediate market prices and short-term energy market agreements; whether the forecasts become reality is less important for long-term prices), *power generating equipment developments* (cessation of nuclear energy old equipment, transfer of coal factories, etc.), *transportation of energy, global factors* (despite

6 European Commission (2021). Fit for 55. Available: https://www.consilium.europa.eu/en/policies/green-deal/eu-plan-for-a-green-transition/

7 European Commission (2022). Joint Statement between the European Commission and the United States on European Energy Security. Available: https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_22_3285

8 United States National Broker Organization (The Applied Energy Partners) (2016). 10 Factors Affecting the Energy Markets. Available: https://www.appenergy.com/2016/11/03/10-factors-affecting-the-energy-markets/

the changes in the volume of shale gas, production of global oil supply can affect the local energy costs), *import and export* (global oil and gas prices determine the relative profits that suppliers can obtain by selling fuel locally or abroad), *regulation* (legal framework can quickly and significantly change both supply and demand costs), *financial speculation* (similarly like the majority of other market goods, energy prices can be significantly affected by financial speculation, which is the least transparent factor).

The set of energy costs affecting factors indicated above actually reflects the most common reasons named by analysts as the causes of energy price fluctuation.

Box

Practical example with description of the situation

Prices of natural gas on the European stock exchanges, Germany's Trading Hub Europe (THE), the Netherlands Title Transfer Facility (TTF) and Belgium's Zeebrugge Trading Point (ZTP) have risen sharply since the middle of 2020, when they were at record lows. In October 2021, the average monthly price on stock exchanges reached an unprecedented level of around 90 EUR/MWh, which is 6.5 times higher compared to October 2020. However, on 26 August 2022 markets were shocked with the gas price TTF of 346 EUR/MWh.

According to the Public Utilities Commissions data, there are several reasons for this. Mostly European countries, like Latvia, are importers of natural gas. Stockpiles in European natural gas storage following the cold winter of 2020/2021 were significantly lower, while demand, along with a recovery in economic activity following the crisis caused by Covid-19, increased globally (particularly in China and the Asian region). Also, the reason is the reduced supply of natural gas on the global market, in line with the OPEC + oil importing group's agreement on limits on oil extraction volumes. The impact on the price increase in 2021 was also the comparison with the record low oil and natural gas prices in 2020. As a result, there was no investment in the development of U.S shale-oil wells.[9]

War in Ukraine, prices in June 2022

The war in Ukraine has dealt a major shock to commodity markets, altering global patterns of trade, production, and consumption in ways that will keep prices at historically high levels through the end of 2024, according to the World Bank's latest Commodity Markets Outlook report. The increase in energy prices over the past two years has been the largest since the oil crisis of 1973. The increases in price for food

9 Public Utilities Commission of Latvia (2021). SPRK skaidro dabasgāzes cenas pasaulē un to ietekmi uz Latvijas dabasgāzes lietotājiem. Available: https://www.sprk.gov.lv/events/sprk-skaidro-dabasgazes-cenas-pasaule-un-ietekmi-uz-latvijas-dabasgazes-lietotajiem

commodities – of which Russia and Ukraine are large producers – and fertilizers, which rely on natural gas as a production input, has been the largest since 2008. Energy prices are expected to rise by more than 50% in 2022 before easing in 2023 and 2024. Non-energy prices, including agriculture and metals, are projected to increase by almost 20% in 2022, and will also moderate in the following years. Nevertheless, commodity prices are expected to remain well above the most recent five-year average. In the event of a prolonged war, or additional sanctions on Russia, prices could become even higher and more volatile than projected in the summer of 2022.[10]

Europe's biggest Russian gas buyers raced to find alternative fuel supplies and decided burning more coal to cope with reduced gas flows from Russia that threaten an energy crisis in winter, if stores are not refilled. Germany, Italy, Austria, Denmark, and the Netherlands have all signalled that coal-fired power plants could help getting the continent through a crisis that has sent gas prices surging and added to the challenge facing policymakers battling inflation.[11]

The trend in electricity prices is observed throughout Europe and is based on the factors that have determined price increases: high gas and CO_2 emission allowances prices have risen further (+253% in gas prices and +115% in CO_2 prices comparing those in 2021 to 2020), and electricity consumption has grown as air temperatures fall. In turn, the increase in consumption means that more electricity had to be produced with fossil energy sources, since electricity producers using renewable energy sources were unable to cope with the ascending demand for electricity over that period. Thus, as electricity consumption rose, electricity prices on the stock exchange were increasingly charged by electricity producers using fossil energy sources, which, in view of high gas and CO_2 emissions quota prices, have become more expensive. In total, 47% of electricity produced in the Baltic according to ENTSO-E (the European Association of Transmission System Operators for Electricity) was produced from fossil resources in November 2021.[12]

On the other hand, World Energy Outlook[13] has a horizontal approach reflecting the power related costs according to market system participants. The report summarizes the retail electricity cost components, without wholesale electricity prices, highlighting system control costs (balancing and response costs), transmission and distribution system costs (network infrastructure capital costs,

10 World Bank (2022). Food and Energy Price Shocks from Ukraine War Could Last for Years. Available: https://reliefweb.int/report/world/food-and-energy-price-shocks-ukraine-war-could-last-years-enarruzh

11 Eckert, V., Landini, F. (2022). Europe may shift back to coal as Russia turns down gas flows. Available: https://www.reuters.com/world/europe/europe-may-shift-back-coal-russia-turns-down-gas-flows-2022-06-20/

12 AS "Augstsprieguma tīkls" (2021). Novembrī jauns mēneša un dienas vidējās elektroenerģijas cenas rekords. Available: https://www.ast.lv/lv/events/novembri-jauns-menesa-un-dienas-videjas-elektroenergijas-cenas-rekords

13 International Energy Agency (2021). World Energy Outlook 2021. Available: https://iea.blob.core.windows.net/assets/888004cf-1a38-4716-9e0c-3b0e3fdbf609/WorldEnergyOutlook2021.pdf

operational and maintenance costs, network loss costs), delivery costs (meters, invoices and debt collection costs, other commercial costs), as well as taxes and equivalent payments (value added tax, renewable energy subsidies, other taxes and subsidies).

The International Energy Agency describes the energy sector functionality model, demonstrating the main elements of the energy input and output factors' system. The international and national policy instruments consequently affect the costs of energy users.[14]

The model reflects the factors of external influence where it is possible to define assumptions (input data): fuel prices and CO_2 prices, specific policies, technologies, and socio-economic influential factors. These factors have an impact on an energy system, which combines various system participants from energy supply and demand sides. The prices of the specific energy products and services are formed as a balance between demand and supply, resulting in transactions between market participants. The results of the relevant energy system transactions are reflected in the system output data, creating energy flows (such as cross-border trade), CO_2 emissions and investments. These factors could be divided according to the possibilities to influence them: the EU and the national policy decisions and market impact decisions.

2. Energy policy scenarios and their assumptions

World Energy Council's (WEC) experts have evaluated the most popular energy development scenarios elaborated by various global organizations, categorizing them according to the ideological approach into three groups:

- Plausible scenarios – the scenarios where usually, in addition to technical and economic aspects, social and political elements are also reviewed in detail. They describe new and alternative energy future opportunities, linking the factors that no system participant can directly control and influence.
- Reporting scenarios (outlooks) are usually focused on technically economical elements. The purpose of this evidence-based forecast is to create a baseline that can be used to evaluate additional and/or new policy options and benefits. Outlooks are also commonly referred to as conditional forecasts, basic scenarios, or policy scenarios.
- Normative scenarios are aimed at achieving a specific objective, consistent with global vision, such as avoiding catastrophic climate change or achievement of

14 International Energy Agency (2021, August). World Energy Model Documentation, p. 112. Available: https://www.iea.org/reports/world-energy-model/about-the-world-energy-model

Table 1. **Breakdown of energy development scenarios according to their approach groups**

Plausible scenarios	Outlooks	Normative scenarios
• WEC (2016) World Energy Scenarios (2060): Modern Jazz, Unfinished Symphony, Hard Rock • Shell (2013) New Lens Scenarios (2100): Mountain, Ocean • Statoil (2017) Energy Perspectives (2050): Reform, Rivalry • IEEJ (2018) Outlook (2050): Advanced Technology • Enerdata (2018) Global Energy Scenarios to 2040: Ener Brown	• EIA (2017) International Energy Outlook (2040): Reference • IEA (2017) World Energy Outlook (2040): Current policies, new policies • IEEJ (2018) Outlook (2050): Reference • BP (2018) Energy Outlook (2040): Evolving Transition • CEPSA (2017) Energy Outlook 2030: Reference • ExxonMobil (2018) Outlook for Energy: A View to 2040: Reference • Enerdata (2018) Global Energy Scenarios to 2040: Ener Blue • DNV GL (2018) Energy Transition Outlook: Reference	• Shell (2013) New Lens Scenarios (2100): Sky • Statoil (2017) Energy Perspectives (2050): Renewal • Enerdata (2018) Global Energy Scenarios to 2040: Ener Green • IRENA (2017) Perspective for energy transition: 66% chance <2' • IPCC (2018) Global Warming of 1.5°C: P1, P2, P3, P4

Source: authors' construction on the basis of World Energy Council data

overall development. These target-based ways are designed using back-time frame and collect information on detailed technology and policy travel and guidelines.[15]

Table 1 shows the distribution of the world's best-known energy development scenarios according to the approach group of their classification.

In addition, WEC experts have also assessed the following scenarios that could not be unambiguously classified according to the abovementioned approaches: APEC (2016) Energy Demand and Supply Outlook (2040), EC (2020) EU Reference Scenario (2050), National Grid (2017) Future Energy Scenarios (2050), BDI (2018) Climate Paths for Germany (2050), BNEF (2017) New Energy Outlook, IPCC (2000) Emissions Scenarios, McKinsey (2018) Global Energy Perspective.

It must be admitted, that after 2019 many organizations came out with the renewed scenarios (for example, IRENA, the International Energy Agency, the European Commission, OECD, Shell, BP, Equinor, Bloomberg NEF and other), while the overall approach in them in principle remained unchanged. As new policy players in the scenarios published in 2019–2022 could be highlighted connectivity, demand response, investments, storages, carbon pricing,

15 World Energy Council (2019). Innovation, Insights Brief. Global Energy Scenarios Comparison Review. Technical Annex. London, p. 35. Available: https://www.worldenergy.org/publications/entry/innovation-insights-brief-global-energy-scenarios-comparison-review

digitalization. Despite the fact that the aforementioned scenarios have different approaches (policy-driven, market driven or technology driven), their prospects demonstrate that energy transition is realistic task.[16]

Energy development scenarios according to the approach groups

When assessing the assumptions of energy demand defined in these scenarios, WEC experts concluded that they differ significantly. Energy demand trends are higher in outlooks, but are lower and marked with greater differences in normative scenarios. The rise in electricity generation in all scenarios is marked in principle as an inevitable future. Acceleration of electrification also plays a big role here.

The vision of energy mix structure varies more in the 2040 scenarios. All of the scenarios reflect the increased role of renewable energy sources in the future. At the same time, between plausible and outlook scenarios, the total share of fossil fuel energy resources is predominantly lower than 70%. The share of RES mainly grows at the expense of coal reduction. Also, there is no doubt about the growth of sun and wind energy power. Normative scenarios predict a faster growth of renewable energy sources than outlook scenarios.

The future of coal is under the question mark, while described in the scenarios total share of global oil and gas consumption on average does not lose position compared to the current level. Most of the scenarios published before 2018 forecasted a rapid increase in gas, compensating oil reduction. However, a range of scenarios published after 2020, such as IRENA World Energy Transition Outlook[17], Bloomberg NEF, NGFS, see decrease in natural gas supply volumes by 2050. Oil demand for outlook scenarios and plausible scenarios is relatively stable, while its share of the energy portfolio is less in normative scenarios. It is also assumed that the demand for nuclear energy will grow in the majority of global scenarios.

All the reviewed by WEC scenarios have three main pillars: (1) Reducing energy demand by increasing efficiency, (2) electrification of final consumption and (3) decarbonisation of electricity generation. At the same time, WEC experts have identified several aspects that have less focus or are not reflected in the energy development scenarios at all.

There is a lack of a deeper analysis of the costs, that are related to the renewable energy use acceleration and digitalization in most of the energy policy scenarios.

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16 World Energy Council (2022). The World in 2050: Explore MAP Phase Insights. Visionario project Map Phase Analysis. Future Energy Leaders. Project leads: O. Bogdanova, J. Ohene-Akoto, R. Viggiano, G. Bence-Hebert. London, 39 p. Available: https://www.worldenergy.org/assets/downloads/FEL_Visionario_MAP_Phase_Analysis_Presentation.pdf?v=1662554370

17 The International Renewable Energy Agency (IRENA) (2021). World Energy Transitions Outlook: 1.5°C Pathway, International Renewable Energy Agency. Abu Dhabi, p. 312. Available: https://www.irena.org/publications/2021/Jun/World-Energy-Transitions-Outlook

However, some recent scenarios, for example, IEA Energy Efficiency scenario[18], highlight the importance of digitalization in achieving ambitious Green Deal aims. It is concluded that the assumptions about correlation between the energy transition and digital productivity are linear and positive – accelerated digitalization contributes to the faster use of renewable energy sources and reduction of future costs.

Energy policy development scenarios often fail to consider Energy Return on Investment, namely, the ratio between the amount of energy used and supplied from a particular energy resource versus the amount of energy used for obtaining this energy resource (such as lithium battery sourcing / recycling). Similarly, costs of entire energy system stability are usually not included in the scenarios. In addition, often scenarios do not take into account cyber security risks, system user interface complexity, or the potential interference in digital solutions on the consumers' side.

According to the WEC researchers, the great potential, which is not classically reflected in the world scenarios, is financial innovation to eliminate lack of investments. However, such scenarios as Shell Mountain scenario[19] and International Energy Agency World Energy Outlook 2021 recognized a considerable importance of appropriate public and private investment for speeding up the sustainable transformation. The transition to green energy can be accelerated, with the ability of the financing availability measures to cover the social, environmental, and overall costs of the system, which are difficult to identify, and which are currently not reflected in the discussions on carbon price.

Despite the 'green' funding and progress towards investments in new energy companies, significant shortcomings in energy infrastructure investments still remain unresolved, and that might bring challenges in the future. For example, it would make a significant difference if the new hydrogen solutions were to make it possible to re-use the existing infrastructure and increase the intensity of use of infrastructure as a result.[20][21]

18 International Energy Agency (2021). World Energy Outlook. Available: https://iea.blob.core.windows.net/assets/888004cf-1a38-4716-9e0c-3b0e3fdbf609/WorldEnergyOutlook2021.pdf

19 Shell (2017). World Energy Model. A view to 2100, Shell International BV. Available: https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenarios-energy-models/world-energy-model/_jcr_content/root/main/section/simple/call_to_action/links/item0.stream/1651505502658/2ee82a9c68cd84e572c9db09cc43d7ec3e3fafe7/shell-world-energy-model.pdf

20 World Energy Council (2019). Innovation, Insights Brief. Global Energy Scenarios Comparison Review. Technical Annex. London, p. 35. Available: https://www.worldenergy.org/publications/entry/innovation-insights-brief-global-energy-scenarios-comparison-review

21 World Energy Council (2022). The World in 2050: Explore MAP Phase Insights. Visionario project Map Phase Analysis. Future Energy Leaders. Project leaders: O. Bogdanova, J. Ohene-Akoto, R. Viggiano, G. Bence-Hebert. London, 9 p. Available: https://www.worldenergy.org/assets/downloads/FEL_Visionario_MAP_Phase_Analysis_Presentation.pdf?v=1662554370

3. Examples of energy policy scenarios and their instruments

As noted above, certain components of energy costs can be influenced by energy policy instruments. Along with the new climate neutrality course, world countries review their policies on energy production and consumption by setting specific objectives and introducing relevant instruments. For example, the International Renewable Energy Agency (IRENA) has highlighted sectors with the highest impact on carbon reduction targets in its World Energy Transition review in 2021. According to IRENA forecasts, a wider use of renewable energy sources in electricity generation, as well as direct use of renewable energy and biomass in heat production is able to provide the largest (25%) performance in achieving the CO_2 reduction target – a total of 36.9 gigatonnes of CO_2. Such a strong contribution can also be provided by energy efficiency (25%), which includes measures that reduce energy demand and increase efficiency. Structural changes (e.g., metal production relocation) and circular economy practice are part of energy efficiency. Electrification (20%) includes the direct use of "clean" energy in transport and heating equipment. Hydrogen and its derivatives (10%), which include synthetic fuels and raw materials, is highlighted as the next perspective direction. Carbon capture and storage (CCS) includes carbon collection and storage from fossil fuels and other sources, mainly in industry. Bioenergy with carbon capture and storage (BECCS) and other carbon restriction measures include bioenergy together with CCS electricity and heat in production and industry.

Similarly, IRENA World Energy Transition review in 2021 identifies measures that have the highest contribution to improving energy intensity:

1) energy intensification improvements are achieved through the introduction of renewable energy technologies in the energy sector (wind generation, solar PV, etc.) and direct end-use equipment (solar thermal energy, transition from traditional bioenergy use to modern), renewable resources, etc.);
2) technical efficiency measures which include efficiency measures used in industry, buildings, and transport sectors (e.g., improvement of buildings, more efficient devices, motors, etc.);
3) electrification of heat and transport equipment, for example, using heat pumps and electrical vehicles.

The **International Energy Agency** predicts that in 2070 the primary energy end consumption will remain stable, despite the economic growth (3% per annum and GDP 2.5 times) and the population growth (9.9 billion population in 2050). The main reason for that is energy efficiency, electrification of the energy end consumption, as well as electrolysis. Similar approach has also scenarios developed by BP, Equinor and IRENA. At the same time, experts of the International Energy Agency also recognize that considerable investments are needed to implement successful transformation – on average, 4–8 times higher than now. Significant increase of energy generation is projected based on solar and wind generation technologies, reaching 50–100 TW of installed power capacity.[22]

The European Commission has elaborated several energy development scenarios for the Green Course objectives by 2030, depending on the various priority policy instruments. Considering that the energy sector is responsible for a little more than 75% of emissions, the European Commission sees the use of renewable energy and energy efficiency as the largest GHG reduction promoters.[23]

The European Commission scenario, reaching about 50% of GHG objectives (including the EU internal aviation and navigation fields), achieves 35% of the renewable energy share and 34.5% of the final energy savings, as well as 37% of primary energy savings. Scenarios that reach 55% GHG goals (including the EU internal aviation and navigation) count for a renewable energy share of 37.5% to 39%, final energy savings from 36% to 36.5% and primary energy savings from 39% to 40%. Slightly lower ambitions are needed for the so-called MIXNon-CO_2 variant that provides greater emission reduction in areas that are not directly related to CO_2. In the European Commission's assessment of power generation, household sector and services are able to provide a higher reduction in GHG emissions.

When assessing the necessary investments in achieving the objectives of each of the outlined scenarios, the European Commission considers that implementation of the additional baseline scenario by 2030, on the supply side investments requires from 10.5 to 31.8 billion EUR (depending on the scenario selected), whereas on the demand side – from 38.3 to 90.2 billion EUR (depending on the chosen scenario). The largest investment is expected in the household sector, and it varies from 15.4 to 61.4 billion EUR by 2030 (depending on the chosen scenario).

The European Commission's scenarios include the following measures:

- BSL (base scenario) reflects existing GHG, renewable energy and energy efficiency EU objectives by 2030;
- REG (regulation-based scenario) ensures reduction of a GHG by about 55%. It provides for high energy efficiency, ambitious growth of renewable energy and transport policy, while maintaining the EU ETS working area constant. REG does not provide additional measures for carbon prices and is mainly based on other policies;

22 International Energy Agency (2020). Energy Technology Perspectives, 80. Available: https://iea.blob.core.windows.net/assets/7f8aed40-89af-4348-be19-c8a67df0b9ea/Energy_Technology_Perspectives_2020_PDF.pdf

23 European Commission (2020). Commission staff working document impact assessment, Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social committee and the Committee of the Regions "Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people". SWD/2020/176 final. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0176

Table 2. Annual Investment Comparison

EU27	MIX-50		REG		MIX		MIX-nonCO$_2$		CPRICE		ALLBNK	
	Average 2021–2030	Average 2031–2050	Average 2021–2030	Average 2031–2050	Average 2021–2030	Average 2031–2050	Average 2021–2030	Average 2031–2050	Average 2021–2030	Average 2031–2050	Average 2021–2030	Average 2031–2050
Investments in power grid	2.2	33.3	6.9	32.2	7.7	30.2	6.5	31.1	7.8	31.7	9.6	29.6
Investments in power plants	6.0	68.0	13.6	59.0	14.4	62.1	11.9	63.3	13.5	65.6	17.5	59.0
Investments in boilers	1.4	-0.4	1.9	-0.8	1.8	-0.7	1.6	-0.7	2.1	-0.4	2.6	-0.6
Investments in new fuels production and distribution	0.9	27.1	1.6	24.1	1.3	26.1	1.2	25.8	1.2	27.7	2.0	25.3
Total supply side investments	10.5	128.0	24.0	114.6	25.2	117.6	21.3	119.4	24.5	124.6	31.8	113.3
Industrial sector investments	2.5	4.7	2.5	6.0	3.4	4.4	3.3	4.3	3.6	3.4	5.0	4.8
Residential sector investments	15.4	19.6	61.4	55.2	38.8	37.2	38.0	37.6	21.1	16.6	41.9	39.0
Tertiary sector investments	10.2	24.5	14.1	20.5	14.5	23.8	14.1	24.2	16.1	28.1	19.6	29.1
Transport sector investments	10.2	29.4	12.3	38.8	11.3	31.2	11.5	31.4	-2.5	33.3	9.8	29.0
Total demand side investments	38.3	78.2	90.2	120.5	68.0	96.6	67.0	97.5	38.4	81.4	76.4	101.9
Total demand side investments excl. transport	28.0	48.8	78.0	81.7	56.7	65.4	55.5	66.1	40.9	48.0	66.6	72.9
Total energy system investments	**48.8**	**206.2**	**114.2**	**235.0**	**93.2**	**214.2**	**88.3**	**216.9**	**62.9**	**206.0**	**108.2**	**215.2**
Total energy system investments excl. transport	**38.5**	**176.8**	**102.0**	**196.3**	**81.8**	**183.0**	**76.7**	**185.5**	**65.4**	**172.6**	**98.3**	**186.2**

Source: European Commission, 2020[24]

24 European Commission (2020). Commission staff working document impact assessment, accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people" SWD/2020/176 final. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0176

- CPRICE (carbon price-based scenario) provides for a reduction of greenhouse gases by about 55%. It foresees a carbon price strengthening and further expansion through EU ETS or other carbon pricing tools, transport and building industries, in connection with low transport policy, at the same time without enhancing energy efficiency, renewable energy policy;
- MIX, subject to combined approach of REG and CPRICE, provides for approximately 55% of GHG reduction, both expanding carbon pricing and moderately increasing policy scope, but to a lesser extent than REG;
- MIX-50 – an ambitious scenario that achieves at least 50% of GHG reduction similar to MIX, as it combines both carbon price expansion, greater ambitions of both energy and transport policy objectives, but to a lesser extent than MIX;
- ALLBNK, the most ambitious GHG emission reduction scenario based on MIX and it further strengthens the fuel powers in aviation and maritime sectors, responding to the extended GHG reduction area, that covers all aviation and navigation;
- MIX-NonCO_2 scenario deals with a higher contribution of CO_2 emissions to the GHG reduction target, which means greater reduction in emissions, that are not CO_2 emissions, and lower CO_2 reduction compared to MIX, mainly in the energy power system.

According to the European Commission's assessment, the most expensive scenario, which requires the largest investment compared to the baseline scenario, reaching 55% of GHG reduction by 2030, is REG scenario (114.2 billion EUR), while the cheapest – CPRICE scenario (62.9 billion EUR). The MIX-50 scenario provides only above 50% of GHG emission reduction by 2030, but its costs are lower – 48.8 billion EUR.

However, the opinion of researchers on the 'Green course' impact on the economy is not unambiguous. **The United States Center for Data Analysis Heritage Foundation** (hereafter – HF Center) in its 'green transformation' evaluation forecasts is sceptical about the positive impact of the 'Green course' on the economy. HF Center predicts that increasing requirements for carbon reduction at some point will not be particularly effective against higher fiscal policy instruments and the CO_2 reduction targeted tax implementation. Researchers conclude that, as taxes are gradually raised, the added value of emission reduction shrinks. In the HF Center, simulations as a result of 35 USD carbon tax CO_2 emissions decrease by 44% by 2050, the reduction caused by 100 USD carbon tax is 53%, 200 USD results in a 56% reduction, whereas 300 USD taxes show 58% reduction in 2010. If a carbon tax exceeds 300 USD (as a result of 2050 CO_2 falls by a little more than 50%), the model ceases to function, and thus the CO_2 decrease of 58% compared to the 2010 level is the highest level that is possible to model.

In addition, researchers' simulation reveals that, in case of introducing 300 USD big carbon tax by 2040, it will have a significant negative impact in the United States: total average job lack of more than 1.1 million, maximum employment deficit of more than 5.2 million jobs, total loss of income exceeding 165,000 USD for the family of four people, total loss of gross domestic product – more than 15 trillion USD, increase in household electricity expenditure – 30%.[25]

At the same time, there are other, significantly more ambitious global energy policy scenarios. For example, researchers of "The Rethink X Project" believe that the goals of Net Zero Carbon plan can be achieved much faster than it is usually considered, and just using the existing technologies. Researchers conclude that the overall global emissions can be reduced by more than 90% by 2035, providing reduction of direct consequences of the three main sectors (energy, food, transport) and increasing the recovery of forests as a compensatory mechanism for eliminating the effects of climate.

Researchers consider that the most global GHG by 2021 (56.7%) are related to the use of energy by burning fossil fuels and releasing CO_2. Emissions from the food sector, mainly methane (CH_4) and nitrogen oxide (N_2O) account for 18% of global emissions. The transport sector involves a smaller part – 16.2%, while the road transport sub-sector is the largest permanent source of emissions – 11.9%. Other sources outside these three sectors account for 8.4% of global emissions, the largest source is concrete production with 3%. Scientists believe that 2.7 billion hectares of land could be vacated, if cattle were no longer used for consumption. Using this land for natural (and free) passive reforestation by 2030, in each year it could be possible to reimburse almost 10%, and by 2035 – up to 20% of global emissions.

Food (livestock) transformation will contribute to accurate fermentation economy and cell agriculture, which will compete with all types of animal products. It is concluded that the fermentation will be able to provide an economically substantiated protein production that is 5 times cheaper than the usual animal protein by 2030, and 10 times cheaper until 2035. The accuracy with which it is possible to produce protein means that the resulting foods are of a higher quality and safer, as well as much more extensively available than the animal products that they replace.[26]

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25 Dayaratna, K. D., Loris, N. D. (2019, July 24). Assessing the Costs and Benefits of the Green New Deal's Energy Policies. *Backgrounder, 3427.* Washington DC: The Heritage Foundation, p. 18. Available: https://www.heritage.org/sites/default/files/2019-07/BG3427.pdf

26 Arbib, J., Dorr, A., Seba, T. (2021, August). Rethinking Climate Change. A RethinkX Disruption Implications Report, p. 39. Available: https://www.rethinkx.com/climate-implications

Markets can and must take the dominant role in reducing emissions, optimizing resource redistribution, and rewarding efficiency. It is possible to use their economic benefits and save trillions of dollars, which would otherwise be lost because of the wrong investment in older technologies, while reducing the social and environmental costs of historical industries. The research indicates that the Government's main role must be a well-functioning market provision, removing barriers for the following technologies: solar, wind and battery technologies, electrical transport and autonomous transport, transportation as a service, accurate fermentation, and cell farming.[27]

4. Energy policy instruments and energy costs

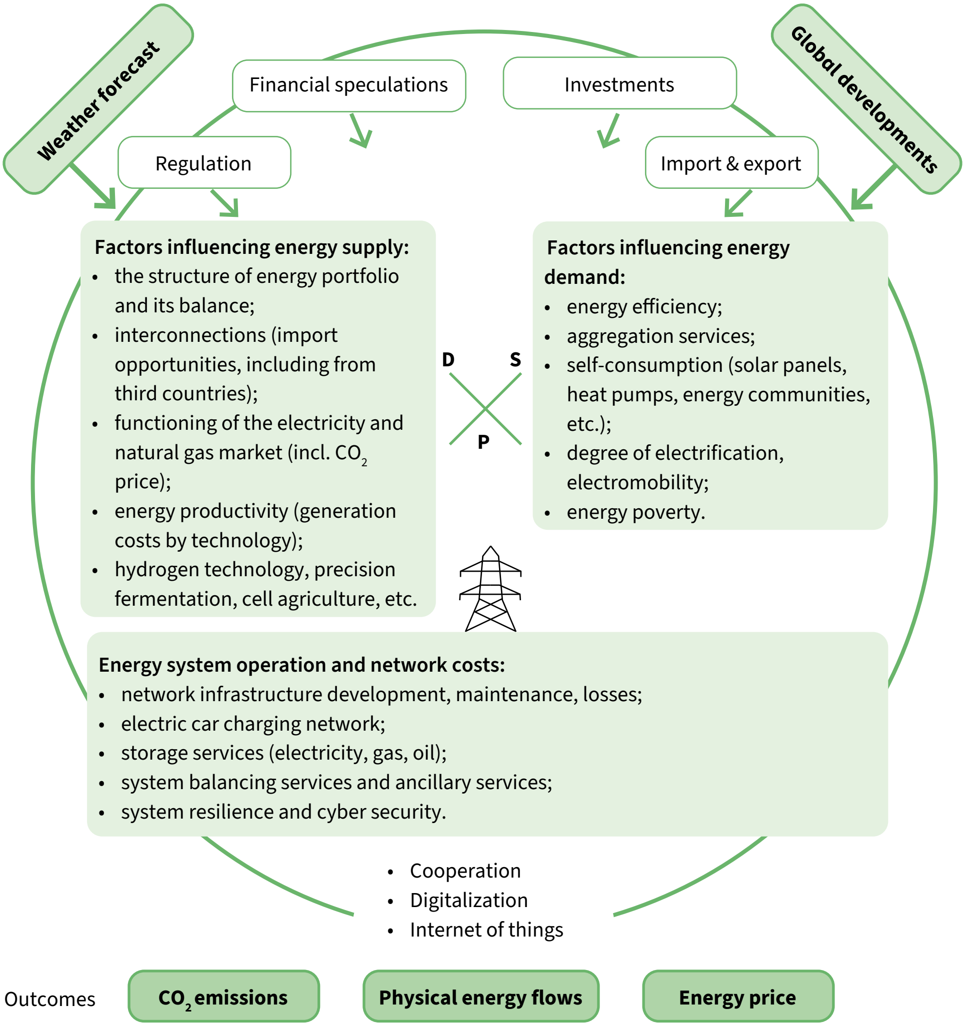
As a result of the analysis of the global energy scenarios, the energy policy measures advancing climate neutrality, and the corresponding factors affecting energy costs of energy consumers, generally applied in the scenarios, as well as more specific energy-related factors are summarized in Figure 1, which characterises a system combining the factors important for sustainable energy policy development, which are related to energy costs. The assessment of the factors reflected in Figure 1 is not detailed (the factors are systemized by applying the grouping method) and by no means exhaustive, and further research is needed to continue expanding it. A set of the factors influencing energy costs consists of the three basic groups: factors affecting energy demand, factors affecting energy supply, as well as costs of the energy system and grid.

Figure 1 shows the main factors influencing energy costs. At the same time, it does not include the weather factor, which has a significant impact on both supply (wind strength, water level, solar energy intensity, which is essential for energy generation) and demand (outdoor temperature and heating or cooling demand), as this factor cannot be affected by energy policy instruments. Also, digitization is emphasized in the figure separately, as its added value is reflected in each of the factors separately (cost drivers).

Demand-side and supply-side measures have a direct impact on the achievement of the Green course objectives, reflecting the respective costs for end-users. However, the costs of the energy system and network infrastructure should react and be adjusted according to the factors of demand and supply. The system adjustments are necessary to ensure the security of energy supply at an appropriate level in response to the policy instruments influencing demand and supply.

27 Arbib, J., Dorr, A., Seba, T. (2021, August). Rethinking Climate Change. A RethinkX Disruption Implications Report, p. 39. Available: https://www.rethinkx.com/climate-implications

Figure 1. Factors influencing energy costs



Source: authors' construction

Moreover, it is important to identify the parties involved in the implementation of the measures to apply the targeted policy measures in specific sectors. There is a great potential for the development of Net Zero Carbon plans at the municipality level facilitating their cooperation, considering local peculiarities, opportunities, and potential of each location. For example, in Italy, the Italian Energy Community Forum was established in autumn 2021 to promote the development of local level sustainability plans and facilitate cooperation on similar initiatives with other countries. Latvia also has an opportunity to use a good practice of other countries as a benchmark.

In order to achieve sustainability goals, countries need to identify an optimal set of measures, considering their current situation, strengths and weaknesses, and opportunities that have not yet been fully exploited. At the same time, moving towards climate neutrality, a healthy balance of the energy trilemma must be ensured without compromising security of energy supply and ensuring energy availability providing the lowest possible energy costs, thus contributing to the competitiveness of a country.

The main conclusions and a view of the future actions

The Renewable Energy Directive, the Energy Efficiency Directive and the Governance Regulation are powerful tools for achieving the objectives of 2030 and 2050 EU climate neutrality. These legal acts determine directions of the action, while ambitious climate goals can be achieved by different sets of measures. The EU Member States must choose the optimum policy measures, appropriately minimizing energy costs for the end users.

Identification of the parties involved in implementation and application of targeted policies in specific sectors is also important. Development of Net Zero Carbon plans at municipality level have particularly high perspectives, considering local characteristics, opportunities, and potential.

Global energy development scenarios delineate a range of measures to achieve Green transition. However, the three basic pillars may be highlighted as the key measures in the majority of all the scenarios, namely: (1) reducing energy demand by increasing efficiency; (2) end-consuming electrification and (3) decarbonisation of electricity generation.

According to the assessment of the European Commission, electricity production, household sector and services are able to provide the highest reduction of greenhouse gas emissions out of all the reviewed sectors.

Evaluating the necessary investments in achieving the relevant objectives in each of the scenarios elaborated by the European Commission, the additional baseline scenario will require investments on the supply side from 10.5 to 31.8 billion EUR (depending on the selected scenario), as well as on the demand side – from 38.3 to 90.2 billion EUR (depending on the chosen scenario). The largest investments are expected in the household sector, and they vary from 15.4 to 61.4 billion EUR by 2030 (depending on the chosen scenario).

The global energy development scenarios often are missing an energy-unrelated resource risk analysis, "the energy efficiency of energy production counting the energy invested to generate the respective energy unit" (for example, ignoring the energy invested in production of lithium batteries) is not calculated, the power system resilience and operational costs are being ignored, nor a sufficient attention to the cyber security risks is ensured. Similarly, most of the energy scenarios do not analyse the risks associated with disturbances in digital solutions that are related to sustainable energy. Reviewed global scenarios do not identify the potential of financial innovation, which could mitigate the lack of investment.

According to the World Energy Council Energy trilemma assessment, Latvia's biggest challenge regarding energy balanced policy is the energy costs – this indicator in Latvia has been the worst among the Baltic states in 2021. Promoting new energy policy initiatives, it is essential to assess the impact of projects on energy costs. At the same time, a sustainable policy indicator tends to decrease in the overall global rating, and more attention should be paid to seeking cost-effective sustainable solutions, as well as to security, which is gaining an extraordinary importance.

When modelling the impact of individual measures on costs incurred to energy users, it is necessary to consider not only the direct impact costs of the relevant measure, but also to take into account the other related costs associated with the measure. The system of the sustainable energy policy factors having impact on energy costs, which has been proposed in the current article, is recommended for the modelling of national sustainable energy policy scenarios, determining their respective economic impact on energy users.

The war in Ukraine has brought about a shift toward more costly trade patterns, and the transition to cleaner energy in Europe has a risk of being delayed for several years. However, in a longer perspective, the Green Deal policy has a potential to contribute significantly to security due to the local-generation nature of renewables. Decreasing dependency on import yields a higher energy security.

Ahmad Humbatov

The role of natural gas in energy transition

The role of natural gas in energy transition has long been debated. Although a fossil fuel, it emits significantly less carbon dioxide and air pollutants than coal and oil. In this regard, many consider it as an intermediate source of energy helping to shift from the world of hydrocarbons to renewables. Others question the role of natural gas in a transition to net zero energy systems as they believe it hinders the decarbonization effort through carbon lock-in and stranded assets. Moreover, there is a belief that investments in natural gas might crowd out investments in renewable alternatives.

The current global energy crisis, to a large extent caused by delayed maintenance of oil and gas fields and underinvestment during the pandemic period, and exacerbated by the war in Ukraine, has brought the issue of natural gas consumption into the spotlight again. Furthermore, the decision of the European Union lawmakers in July 2022 to vote in favour of calling natural gas (and nuclear power) a 'green' and 'sustainable' source of energy has spurred another wave of discussion regarding the role of natural gas in the global energy transition.[1] Such labelling essentially paves the way for potentially billions of euros of funding from investors for the development of natural gas projects. Remarkably, Brussels's position towards natural gas does not fit well into the policy recommendations of the International Energy Agency (IEA), which stated in its "Net Zero by 2050" roadmap in May 2021[2] that there should be no investments in new gas, oil, or coal production if the world is to meet the Paris Agreement targets. The European Union is a global leader in the field of green energy and sustainable development, and Brussels's decisions regarding the classification of environmentally sustainable

1 Abnett, K. (2022, July 7). EU parliament backs labelling gas and nuclear investments as green. *Reuters*. Available: https://www.reuters.com/business/sustainable-business/eu-parliament-vote-green-gas-nuclear-rules-2022-07-06/

2 International Energy Agency (2021, May). Net Zero by 2050: A Roadmap for the Global Energy Sector. International Energy Agency. Available: https://www.iea.org/reports/net-zero-by-2050

economic activities, known as the EU taxonomy, will have a significant impact on decarbonization policies in other jurisdictions around the world.

The thesis that the world can quickly transit to renewables without natural gas certainly does not hold water. However, the statement that natural gas will play a dominant role in global decarbonization efforts is equally questionable. The truth is somewhere in between. As it was mentioned in a report on natural gas by the Centre for Strategic and International Studies (CSIS), “gas does different things in different markets and at different costs, so broad statements about how gas will fare in the future are unhelpful.”[3] Indeed, in some cases sticking to natural gas would bring about more harm than benefit to the environment, while in other cases using more gas could help to decarbonize the global economy. The paper seeks to analyse the potential role of natural gas in energy transition, understand its various uses, and how those uses might evolve under a decarbonization scenario.

1. Current state of the natural gas market

Natural gas, accounting for a quarter of global energy consumption, is the third largest source of energy after crude and coal. Consumption of natural gas increased dramatically in the past decade, accounting for almost one-third of total energy demand growth, more than any other fossil fuel.[4] In 2021, global natural gas consumption increased by 4.5%. This is more than twice the equivalent of the decline experienced in 2020 and the third strongest year since 2000, after 2010 and 2018 (which grew by 7.8% and 5.2% respectively).[5] The strong growth is a result of the global economic recovery after the pandemic-induced constraints coupled with a higher demand for power and heating needs due to the extreme weather conditions of 2020.

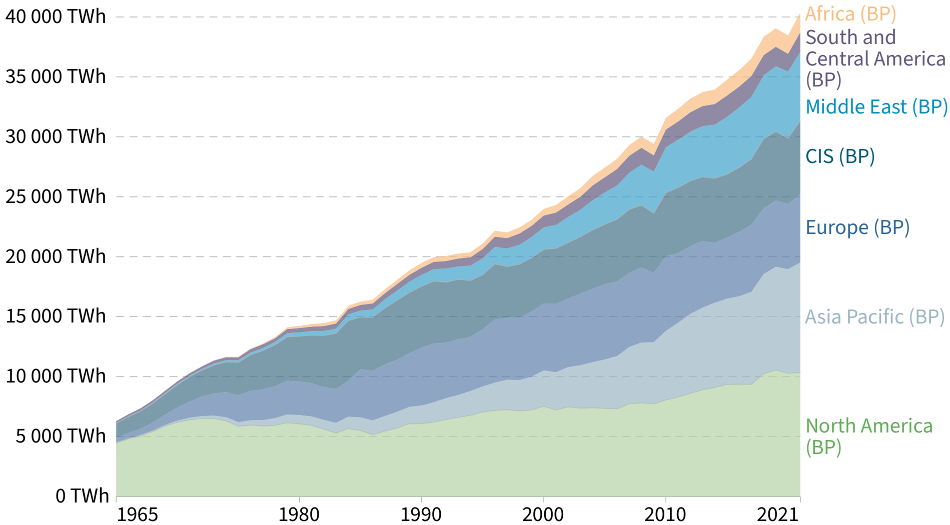
The rapid economic recovery in the second half of 2021 amid limited energy supplies sent natural gas prices soaring. The beginning of the war in Ukraine in February 2022 further exacerbated the situation, causing fuel switching and demand destruction. Current record high prices and supply disruptions negatively impact the image of natural gas as a reliable and affordable energy source, generating mistrust towards the fuel’s future, especially in developing countries where it was supposed to play a leading role in meeting rising energy demand

3 Tsafos, N. (2020, January 14). How Will Natural Gas Fare in the Energy Transition? Center for Strategic and International Studies. Available: https://www.csis.org/analysis/how-will-natural-gas-fare-energy-transition

4 Gas. International Energy Agency, 2022. Available: https://www.iea.org/fuels-and-technologies/gas

5 International Energy (2021). Agency Gas Market Report, Q2-2022, including Global Gas Review. Available: https://iea.blob.core.windows.net/assets/cfd2441e-cd24-413f-bc9f-eb5ab7d82076/GasMarketReport%2CQ2-2022.pdf

Figure 1. **Gas consumption by region. Annual natural gas consumption, measured in terawatt-hour (TWh) equivalents**



Source: https://ourworldindata.org/grapher/natural-gas-consumption-by-region

and decarbonization ambitions. As a result, global natural gas consumption is expected to contract in 2022, with limited growth until 2025, adding around 140 billion cubic meters (bcm) between 2021 and 2025, a significant decrease from the previous forecasts.[6]

Asia Pacific, the second largest consumer of natural gas accounting for 23% of the fuel's global consumption in 2021, is expected to be the driving force behind natural gas consumption growth in the next 3 years, adding around half of the global consumption gains accounting for 70% of the net demand increase. The potential increase in demand, however, remains limited due to high prices and weakening economic growth. China is expected to experience the largest increase in natural gas demand, accounting for more than 75% of Asia Pacific's growth in gas consumption during the 2021–2025 period. India, too, will be a major contributor to an increase in natural gas demand, owing to the residential and transport sectors in the country's fast-growing city gas segment. After Asia Pacific, the Middle East is the second largest contributor to global gas demand growth,

6 International Energy (2021). Agency Gas Market Report, Q2-2022, including Global Gas Review. Available: https://iea.blob.core.windows.net/assets/cfd2441e-cd24-413f-bc9f-eb5ab7d82076/GasMarketReport%2CQ2-2022.pdf

mainly driven by the increasing domestic supply of fuel in both the power and industrial sectors. In North America, currently the largest consumer of natural gas accounting for a quarter of the fuel's global consumption in 2021, demand is steadily growing. Europe, by contrast, experiences direct demand destruction because of the war in Ukraine and record high gas prices.[7]

According to the Annual Short Term Gas Market Report 2021 of the Gas Exporting Countries Forum (GECF), the power sector is the largest consumer of gas, accounting for 40% of the global natural gas consumption.[8] The residential and commercial sector is another significant consumer accounting for 22%, while the industrial sector accounts for 19% of the total gas consumption. The fuel does not play an important role in the transportation sector where it accounts for just 2% of gas consumption.

2. The role of gas in improving access to electricity, clean cooking, and heating

Despite the efforts to provide access to electricity globally, more than 700 million people remain cut off from electric power. In Africa alone, around 600 million people, representing

43% of the continent's population have no access to electricity.[9] Although the continent possesses 60% of the world's best solar resources, Africa generates only 1% of electricity from solar photovoltaic (PV) panels.[10] At the same time, around 2.6 billion people are deprived of clean cooking methods, which is one-third of the global population.[11] As a result, millions of deaths from inhaling indoor cooking smoke occur annually. Similar to the electricity problem, most people without access to clean cooking reside in Sub-Saharan Africa.

7 International Energy (2021). Agency Gas Market Report, Q2-2022, including Global Gas Review. Available: https://iea.blob.core.windows.net/assets/cfd2441e-cd24-413f-bc9f-eb5ab7d82076/GasMarketReport%2CQ2-2022.pdf

8 Gas Exporting Countries Forum (2021). GECF's Annual Short Term Gas Market Report. Gas Exporting Countries Forum. Available: https://www.gecf.org/_resources/files/pages/gecf-annual-short-term-gas-market-report/gecf-annual-short-term-gas-market-report-2021.pdf

9 International Energy Agency (2022). Africa Energy Outlook. Key findings. International Energy Agency. Available: https://www.iea.org/reports/africa-energy-outlook-2022/key-findings

10 Ibid.

11 World Bank (2021, June 7). Report: Universal Access to Sustainable Energy Will Remain Elusive Without Addressing Inequalities. Available: https://www.worldbank.org/en/news/press-release/2021/06/07/report-universal-access-to-sustainable-energy-will-remain-elusive-without-addressing-inequalities

Natural gas has great potential to help with energy poverty alleviation. It is a versatile fuel that can be used for improving access to electricity, clean cooking, and heating. Natural gas has already helped to improve access to electricity for millions of people, in some cases by replacing more polluting coal and crude oil. Today, gas already accounts for about a quarter of global electricity generation, and it can play a particularly important role to play in Africa. While in the West electricity consumption may be plateauing, Africa's demand will at least double (or possibly triple) by 2040 due to population growth and rapid urbanization.[12] Currently, renewables alone will not be able to do that because of several technical and financial reasons. Besides, there are significant gas deposits in Africa, including Algeria, Egypt, Ghana, Nigeria, Mozambique, and Senegal. Moreover, an increase in their consumption will not lead to a notable increase in greenhouse gases due to extremely low energy use and emissions base.

In addition, gas can help address the indoor air pollution problem, associated with 1.6 million premature deaths a year. Switching from solid fuels such as wood charcoal biomass and kerosene to gas for cooking and heating homes – piped gas in urban areas or, more commonly, liquefied petroleum gas (LPG) delivered in cylinders – has considerably helped to lessen indoor air pollution in China, India, Brazil, and Indonesia. It can do the same in many other countries and regions globally. The creation of the LPG infrastructure is also relatively affordable for developing countries and the timelines are much shorter than any form of grid energy.[13]

In some cases, however, renewables would be technically and financially a better option. The cost of solar and wind has decreased substantially over the past decade, making them competitive with fossil fuels for generating electricity in many countries. Since 2010, the price of solar power has decreased by over 80%. As a result, renewables have recently become the most popular source of energy for new capacity additions globally. More than 80% of all new electricity capacity added in 2020 was renewable, with solar and wind accounting for 91% of new renewables, thus exceeding expansion in 2019 by close to 50%.[14] In rural areas, where most people rely on solid fuels for cooking and heating, decentralized renewable energy systems (along with LPG for cleaner cooking and heating) could

12 World Economic Forum (2020, July 23). 12 reasons why gas should be part of Africa's clean energy future. Available: https://www.weforum.org/agenda/2020/07/12-reasons-gas-africas-renewable-energy-future/

13 Kelly, M. (2020, October 12). Why is the switch to gas for cooking still so slow in Africa? *New African Magazine*. Available: https://newafricanmagazine.com/24602/

14 International Renewable Energy Agency (2021, April 5). World Adds Record New Renewable Energy Capacity in 2020. Available: https://www.irena.org/newsroom/pressreleases/2021/Apr/World-Adds-Record-New-Renewable-Energy-Capacity-in-2020

be a better and cheaper option for electrification instead of expanding long and expansive natural gas pipelines to remote consumers.

3. Coal-to-gas switching in the power sector

Coal is the dirtiest fossil fuel releasing the largest amount of greenhouse gases when burned. Natural gas, by contrast, is relatively the cleanest fossil fuel, emitting 30% less CO_2 than oil, and around 50% less CO_2 than coal. Replacing coal with natural gas in power generation can, therefore, deliver significant environmental gains. The United States is a good example of where this strategy has worked well. The share of coal in the US power production decreased from 50% in 2005 to 23% in 2019.[15] Simultaneously, the share of natural gas in the US electricity generation increased from 19% to 38% for the same period. As a result, the electricity sector in the United States produced 1,724 million metric tons (MMmt) of CO_2 in 2019, 32% less than the 2.544 MMmt produced in 2005, largely due to coal-to-gas switching but also an increase in deployment of renewables.[16] According to the International Energy Agency (IEA), coal-to-gas switching decreased CO_2 emissions by about 500 million tonnes between 2010 and 2018.[17]

Despite the significant environmental benefits, coal-to-gas switching in the power sector is not a frequent phenomenon. To a large extent, such a switch does not happen due to the wider availability of coal globally and its lower price. The latter has become the major reason for an increase in coal consumption to generate electricity amid the current high natural gas prices. In 2021, the costs of operating gas-fired power plants in many countries were often notably more expensive than operating coal power plants. As a result, for example, coal power emissions increased by 16% in the United States and by 20% in the European Union. In total, coal's share in the global power mix rebounded above 36%, reaching an all-time high and further distancing the world from reaching the Paris Agreement targets.[18]

The current high gas price environment and inability to compete in some power generation markets with coal and renewables might become a problem for

15 US Energy Information Administration (2021, June 9). Electric power sector CO_2 emissions drop as generation mix shifts from coal to natural gas. Available: https://www.eia.gov/todayinenergy/detail.php?id=48296

16 Ibid.

17 Ranney, K., Mukati, M. (2020). The Role of Natural Gas in Energy Transition. *Sustainalytics*, August. Available: https://connect.sustainalytics.com/hubfs/SFS/SFS%20-%20Transition%20Bonds/The%20Role%20of%20Natural%20Gas%20in%20the%20Energy%20Transition.pdf

18 International Energy Agency (2022). Coal-Fired Electricity. September. Available: https://www.iea.org/reports/coal-fired-electricity

the expansion of the natural gas industry. The power sector has been the primary area for the expansion of natural gas since the 1970s, accounting for almost half the growth in gas demand for the period. Losing the ability to compete in the electricity generation segment, traditionally its largest market, might jeopardize the future of natural gas. The IEA already states that industry is the key sector for natural gas expansion, not the power market. Another important trend that might curb the natural gas demand is the electrification of energy systems, especially in buildings and transportation. As the global economy becomes increasingly electrified and the cost of renewable power generation decreases, the ability of natural gas to compete will be more challenging.

The soaring price of carbon emissions might also become an enabler for an increase in the natural gas demand. Carbon pricing, also known as cap and trade (CAT) or emissions trading scheme (ETS), is a policy instrument that uses market mechanisms to pass the cost of emitting on to emitters. An increase in carbon pricing would therefore make more-carbon intensive sources of energy, including coal, less competitive than natural gas. As for now, however, relatively low prices of carbon have not contributed to a massive switch from coal to gas.

4. Natural gas as an enabler and backup fuel to renewables

While natural gas might directly compete with renewables for a share in the electricity market, the growing wind and solar power capacity can also promote gas use globally. Intermittency is the major problem associated with the development of wind and solar energy. The sun is not shining all the time, and the wind is not blowing all the time. The limited weather conditions mean that the intermittent solar and wind power capacity should be backed up by a baseload power source as currently there is no large-scale and cost-effective way to store electricity for future consumption. In these circumstances, natural gas can provide a relatively low carbon backup at peak energy demand times when the power generation capacity from renewables is limited. Unlike wind and solar, gas can be stored, and can provide flexibility, since gas-based power production can be adjusted according to hourly, daily or seasonal demand.

There is also a concern that much of the necessary infrastructure for producing and transporting natural gas, taking years to develop, can lock in countries into an emissions pathway that derails them from reaching Paris Agreement commitments. In addition, some industry experts believe that pushing forward fossil fuel projects, including in natural gas, crowd out renewable alternatives. Since public and private funds are limited, their commitment to the development of natural gas projects to some extent can curb the penetration of renewables. In Africa alone, around $132 billion in lending and underwriting went into 964 gas, oil and coal projects since the adoption of the Paris Agreement in 2016.[19] A fraction of these funds, according to some critics, could have gone to financing renewables.

5. Methane leaks, flaring and venting

Scientists and policymakers are increasingly recognizing the problems of methane leaks, flaring, and venting, which can undermine the environmental case for switching to natural gas. Methane, the major component of natural gas, has a greater warming effect than carbon dioxide (CO_2), although it releases lower volumes of emissions which break down in the atmosphere sooner. Depending on the timescale of the assessment, methane's warming potential can be up to 90 times stronger than that of CO_2. After agriculture, the energy industry is the second largest contributor to the release of methane into the atmosphere, accounting for around 40% of total methane emissions globally.[20] Of the 135 million tonnes of methane emissions produced by the energy sector, around a third is coming from extracting, processing, and transporting natural gas.[21] Furthermore, some recent studies suggest that the environmental impact of methane emissions could be much worse than previously considered.[22] The problem seems to be especially acute given the current tightness of energy markets and high prices for natural gas. If captured and marketed, methane leaks in 2021 could have provided an additional 180 billion cubic meters (bcm) of gas for consumption, which is equivalent to Europe's current power sector demand.[23] Such volumes could have helped to address today's energy crisis on the continent.

The criticism of the gas industry has been also on the rise due to its highly visible gas flaring activity as well as gas venting. Gas flaring is the burning of natural gas associated with oil extraction. If the gas extracted during the production of crude oil cannot be consumed or marketed, either because of poor planning, a lack of infrastructure, incentives, or appropriate regulations, then this

19 Oil Change International (2022, March 3). New Report: At least $132 billion in finance for fossil fuels is locking Africa out of a Just Transition. Available: https://priceofoil.org/2022/03/03/new-report-at-least-132-billion-in-finance-for-fossil-fuels-is-locking-africa-out-of-a-just-transition/

20 International Energy Agency (2022, September). Global Methane Tracker 2022. Available: https://www.iea.org/reports/global-methane-tracker-2022/overview

21 Ibid.

22 Ivanova, I. (2021, August 18). Methane emissions from oil and gas may be even worse than previously thought. *MoneyWatch*. Available: https://www.cbsnews.com/news/methane-emissions-oil-gas-geofinancial-analytics/

23 International Energy Agency (2022, September). Global Methane Tracker 2022. Available: https://www.iea.org/reports/global-methane-tracker-2022/overview

gas – known as 'associated gas' – can end up being flared or (even worse from an environmental perspective) vented into the atmosphere. A recent IEA analysis suggests that 25% of associated gas produced globally is wasted, totalling 205 bcm in 2019. Of that volume, around 150 bcm was flared and the remaining 55 bcm was released as methane into the atmosphere. Besides being a problem of significant economic waste, studies increasingly suggest that the environmental impact of gas flaring is probably worse than commonly thought as a result of incomplete combustion. According to the IEA, the 150 bcm of flared gas in 2019 contributed to around 300 million tonnes of CO_2 ($MtCO_2$), roughly the same as annual emissions of Italy.[24]

6. Green gas: biomethane and hydrogen

While natural gas has low air pollutant emissions in comparison with coal and crude oil, switching between the unabated combustion of fossil fuels, on its own, is not going to help with deep decarbonization and reaching the Paris Agreement goals. The future of natural gas depends on its ability to evolve into a cleaner/ greener gas, a low-carbon substitute for conventional methane. Currently, there are several ways to decarbonize gas consumption, including biomethane made of waste products and agricultural residues, green hydrogen generated by renewables, and blue hydrogen produced with natural gas and supported by carbon capture, utilization, and storage (CCUS). Each of the methods can help to preserve the role of natural gas in the global energy industry. With the production of blue hydrogen, the natural gas industry could even expand into new hard-to-abate sectors like aviation or trucking.

Biomethane, also known as renewable natural gas or green gas, is a naturally occurring gas produced by the anaerobic digestion of organic matter, such as landfill gas, animal manure, and other agricultural waste products, in an oxygen-free environment. It can be derived either by upgrading biogas in a process that eliminates carbon dioxide and other contaminants in the biogas or through the gasification of solid biomass followed by methanation.[25] The chemical content of biomethane is identical to natural gas. Unlike gas, however, biomethane is defined as a green source of energy due to its negligible carbon footprint. Given the similar chemical content, methane can be supplied to stored and supplied to consumers using the existing natural gas infrastructure. Similarly to natural

24 International Energy Agency (2022, September). Global Methane Tracker 2022. Available: https://www.iea.org/reports/global-methane-tracker-2022/overview

25 International Energy Agency (2022). Outlook for biogas and biomethane: Prospects for organic growth. Available: https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane

gas, biomethane can be used in power generation, industrial processes, cooking, heating, and transportation in the form of bio-CNG (compressed natural gas) and bio-LNG (liquified natural gas). Currently, biomethane represents only about 0.1% of natural gas demand, as green gas has been limited due to land and feedstock availability issues as well as underdeveloped regulatory framework and financial constraints.[26] However, the important role of biomethane in deep decarbonization is increasingly acknowledged globally. According to the World Biogas Association, the use of biogas and biomethane can help to achieve climate neutrality by 2050, as well as to decrease greenhouse gas emissions by 10–13%.[27]

Hydrogen is the simplest and most abundant element on earth, which can store and deliver energy. The current demand for hydrogen is based on several important characteristics: it is light, storable, reactive, and has high energy content per unit mass. Not occurring naturally, it must be derived from compounds that contain it. Around 95% of all hydrogen today is produced from fossil fuels. However, with technological improvements and reductions in costs, hydrogen will be increasingly produced from renewables or natural gas with CCUS. Low-carbon hydrogen options – whether from green hydrogen produced by renewables or blue hydrogen derived with the help of natural gas and supported by CCUS – have a great potential to decarbonize the gas supply chain via hydrogen blending in existing natural gas uses. Moreover, hydrogen can help to decarbonize traditionally hard-to-abate industries like shipping, steel production, and even transport.

While green or blue hydrogen might bring significant economic and environmental benefits, there are still many unknowns about the potential integration of hydrogen into the global economy. New studies suggest that the environmental impacts from hydrogen technologies – even their greenest forms – could be substantially underestimated.[28] Hydrogen's supply chain can be more susceptible to leakage than methane. Although less harmful than methane, hydrogen is an indirect greenhouse gas having a 6 times stronger climate impact than carbon dioxide.[29] Finally, hydrogen's lower density complicates its blending with the gas

26 International Energy Agency (2022). Outlook for biogas and biomethane: Prospects for organic growth. Available: https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane

27 European Biogas Association (2020). The contribution of the biogas and biomethane industries to medium-term greenhouse gas reduction targets and climate neutrality by 2050. Background Paper. April. Available: https://www.europeanbiogas.eu/wp-content/uploads/2020/04/20200419-Background-paper_final.pdf

28 Ocko, I. B., Hamburg, S. P. (2022, July 20). Climate consequences of hydrogen emissions. *Atmospheric Chemistry and Physics Magazine*. https://doi.org/10.5194/acp-22-9349-2022

29 Derwent, R., Simmonds, P., O'Doherty, S., Manning, A., Collins, W., Stevenson, D. (2006, May 22). Global environmental impacts of the hydrogen economy. *International Journal of Nuclear Hydrogen Production and Applications*. https://doi.org/10.1504/IJNHPA.2006.009869

stream and necessitates additional costs and equipment upgrades along the natural gas value chain.

7. Natural gas in the industry

Industry uses natural gas as a fuel for process heating, in combined heat and power systems, as a feedstock to produce chemicals, fertilizer, and hydrogen, and as lease and plant fuel. According to the IEA, the industrial use of gas will be a major source of anticipated growth in gas demand globally.[30] Even in a low-carbon future, gas consumption in petrochemicals is expected to grow, with the fuel continuing to be a key component in producing everyday products such as plastics and fertilizers. Switching from coal to gas in light industries, including textiles, such as food and textiles, may bring significant environmental benefits. Natural gas also has a stronger competitive advantage in industrial processes, where it can displace more expensive oil products.

Replacing natural gas will be especially challenging in heavy industry, which is operating under extremely high temperatures to produce iron, steel, or cement. Indeed, as a study on low-carbon heat options for industry suggests, "unlike the power sector and light-duty vehicles, the operational requirements of temperature, quality, flux, and high-capacity place stringent constraints on viable options."[31] Eventually, the industrial use of natural gas should rely on a mix of CCUS, hydrogen, and bioenergy, which would allow using the fuel without emitting greenhouse gases into the atmosphere.

8. Natural gas in buildings

Currently, the building sector uses natural gas mostly for space heating. The market, however, remains quite concentrated geographically. Nearly three-fourths of the gas used in the building sector comes from 10 countries, with four of them accounting for half of the total: the United States, Russia, China, and

30 International Energy Agency (2019). The Role of Gas in Today's Energy Transitions. Available: https://iea.blob.core.windows.net/assets/cc35f20f-7a94-44dc-a750-41c117517e93/TheRoleofGas.pdf

31 Friedmann, J. Fan, A., Tang, K. (2019, October 7). Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, and Costs Today. Center for Global Energy Policy. Available: https://www.energypolicy.columbia.edu/research/report/low-carbon-heat-solutions-heavy-industry-sources-options-and-costs-today

Iran.[32] Many of the countries using gas in buildings have significant indigenous resource bases allowing to support the role of natural gas in the sector. However, the prospects of expanding natural gas use in space heating are limited and are increasingly challenged by alternative sources. The main competitors of gas in buildings will be coming from an increase in electrification with clean energy sources, the direct use of renewables, heat pumps, and energy efficiency gains. Biomethane, or renewable gas, and hydrogen can also compete with gas for a market share in buildings in the mid and long-term perspective when technological improvements will help to reduce costs.

Competition for the building sector is increasingly fierce, as the sector is expected to experience the most significant carbon dioxide emissions reductions in the Faster Transition Scenario by the IEA. Energy efficiency gains will contribute to global average energy savings of 500 million tonnes of oil equivalent (Mtoe) annually in buildings between 2020 and 2050.[33] High-performance building construction and energy renovations will decrease energy consumption in buildings by around 30% by 2050, even as floor area doubles globally. The share of electricity in energy use in buildings will increase from 33% in 2017 to around 55% in 2050, thus further squeezing the share of natural gas in the sector. In addition, energy efficiency gains will decrease electricity demand in buildings by around 300 million tonnes of oil equivalent (Mtoe) lower in 2050, which also implies a reduction in demand for gas. Substantial improvements in air conditioner performance will further reduce energy demand, as 1.5 billion households are expected to get access to cooling comfort. Finally, heat pumps will help to save four times more energy for heating, while solar thermal will provide carbon-free heat to nearly 3 billion people in buildings by 2050. In total, multiple cost-effective and green technologies along with electrification and energy efficiency gains will lead to lower demand for natural gas in buildings.

The future of gas in new buildings is indeed challenging. Currently, energy demand is shifting towards Asia and Africa, where electrification will lead the building sector. Furthermore, there are not many countries developing new gas networks, let alone starting new gasification programs. There are few countries that have managed to incorporate gas into buildings for the past two decades, thus suggesting a limited growth trajectory of gas in the future. Therefore, while natural gas can increase its share in some markets, it will not be able to expand in buildings

32 Tsafos, N. (2020, January 14). How Will Natural Gas Fare in the Energy Transition? Center for Strategic and International Studies. Available: https://www.csis.org/analysis/how-will-natural-gas-fare-energy-transition

33 International Energy Agency (2019). The Critical Role of Buildings: Perspectives for the Clean Energy Transition. April. Available: https://www.iea.org/reports/the-critical-role-of-buildings

dramatically. Nonetheless, natural gas will likely preserve its market share against an increasingly challenging array of alternatives.

9. Natural gas in transportation

The use of natural gas in the transportation sector accounts for just 1.4% of its global consumption.[34] Almost all of it is used in road transport thanks to the development of compressed natural gas (CNG) vehicles for passenger cars or short-haul trucks or liquefied natural gas (LNG) for commercial trucks, collectively known as natural gas vehicles (NGVs). NGVs can play an important role in the global energy transition as they emit substantially less greenhouse gas emissions compared to traditional gasoline and diesel vehicles, dominating the global vehicle market today. According to a report by the Organization for Economic Cooperation and Development (OECD), NGVs emit on average 80% fewer ozone-forming emissions – i.e. carbon dioxide (CO_2) and nitrogen oxide (NOx) – than petrol-powered vehicles.[35]

Currently, around 2 million NGVs are sold annually. As of the beginning of 2020, 28.5 million NGVs were on the roads globally, with more than 70% of them concentrated in Asia Pacific.[36] Three countries – China, India, and Iran – accounted for the bulk of the growth in gas used for road transport. Expensive fuel storage tanks used for CNG vehicles have been a key barrier to the wide deployment of CNG as a fuel. The shortage of fuelling infrastructure also impedes the development of CNG and LNG-fuelled vehicles globally. In addition, the current energy crisis and high prices for natural gas have dramatically lowered the price competitiveness of the vehicles running on CNG and LNG compared to gasoline and diesel-powered vehicles, while lower gas prices along with the environmental benefits have always been regarded as the main advantage of NGVs.

Hydrogen fuel cell electric vehicles (FCEVs), such as light- and heavy-duty vehicles, trains, ships, planes, and drones, are expected to play an increased role in the transportation sector soon. Next to FCEVs, hydrogen or ammonia can be mixed in diesel engine fuels and gas turbines for planes, as a transition step to fuel cells. Another important aspect is hydrogen transport, which can be done in

34 Tsafos, N. (2020, January 14). How Will Natural Gas Fare in the Energy Transition? Center for Strategic and International Studies. Available: https://www.csis.org/analysis/how-will-natural-gas-fare-energy-transition

35 Organisation for Economic Cooperation and Development (2019). Annex A. Overview of clean technologies and fuels in the transport sector. https://www.oecd-ilibrary.org/sites/baf3778b-en/index.html?itemId=/content/component/baf3778b-en

36 Gas Exporting Countries Forum (2021). GECF's Annual Short Term Gas Market Report. Available: https://www.gecf.org/_resources/files/pages/gecf-annual-short-term-gas-market-report/gecf-annual-short-term-gas-market-report-2021.pdf

different forms, such as liquid, compressed gas, or liquid organic hydrogen carriers (LOHCs) like ammonia.

Blue or green hydrogen can also play an important role in the transportation sector. Hydrogen fuel cell electric vehicles (FCEVs), such as light- and heavy-duty vehicles, trains, ships, planes, and drones, are expected to play an increased role in the transportation sector in the upcoming years. Hydrogen's contribution can be especially strong in hard-to-abate heavy-duty transport – trucking, shipping, and aviation. Along with the industrial production of steel, cement, and plastics, heavy-duty transport account today for 40% of carbon emissions from energy systems today and is expected to increase further in the future.

The major challenge for the expansion of natural gas vehicles is stemming from the electrification of the transportation sector. The sales of electric vehicles (EVs) have been on the rise as the world is looking at them to replace traditional gasoline and diesel vehicles to slow climate change. Global EV sales doubled year over year in 2021 to 6.6 million, from 3.2 million in 2020.[37] EV sales accounted for almost 10% of global car sales in 2021, four times the market share in 2019.[38] There are 16.5 million EVs on the road worldwide in 2021, triple the amount in 2018, according to the Global EV Outlook 2022 by the IEA.[39] Given the current growth trajectory of EVs, their market share will continue growing and suppress NGVs sales, which otherwise would replace internal combustion engine vehicles. On the other hand, the increasing electricity consumption to charge EVs could also be met with gas-fired power plants, thus potentially contributing to some increase in natural gas demand globally.

Conclusion

The global energy transition should be based on finding a balance between the achievement of climate goals, economic growth, and energy security. Natural gas can play an important role in shaping such a balance. First of all, it can be a key tool in fighting energy poverty by providing relatively clean and affordable access to electricity, cooking, and heating. Switching from solid fuels such as wood charcoal biomass and kerosene to gas for cooking and heating homes – piped gas in urban areas or, more commonly, liquefied petroleum gas (LPG) delivered

37 Rives, K. (2022, May 24). Global electric vehicle sales doubled; US made EV comeback in 2021. SP Global. Available: https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/global-electric-vehicle-sales-doubled-us-made-ev-comeback-in-2021-70489884#:~:text=Worldwide%20EV%20sales%20doubled%20year,2.3%20million%20EVs%20were%20sold

38 Ibid.

39 International Energy Agency (2022, May). Global EV Outlook 2022. Available: https://www.iea.org/reports/global-ev-outlook-2022

in cylinders – has considerably helped to lessen indoor air pollution in many countries. Secondly, natural gas can help to reduce emissions when it replaces coal and diesel, especially in electricity generation. Thirdly, gas-fired power plants can also be a reliable partner for intermittent solar and wind energy sources by quickly compensating for their volatility and responding to sudden increases in demand. While several options exist for addressing the intermittency and dispatchability problems of wind and solar, none of them are commercially feasible and available at the required scale to meet the huge flexibility requirements. Finally, gas can play a major role in the sectors which are hard to electrify, including industrial processes and freight transport.

To be able to compete in the long run, however, natural gas should be decarbonized and evolved into a greener gas. Currently, there are several ways to decarbonize natural gas, including biomethane made of waste products and agricultural residues, green hydrogen generated by renewables, and blue hydrogen produced with natural gas and supported by carbon capture, utilization, and storage (CCUS). Each of the methods can help to preserve the role of natural gas in the global energy industry. In addition, methane leaks, flaring, and venting issues, currently undermining the environmental case for natural gas, should be addressed. With the production of blue hydrogen, the natural gas industry could even expand into new hard-to-abate sectors like aviation or trucking. If the industry manages to bring down the costs of CCUS and scale up its application amid the utilization of hydrogen as feedstock to reduce the environmental impact in industrial processes, the role of natural gas in the 2050 global energy mix could be quite robust.

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Substitution elasticity of energy and other production factors: An empirical estimation for 27 EU Member States and other major economies

The timely decarbonisation of the global energy system is necessary to avoid the negative implications of climate change, but it is a quite challenging task as the dynamics of the energy system and its interaction with the economy and social systems are quite complex. Large scale applied mathematical models have been extensively used to assess the economic impacts of alternative climate and energy policies. However, their results are largely governed by the substitution possibilities they portray between energy and other production factors. Bottom-up models of specific sectors are able to capture these substitution possibilities at an adequate detail but top-down economy wide models are based on econometrically estimated elasticities of substitution. This paper contributes to the empirical literature by providing new estimations on the energy – capital substitution elasticity accounting for structural breaks. The estimations are based on the statistics available from the WIOD database and cover all EU – 27 Member States and the UK. Diagnostic tests that allow to specify the econometric model to be used are applied. Strong evidences that a structural break exist is found. The elasticity of substitution is found to be stable across time. Asymmetric relationship between the variables is found in few cases. The elasticity of substitution ranges from 0 to 0.7 in the majority of the cases depending the industry and the country.

The clean energy transition is a capital-intensive process through which low value-added products (fuels) are substituted by investments in high value-added products (wind turbines, PV panels, Energy efficient appliances and machines). As a result, the fossil fuel related sectors are expected to decline and fuel import bills to shrink, but at the same time domestic investment expenditures increase. This process takes place in a dynamic energy system where prices, technology costs, production structures, consumer preferences and habits are all constantly evolving and where different and new types of labour skills, infrastructure and materials are needed. At the early stages of the transition financing requirements are high while the technologies and skills required to make the transition may not have yet reached full learning potential – these are important potential bottlenecks. During this phase, it is possible that energy costs increase compared to business as usual. Policies and measures may create conditions which enable positive externalities, which bring cost reductions and cost-efficient uptake of technologies. Competitiveness impacts are not static, whilst needing to contend with potentially higher energy prices and costs, industry will also transform to produce the novel value-added products and materials. As for all technology-driven growth, first-mover advantages may drive competitiveness gains and export-driven growth. Timely coordination of all changes in the system is essential, including the mobilisation of adequate financing to support the large-scale deployment of new technologies.

All these elements show that the quantification and assessment of the economic and employment implications of energy and climate policies is a quite complex task as the uncertainties and the inter-dependencies and dynamics of multiple systems must be taken into account.

Computable General Equilibrium (CGE) models have been used for decades to assess climate and energy policies and are considered particularly useful as they manage to encompass most of the system inter-dependencies while allowing the user to understand the key mechanisms that drive the model results. Model tractability and a foundation on rigorous microeconomic theory, make CGE models a powerful tool which can be used in a wide range of policy related questions.

However, CGE models are largely dependent on the choice of elasticities (substitution, price, income, trade etc.) which are rarely estimated for the specific dimensions of the model or can be outdated. In this study we use advanced econometric techniques to estimate the elasticity of substitution among energy and value added – a key elasticity when it comes to the decarbonisation of the energy system. In a CGE model the easiness to substitute fuels, electricity with capital determines the flexibility of the system to decarbonise and drives total adjustment costs. The representation of individual technologies (PV, Wind, Hydrogen, Electric Cars, Appliances, Buildings) in a model in a bottom up way allows to better capture the substitution possibilities however this is not always possible or desired – hence, substitution elasticities play a critical role in determining costs and performance of energy and climate policies when simulated by CGE models.

1. Energy substitution possibilities

The focus of this study is on the estimation of the substitution elasticity between energy and value added and on whether the elasticity varies across countries, sectors and over time. The analysis is made using time series with and without structural breaks. Linear and non-linear cointegration relationships have been examined and panel data techniques have been used. The estimations cover the entire EU – Member States and selected non-EU countries and are based on the WIOD[1] database. Time series analysis is applied using the ADF unit root test[2] and unit root tests that allow for one-time structural break proposed by Zivot and Andrews.[3] Secondly, linear and non-linear cointegration are examined by using methodologies that allows a possible structural break. For linear cointegration the methodology of Engle and Granger[4] and Gregory and Hansen[5] that allows for one-time structural break at an unknown time are used. For non-linear cointegration the method of Shin and Yu[6] that include asymmetries from a positive and a negative change in an ARDL model is applied. Panel unit root tests of Levin, Lin, Chu[7] and Im, Pesaran, Shin[8] have been used to identify the order of integration of the panels. Cointegration tests developed by Pedroni[9] and Kao[10] have been used to identify a cointegration relationship. Finally, to estimate the elasticity of substitution of energy and gross value added the OLS estimator with panel corrected standard errors has been used.

1 World Input – Output Database. Available: http://www.wiod.org/home

2 Dickey, D. A., Fuller, W. A. (1979). Distribution of the Estimators for Autoregressive Time Series With a Unit Root. *Journal of the American Statistical Association, 74*(366), 427–431.

3 Zivot, E. and Andrews, D. W. K. (1992). Further Evidence on the Great Crash, the Oil-Price Shock, and the Unit-Root Hypothesis. *Journal of Business & Economic Statistics, 10*(3), 251–270.

4 Engle, R. F., Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica, 55*(2), 251–276.

5 Gregory, A. W., Hansen, B. E. (1996). Residual-based tests for cointegration in models with regime shifts. *Journal of Econometrics, 70*(1), 99–126.

6 Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014). Modelling Asymmetric Cointegration and Dynamic Multipliers in a Nonlinear ARDL Framework. In: Sickles, R., Horrace, W. (eds). *Festschrift in Honor of Peter Schmidt*. Springer, New York, NY. https://doi.org/10.1007/978-1-4899-8008-3_9

7 Levin, A., Lin, Ch.-F., Chu, Ch.-Sh. J. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics, 108*(1), 1–24.

8 Im, K. S., Pesaran, M. H., Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics, 115*(1), 53–74.

9 Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, special issue 0305-9049.

10 Kao, C. (1999). Spurious Regression and Residual Based Tests for Cointegration in Panel Data. *Journal of Econometrics, 90*(1), 1–44.

2. Literature review on econometric methods used to estimate the energy substitution possibilities

Van der Werf[11] and Kemfert[12] mention that the (KL)E[13] nesting structure fits best historical data and their findings reject the null hypothesis that elasticities of substitution between capital-labour and energy are equal to one – they estimate it to be lower than one. Kemfert[14] found the elasticity of substitution between capital-labour and energy to be 0.458 at the Germany aggregate/national level while it ranges from 0.3 to 1 over the German industries. Koesler and Schymura[15] used non-linear least squares estimation in a three-level nested KLEM CES production function using WIOD data and found an elasticity of substitution between capital-labour and energy that varies over countries and industries between 0 to 7.86. Antoszewski[16] obtained data from the WIOD database and by using panel data techniques found the elasticity of substitution between capital-labour and energy lower than one. None of these studies considered structural breaks. To our knowledge there are not yet any empirical studies that consider structural breaks in the timeseries or an asymmetric relationship in the estimation of the elasticity of substitution. Perron[17] developed a unit root test that considers a possible structural break in the timeseries and claimed that if a structural break exists then the ADF unit root test of Dickey and Fuller (1979) and the PP unit root test of Phillips and Perron[18] can be invalid. If a variable is stationary and a structural break exists the ADF and PP unit root test may not-reject the null hypothesis of non-stationarity.

Zivot and Andrews[19] proposed a unit root test that the structural break point is endogenously selected. They proposed three different econometric models:

11 Van der Werf, E. (2008). Production functions for climate policy modelling: an empirical analysis. *Energy Economics, 30*(6), 2964–2979.

12 Kemfert, C. (1998). Estimated substitution elasticities of a nested CES production function approach for Germany. *Energy Economics, 20*(3), 249–264.

13 (KL) represents value added and E energy.

14 Kemfert, C. (1998). Estimated substitution elasticities of a nested CES production function approach for Germany. *Energy Economics, 20*(3), pp. 249–264.

15 Koesler, S., Schymura, M. (2015). Substitution elasticities in a constant elasticity of substitution framework – empirical estimates using nonlinear least squares. *Economic Systems Research, 27*(1), 101–121.

16 Antoszewski, M. (2019). Wide-range estimation of various substitution elasticities for CES production functions at the sectoral level. *Energy Economics, 83*, 272–289.

17 Perron, P. (1989). The great crash, the oil price shock, and the unit root hypothesis. *Econometrica, 57*(6), 1361–1401.

18 Phillips, P. C. B. and Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika, 75*(2), 335–46.

19 Zivot, E. and Andrews, D. W. K. (1992). Further Evidence on the Great Crash, the Oil-Price Shock, and the Unit-Root Hypothesis. *Journal of Business & Economic Statistics*, *10*(3), 251–270.

a model with a structural break on the constant, a model with a structural break on the deterministic trend and a model with a structural break both on the constant and the deterministic trend. Each model is estimated by using the OLS estimator and by assuming that the possible structure break belongs on the time interval. Among all the subsequent values the point that achieves the lowest t-statistic on the null hypothesis of the presence of unit root is selected. Although this approach ensures that the unit root test is consistent with the existence of a structural break in the timeseries, it do not identify if a structural break exist.

Gregory and Hansen[20] developed a cointegration test that allows for a structural break in the cointegration relationship. The classical ADF unit root test may suffice from low power if a structural break exists but has not included in the cointegration relationship. They proposed three different models depending on structural break: (1) a structural break on the constant, (2) a structural break on the constant and trend and (3) a structural break on the constant and the elasticity/slope. Shin and Yu[21] mention that in cases that an asymmetric relationship between the variables of examination exists, the cointegration results of a symmetric linear relationship may not be valid. Ndoricimpa[22] used the non-linear ARDL model of Shin and Yu[23] for the South Africa and identified asymmetries in the relationship among the energy-use, pollution emissions and real output.

3. Methods and econometric results on the energy substitution elasticity

The WIOD data that has been used for the estimation of the elasticity of substitution between gross value added and energy are presented in Table 1. The database contains balanced data for all variables included in the analysis for the period 1995–2009.

20 Gregory, A. W., Hansen, B. E. (1996). Residual-based tests for cointegration in models with regime shifts. *Journal of Econometrics, 70*(1), 99–126.

21 Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014). Modelling Asymmetric Cointegration and Dynamic Multipliers in a Nonlinear ARDL Framework. In: Sickles, R., Horrace, W. (eds). *Festschrift in Honor of Peter Schmidt*. Springer, New York, NY. https://doi.org/10.1007/978-1-4899-8008-3_9

22 Ndoricimpa, A. (2017, April 15). Analysis of asymmetries in the nexus among energy use, pollution emissions and real output in South Africa. *Energy, 125*, 543–551.

23 Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014). Modelling Asymmetric Cointegration and Dynamic Multipliers in a Nonlinear ARDL Framework. In: Sickles, R., Horrace, W. (eds) *Festschrift in Honor of Peter Schmidt*. Springer, New York, NY. https://doi.org/10.1007/978-1-4899-8008-3_9

Table 1. Variables that are used on the econometric model for the estimation of the elasticity of substitution

Variable	Description	Source
QE	Total energy in TJ	Total energy in TJ is derived from the WIOD Environmental Accounts, available at: http://www.wiod.org/database/eas13
QKL	Gross value added (in million $, 1995)	Gross value added at national currencies and constant prices 1995 are derived from the Socio-Economic Accounts available at: http://www.wiod.org/database/seas13 Exchange rates that convert the national currencies into US$ are derived from World Input-Output Tables available at: http://www.wiod.org/database/wiots13
PE	Energy price index	The cost of energy use by sector is derived from World Input-Output Tables available at: http://www.wiod.org/database/wiots13 The energy price index was computed as the ratio of the cost of energy use by sector divided by the total energy use in TJ by sector.
PKL	Gross value-added price index	The gross value-added price index is derived from the Socio-Economic Accounts available at: http://www.wiod.org/database/seas13

Our estimation of the elasticity of substitution between gross value added and energy is based on the first order conditions of the producers' profit maximization problem[24] of a CES production function. The econometric model that is used is:

$$\ln\frac{QE_t}{QKL_t} = a + \varphi \cdot t - \sigma \cdot \ln\frac{PE_t}{PKL_t} + u_t \qquad [1]$$

where: σ the Hicksian elasticity of substitution (Hicks, 1932). The Hicksian elasticity of substitution (HES) is selected as a consistent with the CES production function measure and it is defined as:

$$\sigma = \frac{\partial\left(\frac{QE_t}{QKL_t}\right) / \left(\frac{QE_t}{QKL_t}\right)}{\partial\left(\frac{PKL_t}{PE_t}\right) / \left(\frac{PKL_t}{PE_t}\right)}$$

24 For more details, see: Energy Resilience and Vulnerability in the EU and Other Global Regions. Study on the Macroeconomics of Energy and Climate Policies. Available: https://energy.ec.europa.eu/system/files/2017-05/macro_energy_resilience_and_vulnerability_0_0.pdf

The selected econometric model is an indirect approximation of the elasticity of substitution estimation. Henningsen et al.[25] applied a direct technical approach for the estimation of the elasticity of substitution. That is a direct non-linear estimation of the CES production function. Such an approach does not require any price data to provide estimates of the elasticity of substitution. However, this aspect can be considered as a disadvantage of this technique. Price data may contain important information that is essential for the estimation of the Hicksian elasticity of substitution (Broadstock et al.[26] and Antoszewski[27]). Henningsen et al.[28] used non-linear goodness-of-fit testing to identify the CES production function that best fits with the data. They conclude:

> *none of our estimated elasticities – neither based on the data in Kemfert (1998), nor based on our newly created dataset – are reliable and can be used in policy modelling. Our findings, and those of previous studies following the same approach, are sobering and indicate severe inherent problems with estimating nested CES production functions of the KLE type through a direct approach, in particular when using short time series.*

The results demonstrated by Henningsen et al.[29] indicate that, due to the multi-set of parameters that a typical CES function has, it is unlikely to identify among different nesting schemes. Antoszewski[30] used panel data analysis and the economic approach to estimate the elasticity of substitution of a nested-CES production function by utilising the WIOD database. He provides a wide-range estimates of the elasticity of substitution by sector that most of them lie in the interval [0,1]. Antoszewski[31] also performed a wide-range F-test to conclude that there is a strong argument against the arbitrary use of Leontief and/or Cobb-Douglas specifications in multi-sector CGE models as in many sectors the hypothesis of a Leontief type ($\sigma = 0$) or a Cobb-Douglas type ($\sigma = 1$) elasticity of substitution is rejected. These results are very similar to the case study: Energy

25 Henningsen, A., Henningsen, G., van der Werf, E. (2019). Capital-labour-energy substitution in a nested CES framework: A replication and update of Kemfert (1998). *Energy Economics, 82*, 16–25.

26 Broadstock, D., Hunt, L., Sorrell, S. (2007). UKERC review of evidence for the rebound effect. Technical report 3: elasticity of substitution studies. Working Paper – REF UKERC/WP/TPA/2007/011. Centre, UK Energy Research.

27 Antoszewski, M. (2019). Wide-range estimation of various substitution elasticities for CES production functions at the sectoral level. *Energy Economics, 83*, 272–289.

28 Henningsen, A., Henningsen, G., Van der Werf, E. (2019). Capital-labour-energy substitution in a nested CES framework: A replication and update of Kemfert (1998). *Energy Economics, 82*, 16–25.

29 Ibid.

30 Antoszewski, M. (2019). Wide-range estimation of various substitution elasticities for CES production functions at the sectoral level. *Energy Economics*, 83, pp. 272–289.

31 Ibid.

Resilience and Vulnerability in the EU and Other Global Regions[32] that identifies a weak substitutability between energy and gross value added.

4. Time-series analysis

Unit root tests for the timeseries

$$\text{Q ratio } (\ln \frac{QE_t}{QKL_t}) \text{ and P ratio } (\ln \frac{PE_t}{PKL_t})$$

have been implemented. The standard ADF unit root test and the formula[33] of McKinnon (2010), which provides critical values which are consistent with the small size of the sample, have been used. The Zivot-Andrews test[34] that considers possible structural break in the timeseries has also implemented. In both variables the unit root tests have been applied on all sectors and countries timeseries, 1326[35] cases, by assuming an autoregressive scheme with or without a deterministic part (constant or constant and trend). The lags of the autoregressive scheme have been based on the Schwarz criterion. In the Zivot-Andrews test[36], a structural break either at the deterministic constant or at the deterministic constant and trend, has been examined.

Table 2 presents a summary of the unit roots tests. In a large number of cases (562 cases) it is found that both Q ratio and P ratio series are stationary if a structural break is considered. A different order of integration between the two ratios, zero or one, has been found in 350 cases. Strong non-stationarity for either of the two timeseries has been found to only 39 cases. Finally, in 360 cases have been found that the Q ratio and the P ratio are non-stationary at their levels but they are stationary at their first differences.

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32 European Commission (2017). Study on the Macroeconomics of Energy and Climate Policies. Available: https://energy.ec.europa.eu/data-and-analysis/energy-modelling/macroeconomic-modelling-and-other-modelling-activities_en

33 This is: $\beta_\infty + \beta_1/T + \beta_2/T^2 + \beta_3/T^3$ where β_∞, β_1, β_2 and β_3 are derived from McKinnon (2010) and T the number of observations in the unit root test.

34 Zivot, E. and Andrews, D. W. K. (1992). Further Evidence on the Great Crash, the Oil-Price Shock, and the Unit-Root Hypothesis. *Journal of Business & Economic Statistics, 10*(3), 251–270.

35 15 cases were identified without data available either on price ratio or on volume ratio.

36 Zivot, E. and Andrews, D. W. K. (1992). Further Evidence on the Great Crash, the Oil-Price Shock, and the Unit-Root Hypothesis. *Journal of Business & Economic Statistics, 10*(3), 251–270.

Table 2. ADF and Zivot-Andrews unit root tests

		ADF				Zivot-Andrews			
		Q ratio				Q ratio			
		I(0)	I(1)	>I(1)	Total	I(0)	I(1)	>I(1)	Total
P ratio	I(0)	151	193	15	359	562	140	0	702
	I(1)	253	590	23	866	210	360	8	578
	>I(1)	22	53	11	86	0	9	22	31
	Total	426	836	49	1311	772	509	30	1311

Accounting for the structural break and the order of integration of the Q ratio and the P ratio the econometric models applied in each case are the following:

- Case 1: Both timeseries are integrated of order zero according. The OLS estimator in the linear regression model has been used.
- Case 2: Timeseries have a different order of integration (zero or one). The OLS estimator applied in the linear regression model at the first differences of the timeseries (OLS – FD).
- Case 3: Both timeseries are integrated of order one. A cointegration relationship is examined.
    - ✓ Case 3.1: A cointegration relationship exists. The OLS estimator is applied on the error-correction model (ECM) by using the Engle and Granger 2-step approach.
    - ✓ Case 3.2: A cointegration under the presence of structural break exists. The OLS estimator is applied on the error-correction model (ECM – GH) by using a Gregory Hansen 2-step approach.
    - ✓ Case 3.3: A cointegration relationship does not exist. The OLS estimator applied in the linear regression model at the first differences of the timeseries (OLS – FD).
- Case 4: Timeseries are integrated of order higher than one (strong non-stationarity behaviour). These cases are excluded[37] from the analysis.

Pesaran[38] proposed to estimate an autoregressive distributed lag (ARDL) model at a one step, regardless if the timeseries are stationary or not. Although the ARDL model involving potentially non-stationary variables, a bound test for

37 One can try to transform the model by taking such order of differences in the timeseries as the order of integration.

38 Pesaran, M. H., Shin, Y. and Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics, 16*(3), 289–326. https://doi.org/10.1002/jae.616

Table 3. Model selection depending on the unit roots tests

<table>
<tr><td></td><td></td><td colspan="4">Q ratio</td></tr>
<tr><td></td><td></td><td>I(0)</td><td colspan="3">I(1)</td></tr>
<tr><td rowspan="3">P ratio</td><td>I(0)</td><td>OLS, OLS – FD, ARDL, NARDL</td><td colspan="3">OLS – FD, ARDL, NARDL</td></tr>
<tr><td rowspan="2">I(1)</td><td rowspan="2">OLS – FD, ARDL, NARDL</td><td rowspan="2">Cointegration</td><td>no</td><td>OLS – FD, ARDL, NARDL</td></tr>
<tr><td>yes</td><td>ECM, ECM – GH, OLS – FD, ARDL, NARDL</td></tr>
</table>

cointegration has been proposed that is valid for inference even if the order of integration of the variables is different, zero or one. Shin and Yu[39] proposed a bound test procedure developed by Pesaran[40] in a non-linear ARDL framework for testing non-linear cointegration. The non-linear ARDL (NARDL) model allows to capture possible asymmetries in the adjustment process. The speed of adjustment to the long-run equilibrium may differs if there is a positive or a negative change on the ratio of prices of energy to value added. The different models that have been applied in each case for the estimation of the elasticity of substitution are summarised in Table 3.

The OLS estimator is used for the linear regression model [1] at the 562 cases, that the Q ratio and the P ratio are both stationary. Table 4 presents an overview of the statistical significance of the estimated elasticity of substitution. In many cases the estimated elasticity of substitution is positive and statistically significant (44%). Only in few cases (7%) an opposite sign and statistically significant from the economic theory have been found for the elasticity of substitution. The elasticity of substitution varies over countries and sectors in the interval 0 to 1.6 with the 80% of the cases to be lower to 0.7.

Residual based tests have been used to check the validity of the results: (1) the Breusch-Godfrey serial correlation LM test has been used to test for serial correlation on the residuals, (2) the White heteroskedasticity test has been used to test for heteroskedasticity on the residuals and (3) the Jarque-Bera test has

39 Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014). Modelling Asymmetric Cointegration and Dynamic Multipliers in a Nonlinear ARDL Framework. In: Sickles, R., Horrace, W. (eds). *Festschrift in Honor of Peter Schmidt*. Springer, New York, NY. https://doi.org/10.1007/978-1-4899-8008-3_9

40 Pesaran, M. H., Shin, Y. and Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289–326. https://doi.org/10.1002/jae.616

Table 4. **Estimation of the elasticity of substitution between energy and gross value added on the cases that both timeseries are stationary by using the ADF test**

Estimated equations	OLS
	562
Cases with positive sign on σ and significant results	44%
Cases with positive sign on σ and insignificant results	30%
Cases with negative sign on σ and insignificant results	19%
Cases with negative sign on σ and significant results	7%

Table 5. **Residual based tests on the OLS estimations**

	LM-test	White	JB	All
Cases with positive sign on σ and significant results	87%	88%	97%	77%
Cases with positive sign on σ and insignificant results	89%	85%	95%	72%
Cases with negative sign on σ and insignificant results	91%	89%	94%	75%
Cases with negative sign on σ and significant results	95%	87%	97%	82%

been used to test if the residuals follow the normal distribution. Table 5 presents for each case presented in Table 4 the percentage of cases that do not suffer for serial correlation (LM-test), for heteroskedasticity (White), for non-normality (JB) and for any of the three (All) problem in the residuals. The 77% of the cases with positive sign and significant estimate on σ pass all the residual based test implemented. In the cases that either serial correlation or heteroskedasticity have been found the feasible generalized least square (FGLS) estimator is used. The FGLS uses the OLS estimated variance-covariance matrix to correct for the serial correlation or/and the heteroskedasticity identified in the residuals.

Cointegration tests that examine for a possible cointegration relationship between the Q ratio and the P ratio have been implemented at the 360 cases that both timeseries have been found to be integrated at order one by the Zivot-Andrews unit root tests. Table 6 presents the results of the Johansen and Juselius[41] and the Engle and Granger[42] cointegration tests. Among the 360 cases, that both

41 Johansen, S., Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration – with applications to the demand for money. *Oxford Bulletin of Economics and Statistics, 52*(2), 169–210.

42 Engle, R. F., and Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica, 55*(2), 251–276.

Table 6. Cointegration tests on cases that both *Q* ratio and *P* ratio are integrated of order one

		Johansen and Juselius cointegration test		
		No	Yes	Total
Engle and Granger cointegration test	No	43	117	160
	Yes	51	149	200
	Total	94	266	360

Q ratio and P ratio are integrated of order one, the 149 cases support a cointegration relationship by both cointegration tests. In 317 cases either the Engle-Granger cointegration test or the Johansen and Juselius cointegration test supports the existence of the cointegration relationship between the Q ratio and the P ratio.

Gregory, Nason and Watt[43] demonstrates that the power of the ADF test falls when a structural break occurs, so procedures for cointegration tests that include structural breaks need to be examined. Three model are considered:

- Model A: a cointegration relationship with a deterministic constant and a shift in the constant
- Model B: a cointegration relationship with a deterministic constant and trend and a shift in the constant
- Model C: a cointegration relationship with a deterministic constant and a shift in constant and the elasticity.

Following Gregory and Hansen[44] cointegration test we examined a possible structural break of the form of model A, model B or model C in the cointegration relationship. The number of cases that support the existence of a cointegration relationship are 214. Detailed results by sector can be found in Table 3 in the annex.

Based on the cointegration tests the error correction model (ECM) and the error-correction model with a structural break in the cointegration relationship (ECM – GH) are applied in the 214 cases. It should be noted that at only 34 cases we have found statistical evidences that the elasticity of substitution differs across time. In all other cases the structural break has been found at the constant term of the linear regression. This result indicates that the elasticity of substitution is stable across time but at some points in time there is a structural break that affect the level of the *Q* ratio without affecting the level of the elasticity of substitution. Further analysis is needed to identify which factors can explain such structural breaks.

43 Gregory, A. W., Nason, J. M., Watt, D. G. (1996). Testing for structural breaks in cointegrated relationships. *Journal of Econometrics, 71*(1-2), 321–341.

44 Gregory, A. W., Hansen, B. E. (1996). Residual-based tests for cointegration in models with regime shifts. *Journal of Econometrics, 70*(1), 99–126.

The median estimate of the long-run elasticity of substitution is found 0.38 in ECM model and 0.39 in ECM-GH model. Detailed results by sector can be found in Table 4 and Table 5 in the annex.

In the timeseries analysis the OLS – FD, the ARDL and the NARDL models, have been used in all the 1272 cases regardless the order of integration of the timeseries or if a cointegration relationship exists.

An overview by region and by sector for the OLS estimator at first differences of the timeseries is presented in Table 6 and Table 7 in the annex. In more than 80% of the cases the elasticity of substitution has a positive sign which is consistent with the economic theory. Results strongly support the hypothesis of weak substitutability between energy and other factors of production. The results of the OLS-FD model should be treated with caution as the elasticity of substitution is estimated by a model which includes the first differences of the timeseries and do not correspond exactly to the initial model [1]. The median estimate of the long-run elasticity of substitution by using the OLS-FD method is 0.46.

The ARDL model is an extension of the model [1] with short-term dynamics. By including either one-year or two-year lag dynamics the model becomes:

$$\ln\frac{QE_t}{QKL_t} = a + \varphi \cdot t + \beta \ln\frac{PE_t}{PKL_t} + \sum_{j=1}^{m} \gamma_j \ln\frac{QE_{t-j}}{QKL_{t-j}} + \sum_{j=1}^{m} \delta_j \ln\frac{PE_{t-j}}{PKL_{t-j}} + u_t \qquad [2]$$

which can be written as

$$\begin{aligned} \Delta\left(\ln\frac{QE_t}{QKL_t}\right) &= a + \varphi \cdot t + b \ln\frac{PE_{t-1}}{PKL_{t-1}} + c \ln\frac{QE_{t-1}}{QKL_{t-1}} \\ &\quad + \sum_{j=1}^{m-1} c_j\, \Delta\left(\ln\frac{QE_{t-j}}{QKL_{t-j}}\right) + \sum_{j=1}^{m-1} d_j \ln\left(\frac{PE_{t-j}}{PKL_{t-j}}\right) + u_t \end{aligned} \qquad [3]$$

Pesaran[45] proposed a bound test to test if the estimated model [3] is valid for inference. By comparing the critical values of Pesaran[46] bound tests with the F-statistic of the null hypothesis: $H_0\colon b = c = 0$ allows to identify if a cointegration exists. Based on the ARDL, the Banjeree, Dolado and Mestre[47] t-statistic bound test, provide even more statistical evidence that the selected model is valid for inference. That is a bound test on the t-statistic of the null hypothesis: $H_0\colon b = 0$.

45 Pesaran, M. H., Shin, Y. and Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics, 16*(3), 289–326. https://doi.org/10.1002/jae.616

46 Ibid.

47 Banerjee, A., Dolado, J., Mestre, R. (1998). Error-correction mechanism tests for cointegration in single-equation framework. *Journal of Time Series Analysis, 19*(3), 267–283.

From the 1272 cases examined only 196 cases reject the null hypothesis in both bound tests. The median estimate of the long-run and short-run elasticity of substitution by using the ARDL method is 0.49 and 0.43, respectively. Detailed results by sector can be found in Table 8 and Table 9 in the annex.

The convergence to the long-run equilibrium relationship may follow a different adjustment rate in cases that the short-term dynamics lead to positive or negative change from the long-run equilibrium relationship. Shin and Yu[48] proposed a bound test procedure developed by Pesaran[49] in a non-linear ARDL framework in order to test for cointegration with asymmetric adjustment in the long-run equilibrium relationship. By using the NARDL model only 115 cases accepted the null hypothesis that an asymmetric non-linear cointegration relationship between the Q ratio and P ratio exists. The median estimate of the long-run elasticity of substitution by using the NARDL method is 0.53. It is found that in many cases the elasticity of substitution is higher in periods that there is a decrease in the relative ratio of prices between energy and gross value added as compared to periods in which the relative ratio of prices was increasing. Detailed results by region can be found in Table 10 in the annex.

5. Panel data analysis

Panel data analysis applied for the estimation of the elasticity of substitution between energy and value added. The unit roots test of Levin, Lin, Chu[50] and Im, Pesaran, Shin[51], which applied only to cases that the panels are balanced[52], are presented in Table 7 and Table 8. Since both Q ratio and P ratio can be considered as stationary variables the OLS estimator is used.

The Breusch-Pagan LM test, the Pesaran scaled LM test and the Pesaran cross dependence test have been used to test for cross-section dependence on the residuals of the OLS estimations. It is found that in all cases the residuals are

48 Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014). Modelling Asymmetric Cointegration and Dynamic Multipliers in a Nonlinear ARDL Framework. In: Sickles, R., Horrace, W. (eds). *Festschrift in Honor of Peter Schmidt*. Springer, New York, NY. https://doi.org/10.1007/978-1-4899-8008-3_9

49 Pesaran, M. H., Shin, Y. and Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics, 16*(3), 289–326. https://doi.org/10.1002/jae.616

50 Levin, A., Lin, Ch.-F., Chu, Ch.-Sh. J. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics, 108*(1), 1–24.

51 Im, K. S., Pesaran, M. H., Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics, 115*(1), 53–74.

52 Sectors 23, 61, 62 and L have unbalanced data.

Table 7. ***p*-values of the panel unit root tests on *Q* ratio**

Sectors	LLC[1]	IPS[1]	LLC[2]	IPS[2]	Sectors	LLC[1]	IPS[1]	LLC[2]	IPS[2]
AtB	0.000	0.014	0.000	0.000	F	0.002	0.033	0.000	0.001
C	0.002	0.095	0.000	0.036	50	0.000	0.002	0.000	0.000
15t16	0.001	0.084	0.000	0.000	51	0.000	0.624	0.000	0.000
17t18	0.004	0.893	0.002	0.114	52	0.000	0.000	0.000	0.000
19	0.014	0.555	0.000	0.074	H	0.000	0.000	0.000	0.000
20	0.005	0.362	0.001	0.036	60	0.036	0.590	0.000	0.005
21t22	0.124	0.510	0.000	0.006	61	n/a	n/a	n/a	n/a
23	n/a	n/a	n/a	n/a	62	n/a	n/a	n/a	n/a
24	0.000	0.176	0.000	0.000	63	0.000	0.153	0.000	0.013
25	0.001	0.043	0.000	0.009	64	0.012	0.813	0.000	0.000
26	0.000	0.060	0.000	0.000	J	0.001	0.523	0.007	0.026
27t28	0.266	0.738	0.004	0.150	70	0.000	0.004	0.000	0.000
29	0.000	0.293	0.000	0.016	71t74	0.000	0.064	0.000	0.000
30t33	0.000	0.359	0.000	0.003	L	n/a	n/a	n/a	n/a
34t35	0.000	0.023	0.018	0.017	M	0.000	0.001	0.000	0.030
36t37	0.000	0.027	0.000	0.000	N	0.002	0.135	0.000	0.033
E	0.000	0.000	0.000	0.299	O	0.003	0.001	0.000	0.000

[1] Unit root test with a deterministic constant
[2] Unit root test with a deterministic constant and trend

cross dependent and therefore the covariance matrix with panel corrected standard errors is more valid to be used for inference.

To estimate the elasticity of substitution of energy and gross value added the following steps have been used: 1) Estimate the model with panel least squares; 2) Test by using a LM test if the random effects should be included; 3) Estimate the model with fixed effect approach that allows the intercept to vary across countries or/and time period; 4) Test by using an F-test if the fixed effects should be excluded by the model; 5) If the null hypothesis of (1) and (4) is rejected the Hausman test is used to select between the fixed or random effects. If null hypothesis of the Hausman test is rejected then the model with random effects is selected, otherwise the model with fixed effects is used. Table 9 presents three different estimates of the substitution of elasticity between energy and gross value added by using the OLS (column 2), random

Table 8. *p*-values of the panel unit root tests on *P* ratio

Sectors	LLC[1]	IPS[1]	LLC[2]	IPS[2]	Sectors	LLC[1]	IPS[1]	LLC[2]	IPS[2]
AtB	0.111	0.733	0.000	0.000	**F**	0.000	0.002	0.000	0.011
C	0.000	0.117	0.001	0.018	**50**	0.000	0.182	0.000	0.012
15t16	0.000	0.306	0.000	0.000	**51**	0.009	0.439	0.000	0.000
17t18	0.014	0.584	0.000	0.029	**52**	0.000	0.117	0.000	0.060
19	0.158	0.370	0.000	0.005	**H**	0.000	0.000	0.000	0.694
20	0.000	0.056	0.000	0.037	**60**	0.008	0.445	0.004	0.046
21t22	0.863	0.832	0.000	0.128	**61**	n/a	n/a	n/a	n/a
23	n/a	n/a	n/a	n/a	**62**	n/a	n/a	n/a	n/a
24	0.004	0.990	0.000	0.001	**63**	0.267	0.467	0.000	0.000
25	0.000	0.630	0.000	0.000	**64**	0.317	0.998	0.000	0.000
26	0.002	0.241	0.000	0.019	**J**	0.000	0.013	0.000	0.017
27t28	0.000	0.736	0.000	0.145	**70**	0.000	0.001	0.000	0.032
29	0.004	0.786	0.000	0.000	**71t74**	0.000	0.000	0.000	0.013
30t33	0.009	0.888	0.000	0.004	**L**	n/a	n/a	n/a	n/a
34t35	0.000	0.440	0.000	0.044	**M**	0.000	0.000	0.000	0.029
36t37	0.000	0.071	0.000	0.000	**N**	0.000	0.000	0.000	0.001
E	0.086	0.391	0.000	0.000	**O**	0.000	0.000	0.000	0.039

1 Unit root test with a deterministic constant
2 Unit root test with a deterministic constant and trend

effects (column 3) and fixed effects (column 4), and the p-value of the Hausman test (column 5). The econometric results are compared with the corresponding estimates of Antoszewski[53] (column 1). All the estimates are statistically significant at 1% level and supports the weak substitutability between energy and gross value added.

53 Antoszewski, M. (2019). Wide-range estimation of various substitution elasticities for CES production functions at the sectoral level. *Energy Economics, 83*, 272–289.

Table 9. Panel data estimates by sector of the elasticity of substitution between energy and gross value added

	(1)	(2)	(3)	(4)	HT
AtB	0.212	0.217	0.152	0.155	0.687
C	0.211	0.359	0.322	0.325	0.709
15t16	0.390	0.433	0.190	0.201	0.225
17t18	0.498	0.448	0.272	0.288	0.291
19	0.318	0.476	0.252	0.275	0.145
20	0.468	0.586	0.380	0.400	1.000
21t22	0.318	0.601	0.200	0.221	1.000
23	0.493	n/a	n/a	n/a	n/a
24	0.252	0.663	0.252	0.265	0.193
25	0.638	0.481	0.415	0.421	0.716
26	0.522	0.536	0.256	0.272	0.205
27t28	0.346	0.720	0.218	0.260	0.000
29	0.724	0.557	0.512	0.515	0.897
30t33	0.786	0.655	0.531	0.543	0.693
34t35	0.458	0.399	0.439	0.436	0.858
36t37	0.627	0.504	0.427	0.434	0.338
E	0.084	0.343	0.070	0.081	1.000
F	0.343	0.382	0.097	0.107	1.000
50	0.378	0.493	0.297	0.308	0.362
51	0.396	0.349	0.301	0.305	0.804
52	0.359	0.284	0.127	0.137	1.000
H	0.430	0.481	0.117	0.137	0.007
60	0.036	0.350	0.076	0.087	1.000
61	0.433	n/a	n/a	n/a	n/a
62	0.248	n/a	n/a	n/a	n/a
63	0.258	0.351	0.095	0.112	1.000
64	0.573	0.527	0.352	0.368	0.429
J	0.398	0.581	0.181	0.207	0.142
70	0.181	0.543	0.088	0.097	0.069
71t74	0.189	0.429	0.177	0.187	0.370
L	0.262	n/a	n/a	n/a	n/a
M	−0.2250	0.475	0.139	0.146	0.125
N	0.303	0.549	0.188	0.200	0.144
O	0.306	0.488	0.185	0.195	1.000

(1): Antoszewski (2019) σ(kle) estimates
(2): Estimates by using the OLS estimator with panel corrected standard errors
(3): Estimates by using the OLS random effects estimator with panel corrected standard errors
(4): Estimates by using the OLS fixed effects estimator with panel corrected standard errors
(5): Hausman test

Conclusion

A wide range of econometric methods have been used to estimate the elasticity of substitution between energy and gross value added by region and by sector. Both timeseries and panel data analysis strongly supports the weak substitutability between energy and gross value added.

By applying the Zivot-Andrews test and the Gregory and Hansen cointegration test it is found that in most cases there are enough statistical evidences that support the existence of a structural break at the constant term of the econometric equation [1]. This result indicates that possibly there are other factors, not only the prices, that affect the ratio of energy to gross value added and that a change in the level of the energy intensity to gross value added is appeared suddenly at a point in time. The estimates of the error correction and the ARDL models that allow to differentiate between the short-run and long-run elasticity of substitution of energy and gross value added do not provide statistically evidences that the long run elasticity can be considered as greater to the short run elasticity. The elasticity of substitution between energy and gross value added remain stable across time. Finally, by using the NARDL model that allows to examine for non-linearities in the elasticity of substitution between the energy and gross value added, it is found that in some cases there is an asymmetric adjustment to the long-run equilibrium which is more intense in periods that there is a decrease in the relative ratio or prices of energy to gross value added.

Annex

Table 10. Sector definitions for abbreviations used in econometric analysis

Abbr.	Description
TOT	Total industries
AtB	Agriculture, Hunting, Forestry and Fishing
C	Mining and Quarrying
15t16	Food, Beverages and Tobacco
17t18	Textiles and Textile Products
19	Leather, Leather and Footwear
20	Wood and Products of Wood and Cork
21t22	Pulp, Paper, Paper, Printing and Publishing
23	Coke, Refined Petroleum and Nuclear Fuel
24	Chemicals and Chemical Products
25	Rubber and Plastics
26	Other Non-Metallic Mineral
27t28	Basic Metals and Fabricated Metal
29	Machinery, Nec.
30t33	Electrical and Optical Equipment
34t35	Transport Equipment
36t37	Manufacturing, Nec; Recycling
E	Electricity, Gas and Water Supply
F	Construction
50	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
51	Wholesale Trade and Commission Trade, Except Motor Vehicles and Motorcycles
52	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
H	Hotels and Restaurants
60	Inland Transport
61	Water Transport
62	Air Transport
63	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
64	Post and Telecommunications
J	Financial Intermediation
70	Real Estate Activities
71t74	Renting of M&Eq and Other Business Activities
L	Public Admin and Defence; Compulsory Social Security
M	Education
N	Health and Social Work
O	Other Community, Social and Personal Services

Table 11. Description of the regional abbreviations used in the analysis

Abbr.	Description
AUS	Australia
AUT	Austria
BEL	Belgium
BRA	Brazil
BGR	Bulgaria
CAN	Canada
CHN	China
CYP	Cyprus
CZE	Czech Republic
DNK	Denmark
EST	Estonia
FIN	Finland
FRA	France
DEU	Germany
GRC	Greece
HUN	Hungary
IND	India
IDN	Indonesia
IRL	Ireland
ITA	Italy
JPN	Japan
KOR	Korea, Republic of
LVA	Latvia
LTU	Lithuania
LUX	Luxembourg
MLT	Malta
MEX	Mexico
NLD	Netherlands
POL	Poland
PRT	Portugal
ROU	Romania
RUS	Russia
SVK	Slovak Republic
SVN	Slovenia
ESP	Spain
SWE	Sweden
TUR	Turkey
GBR	United Kingdom
USA	United States

Table 12. Cointegration test with possible structural break based on Gregory Hansen

	Number of cases that a cointegration exist by using either				Number of cases that both Q ratio and P ratio are I (1)
	A	B	C	A or B or C	
Agriculture, Hunting, Forestry and Fishing	3	5	3	6	11
Mining and Quarrying	3	3	3	4	10
Food, Beverages and Tobacco	4	4	2	5	8
Textiles and Textile Products	2	5	2	6	11
Leather, Leather and Footwear	3	5	3	7	11
Wood and Products of Wood and Cork	3	4	2	5	12
Pulp, Paper, Paper, Printing and Publishing	5	5	4	9	15
Coke, Refined Petroleum and Nuclear Fuel	2	4	5	7	9
Chemicals and Chemical Products	1	5	1	5	10
Rubber and Plastics	0	3	1	4	10
Other Non-Metallic Mineral	5	7	6	8	12
Basic Metals and Fabricated Metal	5	7	8	10	16
Machinery, Nec.	5	3	4	7	14
Electrical and Optical Equipment	7	4	4	8	10
Transport Equipment	4	4	4	5	11
Manufacturing, Nec; Recycling	3	6	1	6	11
Electricity, Gas and Water Supply	7	11	10	14	16
Construction	4	6	5	7	11
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	3	3	3	5	6
Wholesale Trade and Commission Trade, Except Motor Vehicles and Motorcycles	5	3	5	6	9
Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	2	4	4	6	11
Hotels and Restaurants	4	7	4	8	9
Inland Transport	2	5	4	6	11
Water Transport	1	1	1	2	5
Air Transport	7	10	6	11	18
Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	1	4	3	5	6
Post and Telecommunications	1	1	1	3	5
Financial Intermediation	3	3	2	4	10
Real Estate Activities	3	1	1	4	9
Renting of M&Eq and Other Business Activities	4	4	3	6	10
Public Admin and Defence; Compulsory Social Security	3	6	2	7	11
Education	6	4	3	7	10
Health and Social Work	4	6	3	7	13
Other Community, Social and Personal Services	2	2	2	4	9
ALL	117	155	115	214	360

Table 13. Long-run elasticities of substitution by using the ECM model (sectoral overview)

	Max (1)	Min (1)	Median (1)	% of total (1)	% of total (2)	% of total (3)	# of cases
AtB	0.59	0.33	0.41	66.7	16.7	16.7	6
C	0.00	0.00	0.00	0.0	25.0	75.0	4
15t16	0.41	0.22	0.31	80.0	20.0	0.0	5
17t18	0.56	0.33	0.51	50.0	33.3	16.7	6
19	0.55	0.22	0.40	71.4	0.0	28.6	7
20	0.63	0.28	0.63	60.0	0.0	40.0	5
21t22	0.75	0.31	0.42	55.6	11.1	33.3	9
23	1.21	0.18	0.51	85.7	0.0	14.3	7
24	0.22	0.17	0.20	40.0	40.0	20.0	5
25	0.43	0.27	0.39	75.0	25.0	0.0	4
26	1.25	0.22	0.38	37.5	37.5	25.0	8
27t28	0.67	0.26	0.43	40.0	10.0	50.0	10
29	0.75	0.38	0.66	42.9	14.3	42.9	7
30t33	0.97	0.16	0.33	37.5	12.5	50.0	8
34t35	0.60	0.25	0.36	60.0	40.0	0.0	5
36t37	0.43	0.25	0.31	66.7	33.3	0.0	6
E	0.79	0.08	0.16	42.9	21.4	35.7	14
F	0.48	0.18	0.23	71.4	0.0	28.6	7
50	0.58	0.38	0.40	60.0	40.0	0.0	5
51	0.46	0.46	0.46	16.7	16.7	66.7	6
52	0.15	0.15	0.15	16.7	16.7	66.7	6
H	0.83	0.21	0.46	50.0	12.5	37.5	8
60	0.00	0.00	0.00	0.0	0.0	100.0	6
61	0.00	0.00	0.00	0.0	0.0	100.0	2
62	0.49	0.22	0.31	27.3	45.5	27.3	11
63	0.54	0.34	0.44	80.0	20.0	0.0	5
64	0.00	0.00	0.00	0.0	0.0	100.0	3
J	0.35	0.35	0.35	25.0	25.0	50.0	4
70	0.00	0.00	0.00	0.0	50.0	50.0	4
71t74	0.63	0.17	0.40	33.3	16.7	50.0	6
L	0.36	0.16	0.16	42.9	14.3	42.9	7
M	0.23	0.23	0.23	14.3	14.3	71.4	7
N	0.55	0.55	0.55	14.3	42.9	42.9	7
O	0.32	0.32	0.32	25.0	25.0	50.0	4
ALL	1.25	0.08	0.38	42.5	20.1	37.4	214

(1): The cases with a negative σ in equation [1]
(2): The cases with a positive but statistically insignificant σ in equation [1] at a 5% level of significance
(3): The cases with a positive and statistically significant σ in equation [1] at a 5% level of significance

Table 14. Long-run elasticities of substitution by using the ECM-GH model (sectoral overview)

	Max (1)	Min (1)	Median (1)	% of total (1)	% of total (2)	% of total (3)	# of cases
AtB	0.53	0.24	0.31	83.3	16.7	0.0	6
C	0.45	0.18	0.31	50.0	0.0	50.0	4
15t16	0.37	0.13	0.37	60.0	40.0	0.0	5
17t18	0.68	0.17	0.31	83.3	16.7	0.0	6
19	1.63	0.25	0.53	85.7	14.3	0.0	7
20	0.91	0.27	0.51	80.0	20.0	0.0	5
21t22	0.77	0.23	0.31	55.6	22.2	22.2	9
23	1.25	0.13	0.49	71.4	0.0	28.6	7
24	0.45	0.28	0.37	40.0	60.0	0.0	5
25	0.94	0.27	0.50	100.0	0.0	0.0	4
26	1.31	0.24	0.27	50.0	37.5	12.5	8
27t28	0.46	0.36	0.41	20.0	30.0	50.0	10
29	0.91	0.20	0.43	100.0	0.0	0.0	7
30t33	0.98	0.29	0.72	50.0	25.0	25.0	8
34t35	0.48	0.19	0.35	80.0	20.0	0.0	5
36t37	0.69	0.28	0.37	66.7	16.7	16.7	6
E	0.34	0.12	0.17	28.6	50.0	21.4	14
F	0.22	0.16	0.19	57.1	42.9	0.0	7
50	0.54	0.15	0.54	60.0	40.0	0.0	5
51	0.84	0.25	0.25	50.0	33.3	16.7	6
52	0.42	0.42	0.42	16.7	16.7	66.7	6
H	1.40	0.24	0.72	37.5	37.5	25.0	8
60	1.31	0.16	0.42	50.0	0.0	50.0	6
61	0.00	0.00	0.00	0.0	0.0	100.0	2
62	0.55	0.36	0.44	45.5	54.5	0.0	11
63	0.87	0.21	0.40	80.0	20.0	0.0	5
64	0.71	0.71	0.71	33.3	0.0	66.7	3
J	0.74	0.74	0.74	25.0	25.0	50.0	4
70	0.63	0.27	0.45	50.0	0.0	50.0	4
71t74	0.56	0.56	0.56	16.7	33.3	50.0	6
L	0.43	0.13	0.21	57.1	28.6	14.3	7
M	0.26	0.11	0.18	28.6	28.6	42.9	7
N	0.61	0.61	0.61	14.3	14.3	71.4	7
O	0.00	0.00	0.00	0.0	25.0	75.0	4
ALL	1.63	0.11	0.39	50.5	25.7	23.8	214

(1): The cases with a negative σ in equation [1]
(2): The cases with a positive but statistically insignificant σ in equation [1] at a 5% level of significance
(3): The cases with a positive and statistically significant σ in equation [1] at a 5% level of significance

Table 15. Elasticity of substitution by using the OLS-FD model (region overview)

	Max (1)	Min (1)	Median (1)	% of total (1)	% of total (2)	% of total (3)
AUT	0.87	0.24	0.56	61.8	35.3	2.9
BEL	0.71	0.10	0.26	55.9	32.4	11.8
DEU	0.99	0.13	0.57	55.9	38.2	5.9
ESP	0.90	0.08	0.37	55.9	38.2	5.9
FRA	0.64	0.11	0.55	17.6	47.1	35.3
GBR	0.72	0.13	0.29	50.0	38.2	11.8
GRC	1.19	0.18	0.59	32.4	29.4	38.2
ITA	0.83	0.21	0.34	29.4	44.1	26.5
NLD	0.70	0.17	0.45	47.1	44.1	8.8
POL	0.70	0.11	0.62	20.6	61.8	17.6
PRT	0.77	0.23	0.39	58.8	38.2	2.9
ROU	0.85	0.10	0.41	67.6	29.4	2.9
AUS	0.88	0.13	0.50	61.8	35.3	2.9
BGR	0.43	0.08	0.14	20.6	29.4	50.0
BRA	0.82	0.15	0.19	23.5	64.7	11.8
CAN	1.07	0.14	0.58	26.5	61.8	11.8
CHN	0.86	0.27	0.57	67.6	26.5	5.9
CYP	0.99	0.32	0.54	38.2	50.0	11.8
CZE	0.82	0.28	0.49	26.5	50.0	23.5
DNK	0.92	0.15	0.29	35.3	35.3	29.4
EST	0.83	0.16	0.48	58.8	35.3	5.9
FIN	1.34	0.16	0.57	35.3	44.1	20.6
HUN	0.96	0.22	0.50	52.9	41.2	5.9
IDN	0.78	0.07	0.23	35.3	47.1	17.6
IND	1.03	0.19	0.64	64.7	20.6	14.7
IRL	0.75	0.17	0.33	29.4	47.1	23.5
JPN	0.85	0.10	0.33	41.2	47.1	11.8
KOR	0.85	0.08	0.36	52.9	29.4	17.6
LTU	0.91	0.12	0.49	32.4	50.0	17.6
LUX	1.00	0.21	0.49	44.1	35.3	20.6
LVA	1.21	0.17	0.48	35.3	38.2	26.5
MEX	0.56	0.08	0.23	41.2	52.9	5.9
MLT	2.32	0.44	0.91	73.5	11.8	14.7
RUS	0.22	0.13	0.17	14.7	55.9	29.4
SVK	0.65	0.20	0.45	29.4	52.9	17.6
SVN	1.02	0.07	0.75	85.3	11.8	2.9
SWE	0.56	0.11	0.33	32.4	55.9	11.8
TUR	0.84	0.08	0.41	38.2	44.1	17.6
USA	0.78	0.23	0.38	23.5	52.9	23.5
ALL	2.32	0.07	0.46	42.9	41.1	16.0

(1): The cases with a negative σ in equation [1]
(2): The cases with a positive but statistically insignificant σ in equation [1] at a 5% level of significance
(3): The cases with a positive and statistically significant σ in equation [1] at a 5% level of significance

Table 16. Elasticity of substitution by using the OLS-FD model (sectoral overview)

	Max (1)	Min (1)	Median (1)	% of total (1)	% of total (2)	% of total (3)
AtB	0.72	0.07	0.38	38.5	46.2	15.4
C	0.96	0.18	0.54	56.4	30.8	12.8
15t16	0.66	0.15	0.44	46.2	43.6	10.3
17t18	1.06	0.20	0.46	56.4	38.5	5.1
19	1.34	0.19	0.58	61.5	28.2	10.3
20	1.00	0.20	0.54	74.4	23.1	2.6
21t22	0.84	0.11	0.42	53.8	38.5	7.7
23	1.02	0.08	0.24	35.9	35.9	28.2
24	2.32	0.17	0.41	41.0	38.5	20.5
25	0.92	0.15	0.62	69.2	30.8	0.0
26	0.86	0.13	0.34	38.5	53.8	7.7
27t28	0.77	0.11	0.32	33.3	48.7	17.9
29	0.97	0.15	0.47	59.0	30.8	10.3
30t33	1.10	0.20	0.44	46.2	38.5	15.4
34t35	0.97	0.18	0.49	59.0	30.8	10.3
36t37	1.21	0.22	0.62	64.1	30.8	5.1
E	0.65	0.07	0.25	25.6	43.6	30.8
F	0.81	0.08	0.29	64.1	30.8	5.1
50	0.91	0.13	0.47	35.9	48.7	15.4
51	1.01	0.11	0.34	51.3	30.8	17.9
52	0.76	0.17	0.37	30.8	56.4	12.8
H	0.96	0.22	0.56	25.6	51.3	23.1
60	1.09	0.10	0.25	28.2	59.0	12.8
61	0.96	0.08	0.30	30.8	35.9	33.3
62	1.02	0.21	0.56	61.5	30.8	7.7
63	1.00	0.21	0.42	23.1	59.0	17.9
64	0.91	0.27	0.47	33.3	35.9	30.8
J	1.03	0.18	0.43	33.3	46.2	20.5
70	1.08	0.22	0.70	20.5	41.0	38.5
71t74	1.04	0.17	0.60	28.2	51.3	20.5
L	0.80	0.11	0.34	38.5	41.0	20.5
M	1.05	0.08	0.40	35.9	35.9	28.2
N	1.15	0.21	0.54	30.8	43.6	25.6
O	0.75	0.11	0.60	28.2	69.2	2.6
ALL	2.32	0.07	0.46	42.9	41.1	16.0

(1): The cases with a negative σ in equation [1]
(2): The cases with a positive but statistically insignificant σ in equation [1] at a 5% level of significance
(3): The cases with a positive and statistically significant σ in equation [1] at a 5% level of significance

Table 17. Long-run elasticities of substitution by using the ARDL model (sectoral overview)

	Max (1)	Min (1)	Median (1)	% of total (1)	% of total (2)	% of total (3)	% of total (4)	# of cases
AtB	0.43	0.27	0.34	10.5	7.9	21.1	60.5	38
C	1.06	0.21	0.46	10.3	10.3	15.4	64.1	39
15t16	0.40	0.28	0.34	5.3	13.2	23.7	57.9	38
17t18	1.00	0.28	0.59	13.5	5.4	21.6	59.5	37
19	1.25	0.30	0.74	16.2	10.8	8.1	64.9	37
20	1.36	0.38	0.60	8.3	13.9	11.1	66.7	36
21t22	0.95	0.12	0.50	13.2	10.5	23.7	52.6	38
23	1.26	0.17	0.69	15.2	18.2	18.2	48.5	33
24	0.23	0.08	0.16	5.3	7.9	18.4	68.4	38
25	2.13	0.45	1.15	10.8	16.2	32.4	40.5	37
26	1.28	0.29	0.43	8.1	32.4	21.6	37.8	37
27t28	0.09	0.09	0.09	2.6	10.3	20.5	66.7	39
29	0.00	0.00	0.00	0.0	16.2	18.9	64.9	37
30t33	0.85	0.38	0.62	7.9	2.6	21.1	68.4	38
34t35	0.87	0.40	0.58	10.3	28.2	12.8	48.7	39
36t37	0.69	0.23	0.46	5.1	17.9	12.8	64.1	39
E	0.00	0.00	0.00	0.0	10.5	26.3	63.2	38
F	0.64	0.17	0.25	7.9	10.5	15.8	65.8	38
50	0.60	0.24	0.30	10.8	18.9	13.5	56.8	37
51	1.63	0.51	0.72	10.8	13.5	10.8	64.9	37
52	0.72	0.27	0.48	10.3	5.1	20.5	64.1	39
H	0.28	0.28	0.28	2.6	15.4	38.5	43.6	39
60	0.77	0.36	0.57	5.6	8.3	25.0	61.1	36
61	1.17	1.12	1.15	6.1	15.2	21.2	57.6	33
62	1.17	0.84	1.00	5.4	10.8	13.5	70.3	37
63	0.75	0.11	0.43	5.3	7.9	23.7	63.2	38
64	0.59	0.29	0.47	10.5	7.9	13.2	68.4	38
J	0.57	0.57	0.57	2.8	13.9	16.7	66.7	36
70	0.73	0.32	0.68	7.7	12.8	25.6	53.8	39
71t74	0.81	0.17	0.35	11.1	16.7	22.2	50.0	36
L	0.43	0.22	0.40	11.1	11.1	16.7	61.1	36
M	0.00	0.00	0.00	0.0	10.5	36.8	52.6	38
N	0.26	0.26	0.26	2.6	10.5	23.7	63.2	38
O	1.37	0.26	0.47	10.3	7.7	41.0	41.0	39
ALL	2.13	0.08	0.49	7.7	12.6	20.8	58.9	1272

(1): The cases with a negative b/c in equation [3]
(2): The cases with a positive but statistically insignificant b/c in equation [3] at a 5% level of significance
(3): The cases with a positive and statistically significant b/c in equation [3] at a 5% level of significance
(4): The cases that no cointegration is found based on bound tests of Pesaran[54] and Banjeree[55].

54 Pesaran, M. H., Shin, Y. and Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics, 16*(3), 289–326. https://doi.org/10.1002/jae.616

55 Banerjee, A., Dolado, J., Mestre, R. (1998). Error-correction mechanism tests for cointegration in single-equation framework. *Journal of Time Series Analysis, 19*(3), 267–283.

Table 18. Short-run elasticities of substitution by using the ARDL model (sectoral overview)

	Max (1)	Min (1)	Median (1)	% of total (1)	% of total (2)	% of total (3)	% of total (4)	# of cases
AtB	0.71	0.12	0.28	13.2	10.5	15.8	60.5	38
C	0.69	0.34	0.40	15.4	7.7	12.8	64.1	39
15t16	0.38	0.15	0.33	7.9	10.5	23.7	57.9	38
17t18	0.95	0.44	0.62	10.8	10.8	18.9	59.5	37
19	1.66	0.18	0.72	24.3	5.4	5.4	64.9	37
20	1.12	0.37	0.47	22.2	5.6	5.6	66.7	36
21t22	0.58	0.13	0.45	18.4	10.5	18.4	52.6	38
23	1.08	0.21	0.48	21.2	9.1	21.2	48.5	33
24	0.40	0.17	0.19	7.9	5.3	18.4	68.4	38
25	1.17	0.42	0.71	24.3	10.8	24.3	40.5	37
26	1.18	0.20	0.38	18.9	18.9	24.3	37.8	37
27t28	0.45	0.29	0.33	7.7	5.1	20.5	66.7	39
29	0.62	0.19	0.46	13.5	10.8	10.8	64.9	37
30t33	0.75	0.56	0.60	7.9	5.3	18.4	68.4	38
34t35	0.84	0.18	0.51	33.3	5.1	12.8	48.7	39
36t37	0.76	0.34	0.66	20.5	2.6	12.8	64.1	39
E	0.22	0.22	0.22	2.6	10.5	23.7	63.2	38
F	0.84	0.12	0.24	15.8	10.5	7.9	65.8	38
50	0.58	0.23	0.24	13.5	21.6	8.1	56.8	37
51	1.61	0.19	0.50	16.2	5.4	13.5	64.9	37
52	0.51	0.17	0.29	12.8	5.1	17.9	64.1	39
H	0.48	0.23	0.33	12.8	10.3	33.3	43.6	39
60	0.57	0.13	0.39	13.9	2.8	22.2	61.1	36
61	0.90	0.16	0.27	9.1	12.1	21.2	57.6	33
62	0.93	0.32	0.81	10.8	2.7	16.2	70.3	37
63	0.87	0.25	0.67	10.5	7.9	18.4	63.2	38
64	0.48	0.46	0.47	5.3	15.8	10.5	68.4	38
J	0.59	0.35	0.42	11.1	8.3	13.9	66.7	36
70	0.69	0.23	0.46	5.1	10.3	30.8	53.8	39
71t74	0.42	0.18	0.35	11.1	16.7	22.2	50.0	36
L	0.40	0.16	0.39	8.3	8.3	22.2	61.1	36
M	0.73	0.19	0.51	7.9	7.9	31.6	52.6	38
N	0.75	0.75	0.75	2.6	13.2	21.1	63.2	38
O	0.68	0.49	0.63	7.7	17.9	33.3	41.0	39
ALL	1.66	0.12	0.46	13.1	9.4	18.6	58.9	1272

(1): The cases with a negative b/c in equation [3]
(2): The cases with a positive but statistically insignificant b/c in equation [3] at a 5% level of significance
(3): The cases with a positive and statistically significant b/c in equation [3] at a 5% level of significance
(4): The cases that no cointegration is found based on bound tests of Pesaran[56] and Banjeree[57].

56 Pesaran, M. H., Shin, Y. and Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics, 16*(3), 289–326. https://doi.org/10.1002/jae.616

57 Banerjee, A., Dolado, J., Mestre, R. (1998). Error-correction mechanism tests for cointegration in single-equation framework. *Journal of Time Series Analysis, 19*(3), 267–283.

Table 19. Short-run and long-run substitution of elasticity by using an NARDL model

Region	Sector	long-run positive	long-run negative	short-run positive	short-run negative
ITA	15t16	0.23	1.20	stat	1.13
RUS	15t16	0.44	sign	0.49	0.14
TUR	15t16	0.61	0.13	stat	0.41
FRA	17t18	0.69	0.35	0.74	sign
BGR	17t18	0.88	stat	stat	stat
BGR	19	0.89	stat	stat	stat
RUS	19	0.79	stat	stat	0.38
CHN	20	0.56	1.80	0.73	stat
LUX	20	1.02	1.42	1.00	1.13
BEL	21t22	stat	0.20	sign	0.39
ESP	21t22	stat	0.77	stat	1.16
TUR	21t22	0.62	stat	stat	stat
ESP	23	stat	0.62	sign	stat
CZE	23	0.54	0.90	0.33	0.70
IND	24	0.68	stat	stat	sign
LUX	24	0.89	2.68	stat	stat
DNK	25	0.65	1.02	0.47	0.90
PRT	26	0.16	1.06	stat	sign
BGR	26	0.61	sign	0.55	sign
IDN	26	0.58	0.39	1.04	stat
KOR	26	0.12	stat	0.44	sign
IRL	27t28	stat	sign	0.38	sign
RUS	27t28	0.31	stat	stat	0.23
FRA	29	0.24	sign	sign	sign
BRA	29	sign	stat	sign	0.27
JPN	29	0.93	1.64	stat	4.20
SVK	29	0.56	stat	stat	1.05
SVN	29	stat	stat	0.82	sign
FRA	30t33	0.29	sign	sign	sign
ITA	30t33	0.24	0.94	sign	1.11
POL	34t35	0.52	sign	sign	0.36
ROU	34t35	1.16	0.26	1.19	stat
CZE	34t35	0.57	stat	0.57	stat
IRL	34t35	0.44	stat	stat	stat
SWE	34t35	0.31	sign	stat	1.45
TUR	34t35	0.94	0.31	0.71	0.39
AUT	36t37	stat	0.78	stat	0.82
ITA	36t37	stat	0.58	stat	0.65
SVK	36t37	0.44	sign	stat	sign
BEL	50	0.20	0.27	0.47	stat
AUS	50	stat	sign	0.44	sign

BGR	50	0.37	1.11	stat	stat
IDN	51	1.01	0.80	1.04	stat
SVN	51	stat	stat	0.86	stat
BRA	52	0.26	0.20	0.31	stat
IDN	52	0.97	0.78	1.06	stat
GBR	60	0.57	stat	stat	stat
IDN	60	0.17	0.41	stat	0.19
KOR	60	0.15	sign	sign	0.34
ITA	61	stat	0.52	sign	stat
DNK	61	stat	2.71	stat	1.50
IND	61	sign	stat	0.74	stat
USA	61	0.93	1.90	stat	stat
BEL	62	0.31	stat	0.31	sign
CZE	62	0.60	1.22	sign	1.50
TUR	62	1.00	0.28	stat	stat
POL	63	stat	0.58	stat	stat
JPN	63	stat	0.75	0.64	sign
MLT	63	0.85	1.32	0.95	1.47
EST	64	0.27	sign	stat	sign
LTU	64	0.23	stat	stat	sign
LVA	64	stat	4.18	sign	4.31
GRC	70	stat	stat	sign	2.35
NLD	70	stat	stat	0.61	sign
HUN	70	stat	1.17	1.27	sign
BRA	71t74	0.09	sign	0.10	sign
SVK	71t74	0.38	stat	stat	sign
FIN	AtB	0.23	0.55	sign	stat
CZE	C	0.79	1.13	stat	1.38
BGR	F	stat	0.98	0.90	0.85
FIN	F	0.14	0.41	sign	0.42
IDN	F	0.40	0.33	0.53	stat
JPN	F	0.14	stat	0.19	sign
BGR	H	0.49	stat	stat	stat
DNK	H	sign	0.34	stat	sign
PRT	J	0.30	sign	0.52	sign
BRA	J	0.54	stat	stat	stat
DNK	J	0.64	stat	0.94	stat
FIN	J	1.33	3.07	sign	1.18
SVN	J	0.75	sign	0.68	sign
IDN	L	0.79	0.46	0.90	sign
LUX	L	0.41	1.32	sign	0.95
SVN	L	0.48	stat	1.14	sign
SWE	L	0.31	0.72	stat	0.44
BGR	M	stat	1.10	stat	0.74
IDN	M	sign	sign	sign	0.36

IRL	M	stat	0.46	stat	sign
JPN	M	0.80	0.52	stat	stat
LUX	M	0.30	1.28	stat	stat
DNK	N	stat	sign	0.60	sign
LUX	N	0.49	0.70	stat	0.70
IRL	O	stat	0.61	sign	sign
TUR	O	stat	0.27	sign	stat

*sign: The cases that the elasticity of substitution has a negative sign
*stat: The cases that the elasticity of substitution has a positive but insignificant sign

Part III

Finding the best balance of Energy Trilemma

Edgars Groza, Kārlis Gičevskis, Edgars Smiltāns, Inese Karpoviča, Gunārs Valdmanis

Latvia's energy supply and security

The paper focuses on one of the Trilemma Index dimensions – Energy security. The criteria that are impacting the energy security dimensions score the most are reviewed. The review focuses on the current state of the energy system, the current and future issues, possible solutions and suggestions to maintain and increase the energy security dimension's score. The data mostly are obtained from public sources, market reviews, statistical databases. The authors would like to express their gratitude to an executive committee of programme "Future Energy Leaders in Latvia". This research was also supported by Riga Technical University's Doctoral Grant programme.

1. Energy Security Trilemma Index

Energy systems security defines the energy systems ability to satisfy current and futures energy demand. It shows its ability to maintain stability in different scenarios, to recover from disruptions with the least outages of power supply. Energy systems security covers the efficiency of the management of local and external energy sources, as well as the reliability and sustainability of energy infrastructure[1]. World energy council (WEC) has developed a methodology how to measure country's ability to maintain energy security.

1 World Energy Council (2022). World Energy Trilemma Index 2021. Available: https://www.worldenergy.org/publications/entry/world-energy-trilemma-index-2021

2. WEC methodology

Latvia is among the top 5 countries in the world according to the current Trilemma score on the Energy security index. Globally, energy security index is focusing on oil and other fossil fuels. Although fossil fuels have been a resource Latvia is importing, well diversified power generation portfolio has granted this high score. Energy security index includes other important criteria that have a positive effect on overall system and its stability.

Three main pillars can measure energy systems security in the context of Trilemma Index:

a) import – national dependency on resource import in the total energy consumption and supplier diversification;
b) energy generation capacities and their diversity – country has well balanced and diversified generation portfolio;
c) energy storage capabilities – countries ability to satisfy its energy demand, in accordance with the available infrastructure.

Energy resource availability, economic development, technological development, investment flow, well designed energy market, ability to react on disturbances: these are few aspects that characterizes energy systems security index and are evaluated within WEC methodology.

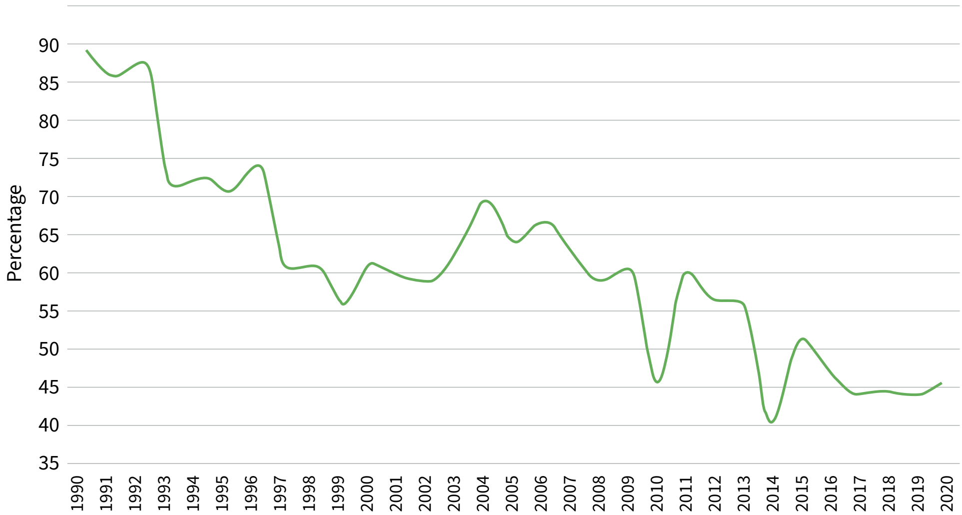
Daniel Yergin, an American author, economic researcher and energy analyst, has argued that energy security cannot be viewed as independent criteria in separate country: it needs to be seen in a broader context between different countries, and attention needs to be paid to how the energy system between these countries interact[2]. Therefore, also in the context of Latvia, one of the directions of the research is regional cooperation, which is at the same time one of the basic principles of the Energy Union. It is the case of the Baltic states that demonstrates that the integration of energy infrastructure through the interconnection of pipelines and the interconnection of electricity networks between the EU Member States is necessary for the functioning of the EU's common energy market and the strengthening of energy security in the region.

3. Case of Latvia: The current state of energy system

Latvia's final energy consumption consists of the following resources: solid fossil fuels, electricity, natural gas, heat, oil products, peat products, renewable resources and biofuels, non-renewable waste. Based on Eurostat data, Latvia has reduced its

2 Yergin, D. (2006). Ensuring Energy Security. *Foreign Affairs, 85*(2), 69–82. https://doi.org/10.2307/20031912

Figure 1. **Energy imports dependency of Latvia**



Source: Eurostat

solid fuel consumption by 50% since 2015. There are also changes in the use of renewable resources and biofuels. Consumption of other resources has not changed significantly in the last five years.

Looking at the total consumption of energy resources, it can be observed that the total consumption of renewable energy resources in Latvia is increasing, which allows to approach the goals set by the European Union ensure at least 50% share of renewable energy in Latvia's final energy consumption until 2030 and become climate neutral by 2050.

According to Eurostat data, Latvia has an average high dependence on energy imports (~45%). The most important imported resources are natural gas, oil products, biofuels and electricity, which a few years ago had not such a huge impact on energy security.

4. Raw resources

4.1. Gas

Within ten years (2011–2020), the share of natural gas consumption decreased by 8.7 percentage points and in 2020 was 20.6%. Along with the decrease in natural gas consumption, the volume of imported natural gas has also decreased, which is largely related to the use of alternative fuel resources and the promotion of energy efficiency measures as well as increase of CO_2 emission price for gas users. Despite the decrease in this share, natural gas still plays an important role in Latvia's total energy consumption. Most natural gas is used to produce electricity and heat in boiler houses and cogeneration plants. At the same time, it should be kept in mind that natural gas consumption in Latvia is seasonal, as, for example, the high demand for natural gas in 2020 can be explained by relatively low outdoor temperatures during the months of the heating season. Additionally, the overall natural gas demand was influenced by several other factors – low natural gas price in first two quarters of the year, which contributed to the higher usage of natural gas in power production, and malfunction of one of largest natural gas power plants in Latvia in the last two quarters of the year, which limited the usage of natural gas for power production in respective period. In 2021, the volume of gas consumed for the needs of Latvian users was 12.5 TWh[3], which represents 8% over the indicator of 2020. Increase in consumption was influenced by climatic conditions in winter, as the average air temperatures dropped to –2.8 °C, which is 0.4 °C below the seasonal norm, furthermore, January and February saw the harshest frost in the recent years[4]. At the same time, the cold climatic conditions raised natural gas consumption for electricity production – the year of 2021 shows higher volume of electricity produced by thermal power stations – JSC Augstsprieguma tīkls (AST) data)[5].

An integrated and liquid natural gas market between LV, EE and FI exists since beginning of 2020, and Lithuania is planning to join in 2023[6].

As there is reasonable amount of gas suppliers around the globe, the lack of their diversity can be seen as a threat in a short term. The Baltic states have quite good pipeline grid and at the same time the problem is that the infrastructure is built mostly for gas supply from Russia, after the completion of Klaipeda LNG terminal in 2014, Balticconnector gas pipeline between Estonia and Finland in 2020 and the GIPL pipeline interconnection between Lithuania and Poland this year. But still in conditions where gas supply is used as a weapon, reorientations cannot happen so smooth and fast. Shortage of infrastructure capacity in Baltics (as well as in Finland and Poland) is rather high – the capacity of Klaipeda LNG terminal is insufficient to cover consumption of the region – Lithuania, Latvia,

3 AS "Conexus Baltic Grid" (2022). Dabasgāzes pārvades sistēmas operatora ikgadējaā novērtējuma ziņojums par 2021. gadu. Rīga. Available: https://www.conexus.lv/uploads/filedir/Zinojumi/PSO_zinojums_2022_LV.pdf

4 SLLC Latvian Environment, Geology and Meteorology Centre (2022). Available: https://klimats.meteo.lv/laika_apstaklu_raksturojums/2021/gads/

5 AS "Augstsprieguma tīkls" (2021). Available: https://www.ast.lv/lv/electricity-market-review?year=2021&month=13

6 Connexus Baltic Grid (2021). Available: https://conexus.lv/vienotais-dabasgazes-tirgus

Estonia and Finland. Additional terminal is needed. Consequently, there is a plan to build it in Estonia as well as in Finland. There are discussions and feasibility study exploring the potential for development of LNG terminal also in Latvia, however, thus far no decision has been made. It can be expected that the share of Russian pipeline gas will be replaced mostly with LNG and biomethane until the end of 2022.

4.2. Electricity

4.2.1. Market

At the end of 2021, electricity prices set new historical monthly average price records, resulting in 2.6 times higher average yearly electricity price (88.78 EUR/MWh). The rise in electricity prices was driven by several factors including rise of natural gas and CO_2 emissions prices (setting record price 92.37 EUR/MWh and 80.10 EUR/tCO_2), low wind power generation in Europe, lower water levels in Scandinavia.

On 22 May 2022, electricity trading with Russia has been stopped, leaving only technical capacities for grid balancing.

Specifically, in Latvia in year 2021 the generated amount of electricity has risen by 1.8% what is 5.6 TWh and the demand has risen by 3.5% reaching 7.4 TWh. Hydro power stations have generated 4.2% more and cogeneration stations 10.7% more than in 2020. All other generation capacities have shown much smaller contribution comparing to the previous years, which can be explained with changes in subsidized energy scheme as well as with the depletion of some of production capacities. These events in combination with situation in neighbouring countries has led to increase of electricity import to Baltics to around 50%.

On 17 August 2022, Baltic electricity market set new record on highest ever electricity price reaching 4000 EUR/MWh. The sharp rise in prices is caused by the limited supply of electricity in the Baltic market – it is limited both by the repair of the dams of the Daugava HPP, as a result of which the large hydropower plants in Latvia produce little due to the low water level, the availability of gas and its high prices for the production of electricity in cogeneration plants, and also the decision to stop importing electricity from due to the sanctions imposed on it by Russia.

The limited volume of production contributed to the increase in imports to the Baltic states. From the countries of the European Union, a total of 1 138 716 MWh of electricity was imported into the Baltics[7].

7 AS "Augstsprieguma tīkls" (2022). Available: https://www.ast.lv/lv/electricity-market-review

4.2.2. End users

The Latvian electricity market has been fully liberalized since 1 January 2015, which means that households and commercial electricity users are free to choose a trader by agreeing on an electricity price. Based on the data of the Electricity Trade Register of the Public Utilities Commission, a total of 43 electricity traders were registered in November 2021.

Electricity market participants, which include electricity producers, traders, aggregators, end-users, operate in the electricity market and their trading transactions cover the supply of electricity from the electricity producer to the user. The above transactions take place in the wholesale of electricity and then in the retail sale of electricity. Amendments in the Electricity Market Law identifies new entities – prosumers and energy communities, which expands the market participant options to involve in the electricity generation. End users in Latvia can cover their consumption by installing microgeneration and work in cooperation with distribution system operator (DSO).

4.2.3. Generating capacities

The installed generation capacity in Latvia has not changed much in recent years in total 3015 MW. Since 2015, generation capacity has increased by 209 MW. Of which RES capacity has risen by 183 MW in the last 7 years, but natural gas power plant capacity – by 26 MW.

It should be mentioned that the distribution (DSO) and transmission system operator (TSO) have issued technical regulations for the connection of new generating capacity of more than 4 GW, including solar and wind power plants.[8]

Latvia's power generation portfolio consists of hydro powerplants, natural gas power plants, biogas power plants, wind power plants and sun power plants (see Figure 3) all together crafting well diversified and balanced generation portfolio. This list excludes microgeneration (around 36 MW[9]). Unfortunately, the installed capacity now is insufficient to completely cover internal countries electricity demand.

4.2.4. Electricity import

By looking at the load of generation units by months, it can be observed that the generation capacity is the least loaded in June, July and August – respectively, when there is the lowest water flow in local river Daugava and it is not profitable to operate gas power plants (neither cogeneration nor condensation mode).

8 AS "Augstsprieguma tīkls" (2022). Available: https://ast.lv/lv/content/pieslegumu-ierikosanas-un-atlautas-slodzes-izmainu-statuss

9 AS "Sadales tīkls" (2022). Elektroapgādes apskats. Available: https://sadalestikls.lv/lv/elektroapgades-apskats

Figure 2. **Total installed electricity generation capacity**

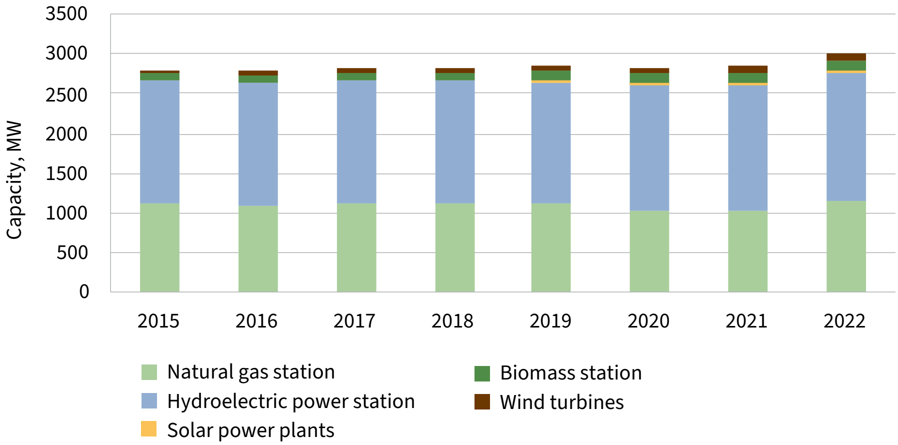
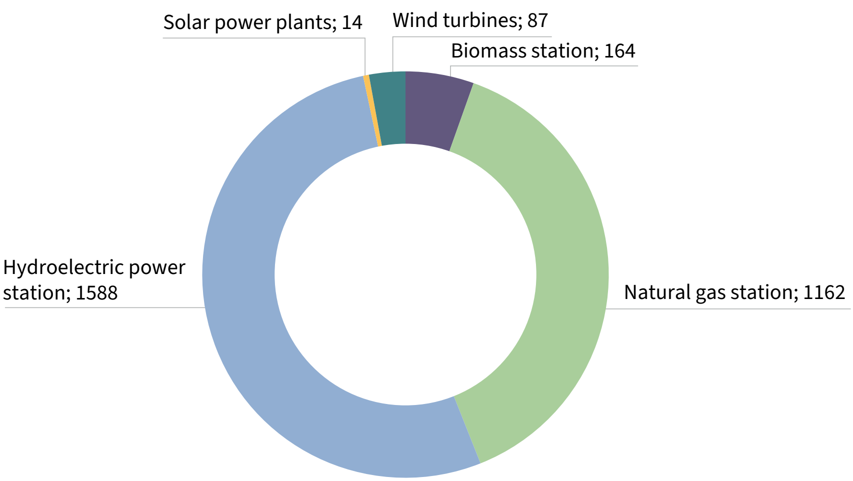
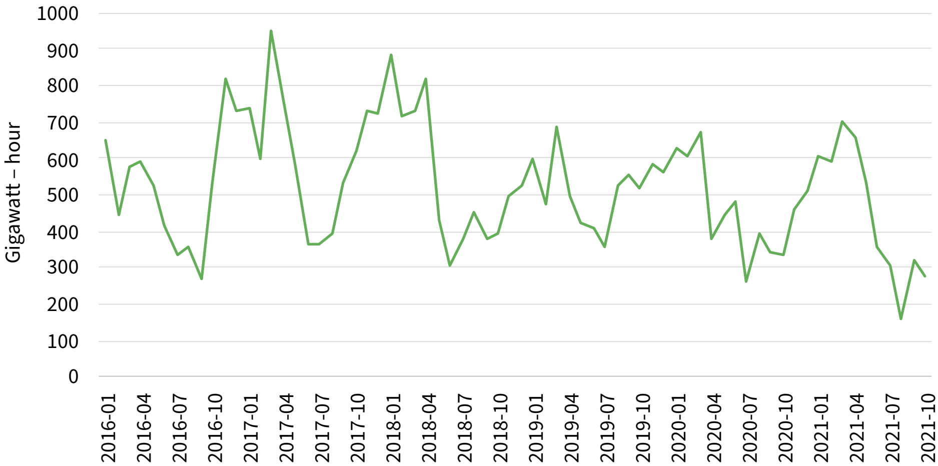


Figure 3. **Generation capacities in 2022 (MW)**



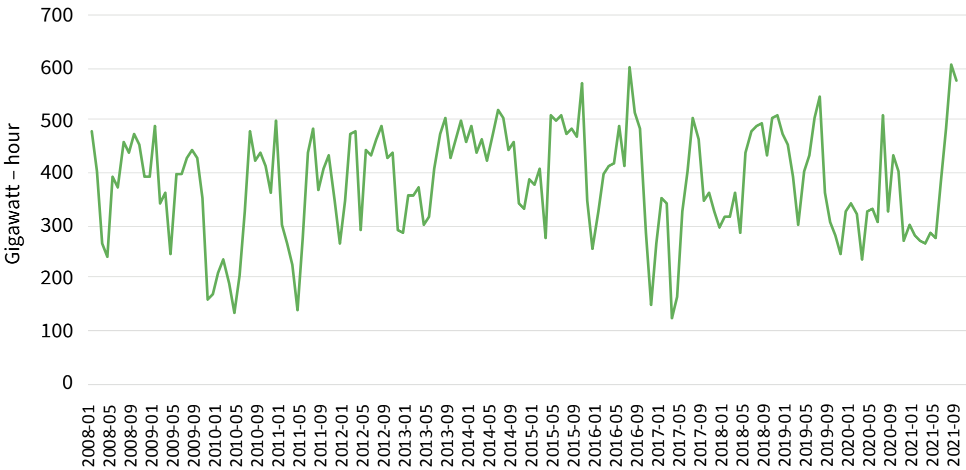
The amount of electricity produced in these months is low, so electricity is imported through interconnectors. Net electricity imports are shown in the Figure 5. In 2019, the maximum interconnection capacity of the Latvian transmission network available for electricity import/export was 947 MW from Estonia to Latvia and 879 MW from Latvia to Estonia. 684 MW from Lithuania to

Figure 4. **Net electricity generation in total**



Source: Eurostat

Figure 5. **Net imports of electricity in Latvia**



Source: Eurostat

Latvia and 1302 MW from Latvia to Lithuania. Since May 2022, there is no import from the third countries. Only necessary technical flows are current to operate the network

4.2.5. Interconnections (BRELL)

The operator of the Latvian electricity transmission system operator AST is responsible for the reliability of electricity supply and for the modernization and development of the transmission network. The most important realized and ongoing development projects can be seen in the table.

Table 1

Project	Kurzeme arc	Riga TEC-2 – Riga HES	EE-LV interconnection	Synchronization Phase 1			Synchronization Phase 2
				Valmiera-Tartu	Valmiera-Tsirgulina	Systems synchronous and intertia equipment	
Planned impl. year	2019	2020	2021	2023	2024	2025	2025
Planned CAPEX	128 MEUR	15 MEUR	83 MEUR	23 MEUR	22 MEUR	32 MEUR	100 MEUR
Total length	214.3	13	180	49	49		

In order to ensure safe operation of the Latvian electricity system, efficient functioning of the electricity market, and to prevent equipment obsolescence, the Latvian electricity TSO reconstructs and modernizes high-voltage substations and electricity distribution points. Observing the development trends of electricity systems of Latvia and neighbouring countries, Latvian electricity TSO evaluates and decides on the development of interconnections of the Latvian electricity transmission system, as well as the need to strengthen and modernize the internal network[10].

10 AS "Augstsprieguma tīkls". Available: https://ast.lv/lv/development-projects/parvades-tikla-modernizacija-un-attistiba

The Baltic states have historically worked and are currently working synchronously with the electricity systems of Russia and Belarus. The goal of synchronization is to start the Baltic electricity system's synchronous work with Europe and reduce dependence on decisions made outside the European Union. Synchronization will increase the ability of Baltics to constantly manage its electricity system, ensuring the balance between production and consumption, managing the necessary safety reserves, as well as regulating electricity flows and frequency without the involvement of countries outside the European Union. The most important benefit is security, because as a result of synchronization, the Baltic electricity transmission system will become a part of the European system, which means significant independence from Russia and more secure electricity supply[11].

4.2.6. Storage

Latvia has unique geological conditions which would allow in 11 locations to develop underground natural gas storage (UGS) facilities with capacity to cover approximately 10% of whole Europe's demand. The only operating underground natural gas storage facility in Baltics is located in Inčukalns with capacity to store 2.32 billion m^3 (~24 TWh) of natural gas. Mostly, storage is used seasonally – the gas is mainly injected in summer for the coming winter season.

Prior to the liberalization of the natural gas market in Latvia, the Inčukalns UGS was filled to its maximum technical capacity every season. As market liberalization approached, the Russian natural gas group Gazprom reduced until it stopped storing natural gas for Russia, significantly reducing the total amount of natural gas stored at the Inčukalns UGS thus reducing the usage of the storage. An important factor was the completion of modernization projects of natural gas storage facilities in Russia, increasing the natural gas storage capacity in the country. The Lithuanian lawsuit against Gazprom also played an important role, which adversely affected Gazprom's desire to store natural gas in the Baltic region.

The liberalization of the market did not oblige natural gas traders to use the Inčukalns UGS, relying on market mechanisms, which have been reflected in the sharp decline in stored volumes in 2017. The decline in the volume of stored natural gas continued in 2018, and taking into account the technical structure of the Inčukalns UGS, created a rickshaw for the energy crisis as extraction capacity correlates with volume of natural gas left in the storage.

In 2020, with the establishment of the common natural gas market between Estonia, Latvia and Finland and the introduction of an inter-operator compensation mechanism that abolished tariffs for natural gas flows between market interconnections, the stored natural gas in Inčukalns UGS and the energy security of Latvia and the Baltic region increased significantly.

11 AS "Augstsprieguma tīkls". Available: https://ast.lv/lv/projects/sinhronizacija-ar-eiropu

Figure 6. **Amount of active natural gas at Inčukalns UGS after natural gas injection at the end of the season (TWh)**[12]

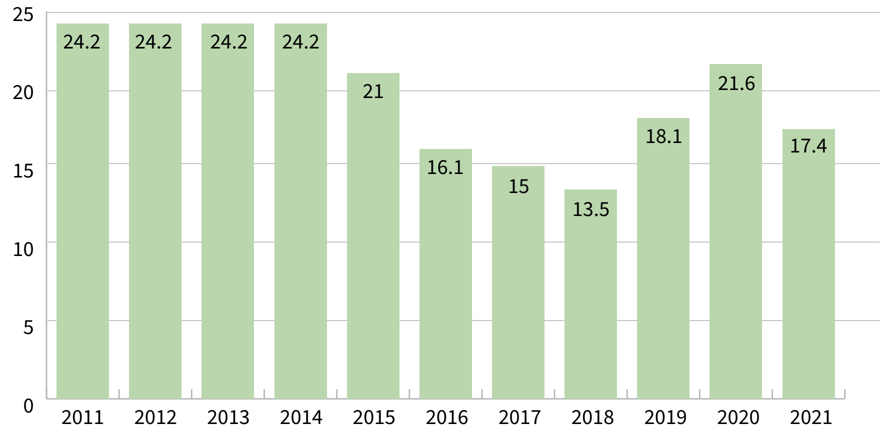
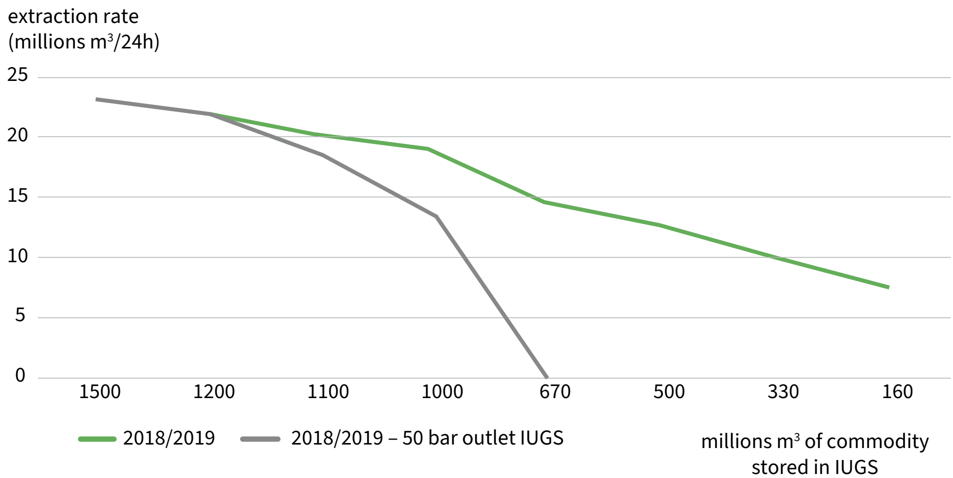


Figure 7. **Inčukalns UGS natural gas extraction productivity in relation to stored volume**[13]



12 AS "Connexus Baltic Grid" (2021). Dabasgāzes pārvades sistēmas operatora ikgadējā novērtējuma ziņojums par 2020. gadu. Available: https://www.conexus.lv/uploads/filedir/Aktualitates/Parskati/Dabasg__parv_sist_operatora-zinojums_par_2020_JUN_ready2.pdf

13 AS "Connexus Baltic Grid" (2018). PCI project 8.2.4. Investment Request. Inčukalns Underground gas storage enhancement. Available: https://www.google.com/url?q=https://www.conexus.lv/uploads/filedir/iugs_pci_investment_request_20181002.pdf&sa=D&source=docs&ust=1655143083818440&usg=AOvVaw2oVDZx0gNG-D7GXGrTvFShC

Situations in which the filling of Inčukalns UGS is relatively low, but the demand for natural gas is reaching its peaks, there is a risk of an energy crisis. This risk can be explained by the decrease in the technical pumping capacity of Inčukalns UGS due to the decrease in the amount of stored natural gas (see Figure 7). The storage system operator JSC Conexus Baltic Grid has started the modernization project of Inčukalns UGS, as a result of which the modernized compressor will ensure the removal of natural gas from the storage facility with increased, stable and predictable daily removal capacity even at low natural gas balances and storage pressures[14].

Steep changes in geopolitical situation promoted role of Inčukalns UGS as one of main pillars for security of supply in whole Baltic region. Particular statement is supported by high demand for Inčukalns UGS storage capacities by natural gas traders in the region. In order to ensure sufficient natural gas stocks for upcoming winter, Inčukalns UGS switched its working regime to injection in an atypically timely manner – in February. The unusual practice resulted in unusually high level of stock, which is crucial to ensure security of supply. Practical tool for mitigation of risks concerning security of supply is creation of strategic stocks. Latvian government via national electricity concern Latvenergo has ordered creation of such stock in amount of 1.8–2.2 TWh[15, 16, 17, 18].

In Latvia, safety reserves of oil products are established in accordance with the requirements of Directive 2009/119/EC, which have been transposed into Latvian legislation by the Energy Law. The EU regulation requires to ensure the fuel reserves for up to 90 days of consumption of the country. As can be seen in the Figure 8, Latvia's reserves of energy products of oil origin have more than doubled in the last decade, in 2020 they are 162% higher than in 2011, which nevertheless is connected with the rise of consumption. The increase in oil product reserves strengthens Latvia's energy security.

14 AS "Connexus Baltic Grid" (2021). Inčukalna pazemes gāzes krātuves modernizācija būtiski uzlabo Latvijas dabasgāzes apgādes stabilitāti. Available: https://www.conexus.lv/aktualitates/incukalna-pazemes-gazes-kratuves-modernizacija-butiski-uzlabo-latvijas-dabasgazes-apgades-stabilitati

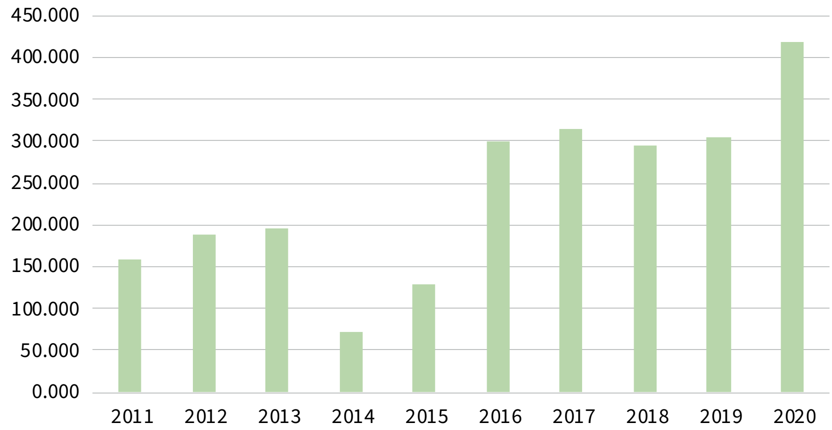
15 Saeima (2022). Saeima noteic energoapgādes drošuma rezerves apjomu gāzei. Available: https://www.saeima.lv/lv/aktualitates/saeimas-zinas/30936-saeima-noteic-energoapgades-drosuma-rezerves-apjomu-gazei

16 AS "Connexus Baltic Grid" (2022). Available: https://conexus.lv/zinas-presei/conexus-pirmajos-tris-gada-menesos-incukalna-pgk-noglabats-rekordliels-dabasgazes-apjoms

17 AS "Connexus Baltic Grid" (2022). Available: https://conexus.lv/zinas-presei/incukalna-pazemes-gazes-kratuve-sagatavota-iesuknesanas-uzsaksanai

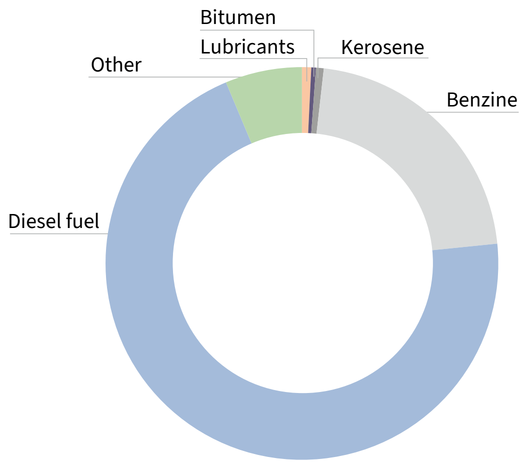
18 Latvijas Sabidriskie mediji (2022). Valdība nolemj Inčukalnā veidot dabasgāzes rezerves par aptuveni 230 miljoniem eiro. Available: https://www.lsm.lv/raksts/zinas/ekonomika/valdiba-nolemj-incukalna-veidot-dabasgazes-rezerves-par-aptuveni-230-miljoniem-eiro.a452974/

Figure 8. Reserves of oil products stored in Latvia, tons



Source: Eurostat

Figure 9. Proportion of oil product reserves held by Latvia by type



Source: Eurostat

In total, more than 400 thousand tons of stored oil products contain around 70% of diesel, and about 22% of gasoline. The other product types, each individually, account for a relatively small percentage of total oil product reserves. Considering the aspect of dependence on certain oil products, it can be concluded that diesel and petrol play the most important role in ensuring energy security.

4.2.7. Possible solutions

One of the most efficient solutions how to improve the security of Latvian energy system in reference to Trilemma Index methodology would be to implement new electricity generation capacities.

Latvia has developed National Energy and Climate Plan for 2021–2030 that highlights national ambitions on energy sectors development in four pillars:

- resourcefulness;
- self-sufficiency and diversity of resources;
- reducing consumption of fossil and non-sustainable resources;
- use of sustainable renewable and innovative resources;

which concludes in a developed and climate neutral economy.

Latvian electricity TSO has developed a map with information about the transmission lines on availability to connect generation or consumption. The map in combination with project list of issued connection permits, it can be concluded that there is around 2GW of renewable projects under development in different stages.

The closest power station to commissioning in 2022 is 58.8 MW wind park in Ventspils parish. Two wind parks after long struggle have obtained positive Environmental impact assessment which is big leap on wind park development and few parks are performing the environmental impact assessment. There are several developers who have granted the connection technical requirements in summer 2020 but yet not decided on finalizing.

Increasing renewable non-dispatchable energy resources in the total generation portfolio can also have negative consequences if dispatchable capacities are not increased at the same time. In a situation where the country has a high share of renewable resources and low dispatchable capacities, windless cloudy weather, large amount of generating power has no production, which can impact the balance between supply and demand.

Dispatchable capacities with synchronous generation provide system services such as system rotating reserve, the insufficiency of which may result in frequency fluctuations and power system instability. Therefore, to increase the resilience of the energy system from the point of view of generation diversity, the generation portfolio must be balanced, including sufficient dispatchable capacity.

4.2.8. Estonian-Latvian offshore wind park

In the Latvian National Energy and Climate Plan 2021–2030 (NEKP 2030) the task of implementing an international project for the construction of an off-shore wind farm in the period up to 2030 has been confirmed. Such a task was included in NEKP 2030, because Latvia has committed to achieve a 50% share of renewable energy in the total final energy consumption by 2030, as well as to ensure a reduction of Latvia's total greenhouse gas emissions by 65%, compared to Latvia's GHG emissions in 1990.

In 2020, Latvia approved the marine spatial planning map, where the potential construction sites of offshore wind farms, as well as the possible connections of the power transmission infrastructure, are also planned. Latvian electricity TSO, together with other institutions, participated in the marine spatial planning process organized by the Ministry of Environmental Protection and Regional Development.

Latvian and Estonian transmission system operators Latvian and Estonian electricity TSOs, respectively, as responsible for infrastructure development and connections to the power transmission network, are also involved in the implementation of this project. At the beginning of 2021, TSOs carried out preliminary calculations of the distribution of power flows for the construction and reinforcement of the power transmission network if new wind farms are connected. Both TSOs plan to conduct a detailed route study for possible connection options, while the ministries and LIAA plan to conduct a cost-benefit analysis of the entire project, including wind farms and infrastructure. CEF RES European co-financing opportunities may appear after 2022. The auction of the wind park project to a potential investor may take place around 2025, and the implementation of the project itself, together with the infrastructure, is scheduled for 2030.[19]

In order to achieve climate neutrality of the energy sector, it is essential to introduce new technologies. Currently, one of them is the use of hydrogen, which has several advantages and development prospects in the industry. Latvian utility company is working on pilot project to implement hydrogen in energy portfolio. It envisages that green hydrogen will be produced using polymer electrolyte membrane electrolysis equipment and electricity from TEC-2 solar batteries or from the planned AS Latvenergo wind power plant in Priekule district, or from Daugava hydroelectric plants. The produced hydrogen will be stored or used immediately for combustion in gas turbines TEC-2. Before burning the produced hydrogen will be mixed with natural gas in a mixing unit.[20]

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19 AS "Augstsprieguma tīkls" (2021). Elektroenerģijas pārvades sistēmas attīstības plāns 2022–2031. Available: https://ast.lv/sites/default/files/AST_Attistibas_plans_2022-2031.pdf

20 AS "Latvenergo" (2022). Elektroenerģijas tirgus apskats. Available: https://latvenergo.lv/storage/app/media/uploaded-files/ETA_jan_2022.pdf

Conclusion

Although Latvia is scoring high in Energy Security Trilemma Index by WEC methodology, it is necessary to highlight that even short but focused bursts of specific issues (gas supply interruption, lack of generating capacities in the region) can dramatically impact the energy security as whole and leave significant footprint in further development. Therefore, it is critical to prioritize the energy security determining factors and purposely act on the improvements.

Latvia should set a clearer plan for decarbonization of its energy system with explicit actions for humanizing energy transition. For example, starting with development of national hydrogen strategy. In authors' view, Latvian energy security dimension should be more decentralized, distributed, digitalized, and decarbonized, and at the same time maintain balanced share of dispatchable baseload capacities in generation portfolio. Authors also acknowledge the need for new sub-indicators to represent an evolving energy system in transition.

Karīna Viskuba, Anrijs Tukulis, Tomass Liepnieks, Haralds Millers

Latvia's environmental sustainability and green energy development in terms of the WEC Energy Trilemma Index Tool

In 2019, the European Union Member States have made a pact to become climate-neutral by 2050. Therefore, one of the EU economy's main sectors – energy sector – also must be ready for a green transformation, simultaneously being safe, sustainable and accessible for all the EU citizens. These aspects for each EU Member States are culminating in a single energy Trillema Index, which is represented by the World Energy Council's (WEC) universal assessment methodology Trillema Index Measurement.[1]

Environmental sustainability has a variety of definitions. In the authors' opinion, one of the most suitable definitions is, as follows: "Meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them, and more specifically, as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity."[2] In WEC methodology, Environmental Sustainability is measured in three main parts: energy resource productivity, decarbonization, and emissions and pollution. These main parts are divided into smaller indicators, that help to see a better overall picture of the indicator. The indicators with the highest-ranking weights are final energy intensity, the efficiency of power generation and T&D, the trend of greenhouse gas emissions from energy, and low carbon electricity generation. Considering the environmental sustainability dimension in

1 European Commission (2022). 2050 Long-term strategy. Available: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2050-long-term-strategy_en; World Energy Council. (2021). World Energy Trilemma Index 2021. Available: https://trilemma.worldenergy.org/

2 Morelli, J. (2011). Environmental Sustainability: A Definition for Environmental Professionals. *Journal of Environmental Sustainability*, Vol. 1. Available: https://scholarworks.rit.edu/cgi/viewcontent.cgi?article=1007&context=jes

Latvia, it can be observed that the most rapid shift in the dynamics of the analysed indicators took place in the period from 1990 to 2000 mainly due to the decrease in total energy consumption and sub-indicators in various sectors of the economy. In the period following 2000, changes in the indicators have been more stagnant. Therefore, it shows that the set of actual activities in the Latvian energy sector is insufficient, because it tends to focus on historical record, rather than on practical implementation. Moreover, an insufficient set of activities in the Latvian energy sector may lead to a gradual Latvian Trilemma Index's environmental sustainability pillar decline, which will also mean a non-achievement of the set objectives related to Latvia in the common EU's goal to become climate neutral.

This research aims to scrutinize Latvia's performance in WEC Trilemma Index tool environmental sustainability pillar and provide the recommendations to further index improvements. This paper discusses the environmental sustainability pillar of the World Energy Council's Trillema Index in the case of Latvia. The research is limited by the three environmental sustainability pillar's components of Trilemma Index – resource productivity, decarbonisation, emissions and pollution. To fully understand the subject and the spectrum of environmental sustainability, qualitative information from multiple sources – World Energy Trilemma Index reports, publications of scientific journals, strategic documents of the Republic of Latvia, European Union's regulatory enactments – have been collected, systematized and analysed. Furthermore, the quantitative analyses were implemented, including compilation, grouping and graphical analysis of statistical data, the authors of the present research give priority to using the statistical data from national data resources of the Republic of Latvia.

1. Resource productivity

To assess the efficiency of the energy system, it is necessary to start with the evaluation of generation efficiency. Generation efficiency is equated to the consumption of primary energy resources per unit of energy produced. Generating capacity can be divided into fossil or renewable energy technologies. The efficiency of fossil fuel power generation is also directly linked to the environmental impact in terms of GHG emissions, so it is critical for these technologies to achieve the highest possible efficiency. The efficiency of renewable energy technologies is generally lower, but GHG emissions from energy production are not directly generated. Of course, the impacts come from the production of renewable technologies, as well as from environmental impacts that are not limited to GHG emissions, but this is discussed in greater detail in Section 3. In order to determine the efficiency of the country's generating capacity, it is important to analyse energy production technologies and their efficiency indicators.

Figure 1. **Electricity production by source in Latvia, TWh, 1990–2021**[3]

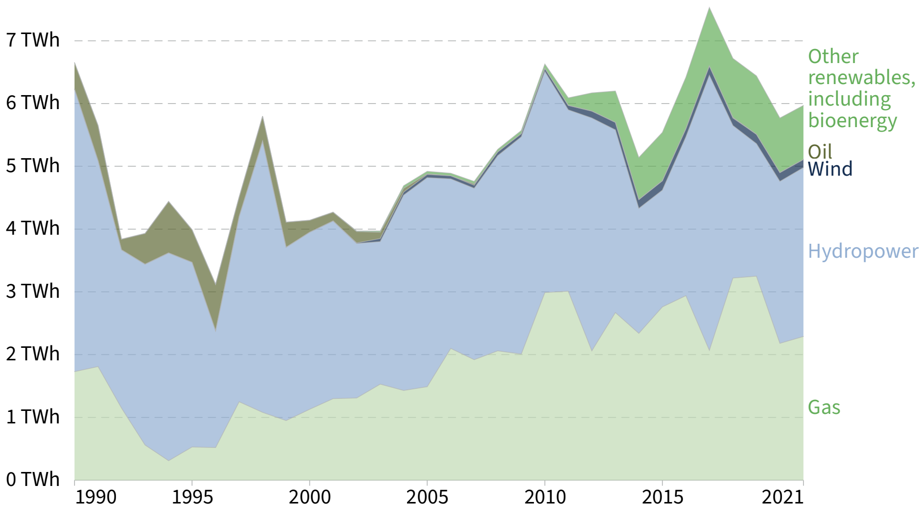
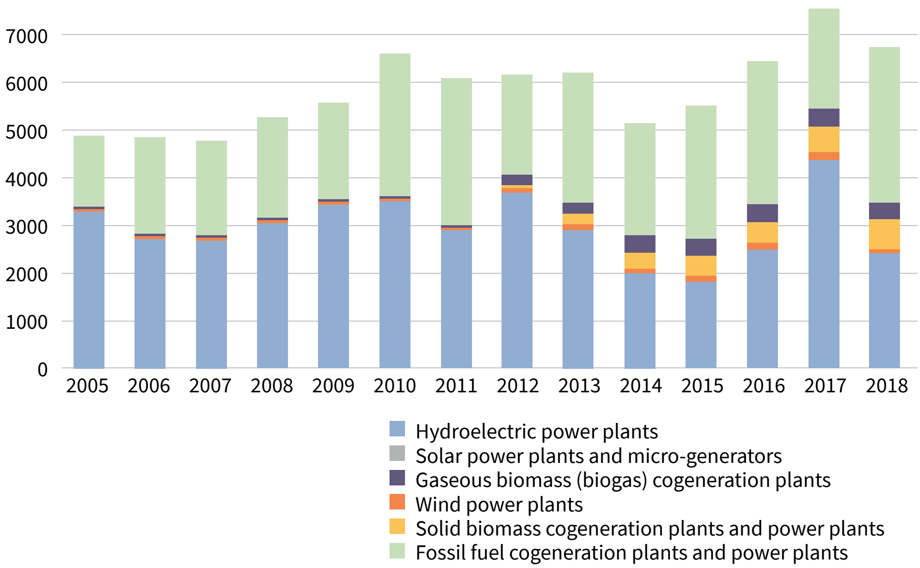


Figure 2. **The amount of electricity produced from RES (and fossil fuels) in Latvia, GWh, 2000–2018**[4]



3 Ritchie, H., Roser, M. (2020). (Our World in Data) Latvia: Energy Country Profile in 2020. Available: https://ourworldindata.org/energy/country/latvia

4 European Network of Transmission System Operators for Electricity. Energy Profile of Latvia. Available: https://www.entsoe.eu

The final energy consumption correlates not only with the amount and efficiency of energy generated from primary energy sources but also with losses in transmission and distribution networks. Loss of power in the electricity grid is one of the most important indicators of the economic activity of the electricity grid company, which also reflects the condition of the electricity meter reading systems and the efficiency of the network. One of the indicators characterizing the efficiency of the transmission segment is the percentage of electricity transmission losses in relation to the total energy received in the network. In 2020, this figure was 2.3%. The loss rates of the Latvian transmission system, 2.3% on average during the explored time period (2016–2020)[5], were well within the average transmission loss rate of the 35 European countries, which ranged from about 0.5% to slightly less than 3% in the last year of the available data (2018).[6]

In 2020, the amount of distributed electricity in Latvia decreased by 246 GWh or 3.8%, compared to the year before. Electricity consumption has decreased in the segment of business customers, while household customers consumption has increased. The amount of electricity consumed for the needs of the distribution system has decreased by 16 GWh or 5.5% in 2020, compared with the previous year. The decline of electricity consumption was facilitated by the reduction of economic consumption through the implementation of efficiency projects for premises and territory, installation of smart electricity meters, monitoring of electricity consumption, capital investments and planned repairs aimed at reducing losses, and the reduction of the total distribution service. The electricity distribution loss rates of the Latvian distribution system were 4.3% on average during the explored time period (2016–2020). In 2020, the distribution system operator JSC Sadales tīkls reached the historically lowest electricity loss rate – 4.0%.[7] In early 2020, the Council of European Energy Regulators (CEER) published the latest report on distribution losses in European electricity networks. The indicators for 2018 included in the report show that Latvia has achieved one of the lowest distribution loss rates in Eastern Europe.[8]

If the efficiency of energy generation depends more on large producers and technologies they use, then the final energy intensity is already closely linked to the individual energy efficiency of businesses and households. Energy intensity is

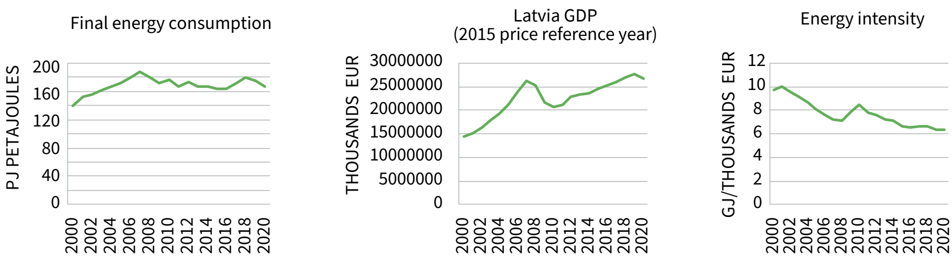
5 AS "Augstsprieguma tīkls" (2021). AS "Augstsprieguma tīkls" ilgtspējas pārskats 2020. Available: https://www.ast.lv/sites/default/files/editor/AST_ilgtspejas_parskats_2020.pdf

6 The World Bank (2020). Electric power transmission and distribution losses (% of output) – European Union. Available: https://data.worldbank.org/indicator/EG.ELC.LOSS.ZS?end=2014&locations=EU&start=1986&view=chart

7 AS "Sadales tīkls" (2021). AS "Sadales tīkls" gada pārskats 2020. Available: https://sadalestikls.lv/storage/app/media/uploads/2021/04/ST_-2020_gada-p-rskats_LV_.pdf

8 Council of European Energy Regulators (2020). The 2nd CEER Report on Power Losses. Available: https://www.ceer.eu/documents/104400/-/-/fd4178b4-ed00-6d06-5f4b-8b87d630b060

Figure 3. Energy intensity assessment in Latvia, 2000–2020[9]



a parameter calculated by final energy consumption divided by Gross Domestic product. This parameter is also used to compare the efficiency of specific industries, as well as to assess the development of countries as a whole. Energy intensity has become particularly acute in today's world, where energy prices are experiencing unprecedented and sharp increases.

Considering final energy consumption, it rose sharply until 2008 but remained stable after the global financial crisis, with a decline in 2020 associated with the onset of Covid pandemic. Looking at Latvia's GDP, we can see that, similarly to consumption, there was rapid growth until 2008, which was followed by a sharp decline due to the financial crisis, but stable growth has been observed for the last 10 years. Of course, the 2020 pandemic clearly shows the impact on GDP. Calculating the energy intensity measured in GJ of energy consumed per thousand euros generated, we can see that in the long run the intensity decreases, except for the crisis of 2008, where GDP fell sharply.

Looking at the final energy consumption by sector, transport and households account for the largest share of consumption of energy, but it is also important to take into account the sectoral barriers that need to be addressed in order to introduce efficiency measures when assessing possible improvements.

Given that energy efficiency measures have not only an economic limit but also a technical one, it is important to assess the added value and contribution to national GDP.

Summarizing Latvia's performance in the resource productivity section of the environmental sustainability pillar, the authors evaluate achievement of the indicators as successful with improving trend of energy intensity ratio, well performed efficiency of power generation and between EU's average electricity power transmission and distribution losses.

9 Central Statistical Bureau of Latvia. Available: https://www.csp.gov.lv/lv

Figure 4. Final energy consumption by sector, %[10]

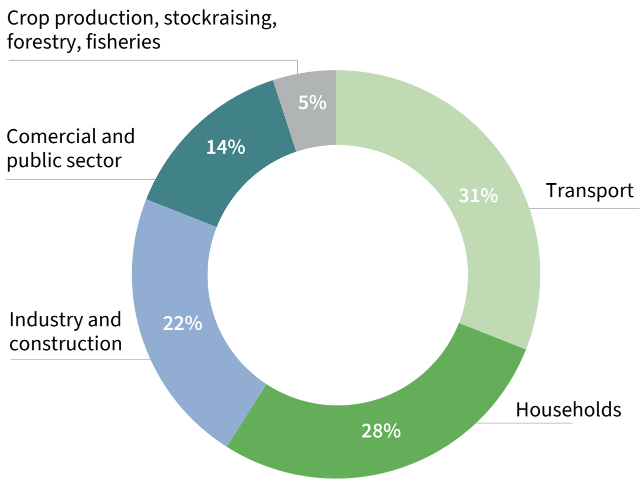
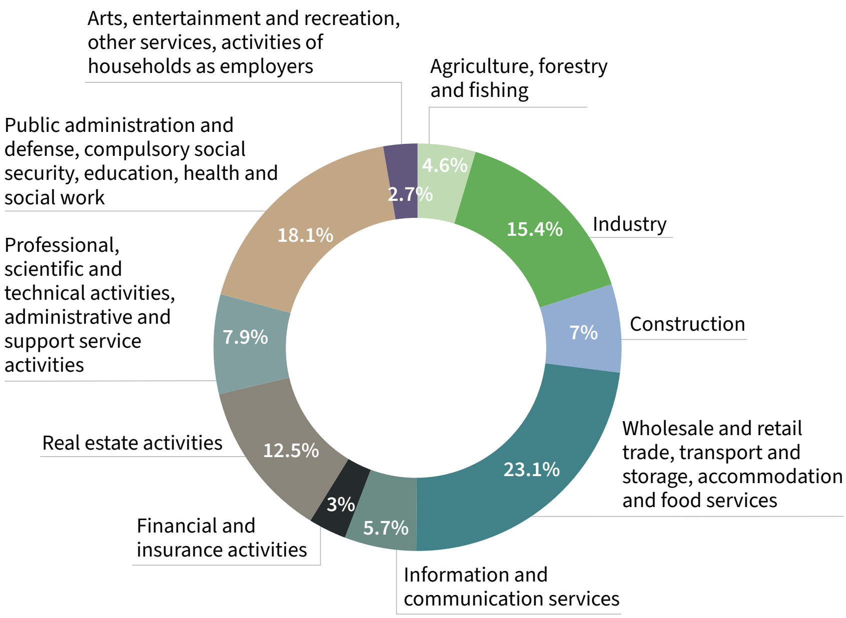


Figure 5. Latvia's GDP by sectors, %[11]



10 Central Statistical Bureau of Latvia. Available: https://www.csp.gov.lv/lv

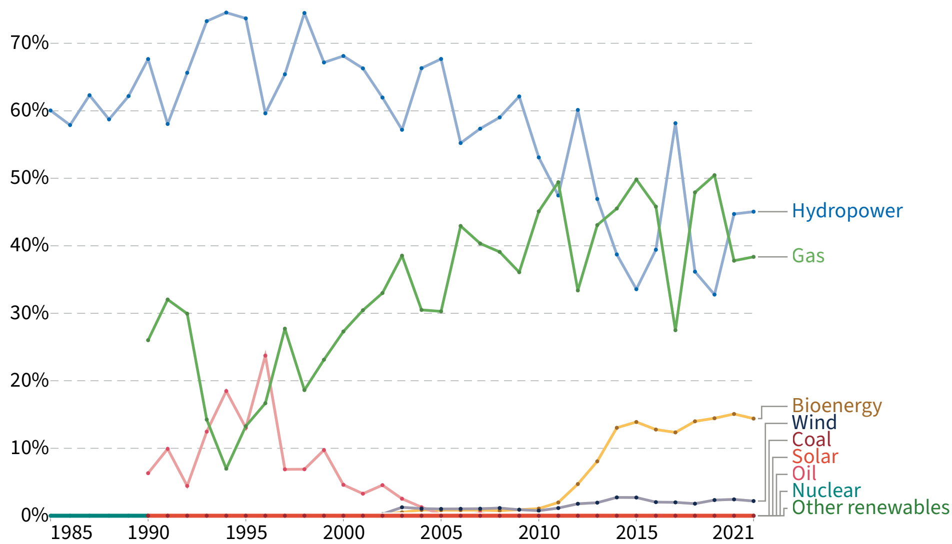
11 Ibid.

2. Decarbonization

The term 'decarbonization' tends to refer to the process of reducing carbon intensity, lowering the amount of GHG emissions produced by burning the fossil fuels. Generally, this involves decreasing CO_2 output per unit of electricity generated. Reducing the amount of carbon dioxide occurring as a result of transport and power generation is essential to meet global temperature standards set by the Paris Agreement.[12]

The graph, which represents the breakdown of Latvia's electricity production by source, shows that in the period from 1985 to 2020 the largest share of electricity production was formed by oil, natural gas and hydro resources.

Figure 6. **Share of electricity production by source in Latvia, %, 1990–2021**[13]



Starting from 1994, the share of oil in Latvia's electricity production profile began to gradually decrease, at the same time the share of gas increased rapidly. From 2011 to 2014 the share of other renewable energy sources, for instance,

12 Corradi, O. (2018, July 3). *Estimating the marginal carbon intensity of electricity with machine learning.* Available: https://www.tmrow.com/blog/marginal-carbon-intensity-of-electricity-with-machine-learning/

13 Ritchie, H., Roser, M. (2020). (Our World in Data) Latvia: Energy Country Profile in 2020. Available: https://ourworldindata.org/energy/country/latvia

biomass, biogas etc. have speedily developed. The main reason for that was a start of the state support mechanism, which allows selling electricity within the framework of mandatory procurement. However, after 2014 it stayed at the same level with some slight fluctuations. In general, no significant changes in Latvia's produced electricity profile by sources were discovered in the last seven years – the largest share still remains for gas and hydro resources, while the development of renewables is more stagnating rather than improving.

According to the data provided by the European Environment Agency, the greenhouse gas emission intensity of the EU power generation has a downward trend. In 2020, 1 kilowatt hour of generated electricity emitted, on average, one third less CO_2 than a decade ago. The decrease was driven by policies addressing climate change, efficient and renewable energy supply and use, and declined industrial emissions.[14]

Latvia's total GHG emissions in 2013 were by more than 58% lower than in 1990, but only about 1% lower than in 2005. Most of Latvia's total GHG emissions come from the use of fuel in stationary combustion plants (38%), from transport (25%) and from agriculture (21%). In 2017, GHG emissions in the energy sector had decreased and generated 34%, the emissions in the transport sector had increased to 29%, in the agriculture sector to 25%, the waste management sector produced 5% of GHG emissions and the sector of industrial process and product use – 7% of the total GHG emissions. JSC Latvenergo, a state-owned utility company, purposefully invests in boosting the efficiency of production facilities, simultaneously increasing the use of RES and reducing CO_2 emissions. A significant contribution to it is the reconstruction projects of combined heat and power plants – TEC-1 and TEC-2, installing highly efficient cogeneration equipment in the modernized production facilities. The use of cogeneration makes it possible to significantly reduce the amount of resources used and emissions, while efficiently producing more energy than working in condensation mode.

The Ministry of Environmental Protection and Regional Development of the Republic of Latvia states that the main measures to reduce GHG emissions in the energy sector are the implementation of building energy efficiency measures, as well as the promotion of the use of non-emission technologies in the production of electricity and thermal energy. Meanwhile, in the transport sector one of the most effective measures to reduce GHG emissions is the increase of renewable

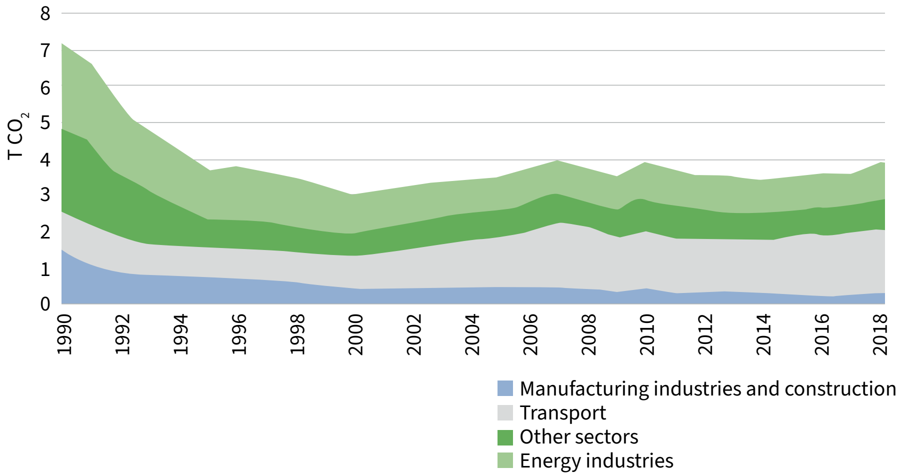
14 The European Environment Agency (EEA) (2022). Greenhouse gas emission intensity of electricity generation in Europe. Available: https://www.eea.europa.eu/ims/greenhouse-gas-emission-intensity-of-1

energy resources in road transport, electrification and the transition to a newer vehicle fleet.[15]

3. Environmental impact

The limited amount of energy sources, low development of renewable energy sources, and a high share of non-renewable energy sources, for example, natural gas, oil, and coal are causing environmental problems: air pollution, solid waste disposal, water pollution, and thermal pollution, to mention a few. One of the indicators that represents the section of emissions and pollution is CO_2 per capita.

Figure 7. **CO_2 per capita by sectors in Latvia, t, 1990–2019[16]**



The graph above (see Figure 7) shows that the level of carbon dioxide in Latvia has dropped sharply from 7.2 to 3.1 tons of CO_2 per capita in the first

15 The Ministry of Environmental Protection and Regional Development of the Republic of Latvia (2020). Ministry: Major emissions reductions in the non-ETS are expected in the energy and transport sectors. Published: 19.02.2020. Available: https://www.varam.gov.lv/en/article/minitry-major-emissions-reductions-non-ets-are-expected-energy-and-transport-sectors

16 Ritchie, H., Roser, M. (2020). (Our World in Data) Latvia: Energy Country Profile in 2020. Available: https://ourworldindata.org/energy/country/latvia

10 years (from 1990 to 2000) of the explored time period. The main sectors that facilitated the ratio decline were manufacturing industries and construction, as well as other sectors (including households). Meanwhile, the share of carbon dioxide produced in energy industries and the transport sector stayed stable from 1990 to 2000. However, after 2000, tons of CO_2 per capita have decreased in energy industries, as well as continued to move down in the manufacturing and construction industries, while in the transport sector CO_2 emissions have started to grow.

Observing the dynamics of carbon dioxide emission level per capita in Latvia, the authors summarize that in the last 20 years there were no improvements in the ratio performance. Moreover, the transport sector is the main trigger of increasing carbon dioxide level in Latvia.

Particulate matter (PM2.5) is one of the pollutants that not only causes environmental acidification, eutrophication and ground-level ozone pollution, but also is dangerous to human health because it bypasses many of the human body's defences. High PM2.5 level significantly increases the risk of respiratory disease, heart disease and stroke, which are the leading causes of death in OECD countries.[17] The emission target for fine suspended particulates (PM2.5) set out in EC Directive 2016/2284 is a 16% reduction in 2020 from the emissions emitted in 2005, which means that the emissions in 2020 should be 23.71 kt. The target for 2030 is a 43% reduction compared to 2005, or emissions in 2030 should not exceed 16.09 kt. The Gothenburg Protocol stipulates that the country's total PM2.5 emissions in the period after 2020 must not exceed 22.68 kt.[18]

In Latvia, total PM2.5 emissions in 2019 have moved down by 22.1%, compared to 1990, and were 19.97 kt. The decrease can be explained by the reduction in total fuel consumption in the energy sector. Compared to 2005, the decrease in emissions is 29.3%, which was mainly driven by the decrease in fuel consumption in the household sector. (See Figure 8). In 2019, the largest sources of PM2.5 emissions are other sectors, which include heating of buildings (small combustion plants in the commercial and public sector and households), as well as the use of fuels in agriculture, forestry and fishing, which emitted 62.9% or 12.56 kt of total PM2.5 emissions. Emissions in the sector have fallen by 46.1% since 2005 due to improved energy efficiency in buildings, which reduces fuel consumption. The second and third largest sources of PM2.5 emissions in

17 OECD iLibrary. Air Quality. Available: https://www.oecd-ilibrary.org/sites/80661e2d-en/index.html?itemId=/content/component/80661e2d-en

18 VSIA "Latvijas Vides, ģeoloģijas un meteoroloģijas centrs" (2022). 2021. gadā iesniegtās gaisa piesārņojošo vielu inventarizācijas kopsavilkums. Available: https://videscentrs.lvgmc.lv/lapas/gaisa-piesarnojums

Figure 8. Average annual exposure value of PM 2.5 air pollution in Latvia, kt, 1990–2019[19]

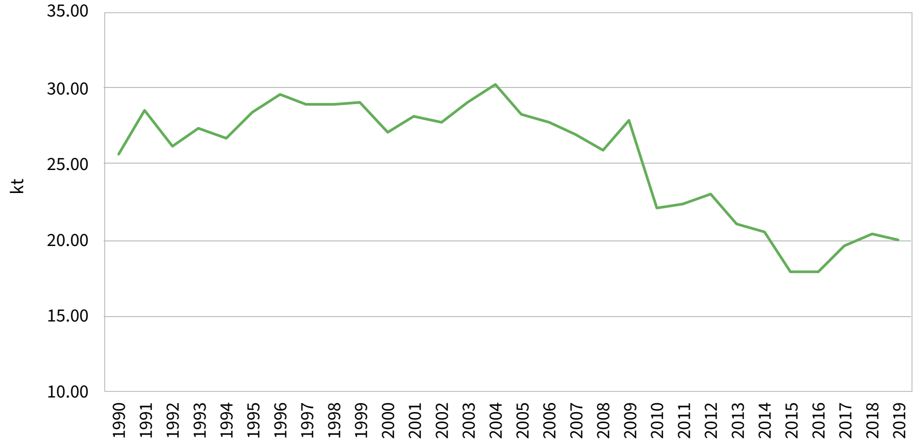
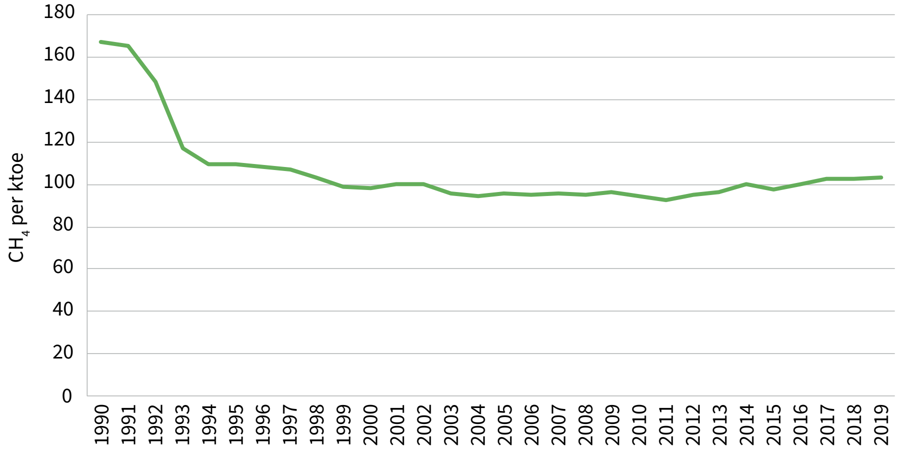


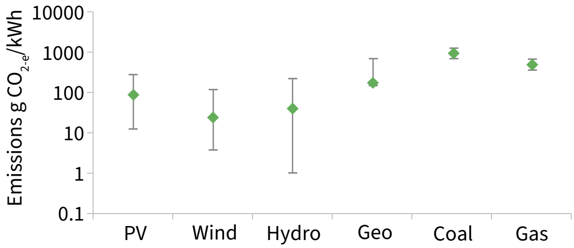
Figure 9. CH_4 from energy per kto, 1990–2019[20]



19 VSIA "Latvijas Vides, ģeoloģijas un meteoroloģijas centrs" (2022). 2021. gadā iesniegtās gaisa piesārņojošo vielu inventarizācijas kopsavilkums. Available: https://videscentrs.lvgmc.lv/lapas/gaisa-piesarnojums

20 Kumar, M. (2020, January 21). Social, Economic, and Environmental Impacts of Renewable Energy Resources. In: Okedu, K. E., Tahour, A., Aissaou, A. G. (eds). *Wind Solar Hybrid Renewable Energy System*. Available: https://www.intechopen.com/chapters/70874

Figure 10. **CO_2 life cycle emission 1 kWh energy**[21]



Latvia are energy and heat production (13.6%) and fuel use in industry (11.4%). Emissions from these sectors have risen since 2005 mainly due to the increased use of biomass.

Although renewable energy technologies do not produce direct emissions during energy production, the production, transport and installation of these technologies also produce GHG emissions. Of course, they are still 70–95% lower than with existing fossil-based technologies. Life cycle impacts are directly linked to both the production technology used and the location. Various studies have analysed the total life cycle emissions for different types of RES. Some of these can be seen in the figure below:

One of the reasons why different types of RES emit so much CO_2 is precisely their efficiency, i.e., how much of the basic renewable energy resource they can convert into useful energy (see Table 1).

For each type of RES technology, it is also important to look at the impact on flora and fauna, the impact on human well-being, the amount of land used, etc. For instance, a high concentration of wind or solar farms can create barriers for species movement, habitat fragmentation and cause disturbance or even loss of wildlife. In addition, RES technologies can cause noise pollution and have a bad impact on cultural heritage. However, many environmental and human well-being problems can be solved or minimized by regulative project implementation criteria, as well as by smart project planning and design in the early stage of the RES projects by conducting deep analysis, including identification of site alternatives, design

21 Kumar, M. (2020, January 21). Social, Economic, and Environmental Impacts of Renewable Energy Resources. In: K. E. Okedu, A. Tahour, A. G. Aissaou (eds.) *Wind Solar Hybrid Renewable Energy System*. Available: https://www.intechopen.com/chapters/70874

Table 1. Efficiency of different electricity generation technologies

Technique	Efficiency
Photovoltaic	4–22 %
Wind	24–54 %
Hydro	> 90 %
Geothermal	10–20 %
Coal	32–45 %
Gas	45–53 %

modifications and continual evaluation and improvement.[22] Nevertheless, it is always important to compare this with the impact of fossil fuels or nuclear power. Climate change is already a human problem today and there is an urgent need to decouple emissions from economic growth and increased energy consumption.[23] Emissions can be reduced by replacing dirty fuels with cleaner ones, focusing development on cleaner industries, reducing consumption of polluting products and adopting cleaner technologies. Behavioural and lifestyle changes are also important.

Both the sources of air pollution and the severity of exposure vary across countries and borders. It is therefore important to tailor policies to specific local circumstances. For example, stricter measures are needed in densely populated areas or for emission sources located upwind of urban areas. Such spatially heterogeneous policies help to achieve environmental objectives at a lower cost than measures applied uniformly to sources in all locations and to populations at all risk levels.

22 Bennun, L., Van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy. Available: https://portals.iucn.org/library/sites/library/files/documents/2021-004-En.pdf

23 Rahman, A., Farrok, O., Haque, Md M. (2022). Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic. *Renewable and Sustainable Energy Reviews, 161*, Article 112279.

Conclusion

The conducted research allows to evaluate the execution and development stage of the three sections of the WEC's Trillema Index environmental sustainability pillar.

The resource productivity section of the environmental sustainability pillar of Latvia is performing successfully due to gradually improving energy intensity ratio, high efficiency of power generation and between the EU's average electricity power transmission and distribution losses. Meanwhile, the share of low-carbon electricity generation in Latvia is based on historical installed capacities. The development level of new capacities from renewable energy sources is low, which is the main weakness of the decarbonisation section. Turning to the section of emissions and pollution, the authors came to the conclusion that the total amount of emissions from the fossil fuel combustion-related sectors in Latvia has decreased significantly, however, there are sectors, for instance, transport sectors, where the emissions continue to grow. To improve the situation in the sections considered above, a complex solution is needed: a revision of sectoral policies – definition of not only aims, but also of precise actions, terms and financial, managerial, scientific support, a prioritization and support mechanisms for promoting the energy production from renewable energy sources, infrastructure adjustments, as well as switching to more environmentally friendly vehicles.

Romāns Oļekšijs, Fēlikss Zajecs, Egons Rozenfelds

Energy equity: Story about equality

Equity common analysis

Energy Equity is important for the economical wealth of the population and business in countries. Several organizations such as United Nations (UN)[1], International Energy Agency (IEA)[2], Morgan Stanley Capital International (MSCI)[3], World Energy Council (WEC)[4] and others thoroughly investigate an issue of Energy Equity in the world and make regular analysis of it. Energy Equity is about economic impact, diversity and physical availability of energy for consumers. Energy Equity can be assumed and rated in different ways, but it always seeks the same target – to assess availability and costs of energy for end users.

In this study the story starts with WEC Energy trilemma methodology, which assesses the performance of more than 100 countries all over the world in terms of their ability to provide universal access to energy, its quality and affordability for both households and commercial enterprises. The WEC has made significant work in part of rating and comparison of different country success in the Energy Equity. The WEC Energy trilemma index represents how good a particular country is compared to the rest of the world. Thus, it is difficult to see how a particular country is progressing or regressing as it is a comparison to the rest of the countries in the rank.

The WEC methodology focuses on Energy Security, Environmental Sustainability and Energy Equity. Each country's overall WEC index ranking is

1 United Nations (2022). SDG indicators. Available: https://unstats.un.org/sdgs/report/2019/goal-07/

2 International Energy Agency (2022). IEA energy access. Available: https://www.iea.org/topics/energy-access

3 MSCI (2022). Equity index methodology. Available: https://www.msci.com/index-methodology

4 World Energy Council (2022). Energy trilemma index. Available: https://trilemma.worldenergy.org/

based on the calculation of 31 underlying indicators. For Energy Equity the top metrics with the highest weights are access to electricity, access to clean cooking and access to modern energy. Also, the Energy Equity index evaluates the prices of electricity, natural gas, gasoline and diesel fuel, as well as the availability of electricity for residents and enterprises. The WEC methodology uses various data sets usually provided by global organizations and does not reflect the situation in real time since the statistics available are usually 1–2 years old.

According to the WEC methodology, Latvia ranks 20th overall, which is quite a high ranking for such a small country without any local fossil fuels. Despite the fact that the main indicators of the Energy Equity of Latvia according to the WEC methodology are high, i.e., electricity Latvia has been 100% technically available for several decades; about 94–96%[5] of the population of Latvia have the opportunity to cook using clean energy and technologies; the affordability of electricity prices for the population in Latvia is rated the highest – Latvia ranks only 44th place in the WEC Energy Equity rating. This means that fuel and electricity prices downgrade Latvia's rating compared to the rest of more than 100 countries.

Since the WEC methodology covers a huge number of countries, it is necessary to use common and available data for all countries within the rank, which will allow for a global comparison. However, analysing the performance of one particular country is a challenge. Appropriate parameters are needed to take into account the uniqueness of each country, so local WEC organizations are starting to propose energy indexes and analysis of the Energy trilemma analysis at the national level so they can conduct a deeper analysis to understand weakness or strengths of municipalities within the country and country as whole, which later could be used to improve policies and development strategies in a particular country.

To develop a new model for analysing local energy trilemma, various sources of information and databases should be scrutinized, taking into account the experience of other Energy Equity methodologies. The aim of this research is to develop indicators that would allow us to analyse the situation in Latvia or other countries with similar climatic conditions, population or gross domestic product (GDP). For example, new indicators should take into account the aspect of heating, which is important in Northern Europe and is not covered in the WEC methodology. It is expected that the proposed analysis and rating model will identify the opportunities to improve the Energy Equity in Latvia, as it indicates processes within Latvia, rather than processes in Latvia compared to processes in the rest of Europe or even the world.

5 Our World in Data. Available: https://ourworldindata.org/

1. The way we see the energy equity

Existing equity assessment methodologies are global and do not take into account local peculiarities, which may be a key to improvement of a country's energy performance. The methodology is introduced by the authors for the analysis of Energy Equity analysis in Latvia or another similar county, where there is only one common market for electricity, gas and other fuel without regional markets, but there are several district heating centres representing different cities across the county. Such countries can also be characterized by relatively low density of population, production and manufacturing capacities. It is proposed to make a deeper dive at the local level and look at the economic impact on the local society. The research focuses primarily on household consumers, but some indicators also can show effect on business. The methodology was developed as a result of research in the field of Energy Equity and analysis of various sources of statistics and data sets. It uses indicators listed in Table 1, which are analysed and discussed further in the work. Required data for proposed indicators is shown in Table 2.

Two types of indicators are proposed. The main indicators can be ranked using scores and are meant to show the real impact on Energy Equity, whereas additional indicators allow us to better understand the trend and the reasons behind changes in the main indicators. Additional indicators do not have a scoring scale as they are more difficult to evaluate.

Table 1. Proposed indicators

Sector	Main indicator	Additional indicator
Electricity	1.a. Average share of household spendings on electricity compared to average household income	1.b. Percentage of the cost of electricity in the end user tariff
Heating	2.a. Average share of household spendings on district heating compared to average household income by regions	2.b. Heating tariff by regions
Fuels	3.a. Average share of household spendings on fuel compared to average household income	3.b. Fuel average price and brent average price trend comparison
Physical availability	4.a. The average power rating of installed microgenerators	4.b. Number of newly connected microgenerators to the grid per year and average PV kW price in EU
Transport electrification	5.a. Number of electric vehicles per one public electric vehicle charger	5.b. EV charger usage rate

Table 2. Required data for proposed indicators

Sector	Indicator	Required data for analysis
Electricity	1.a.	Average electricity consumption by income level group, average end-user electricity price by consumption level and average income per income group.
	1.b.	Average electricity spot price per period and average end-user electricity price by consumption level
Heating	2.a.	Average heating energy consumption by income level group which use district heating, average end-user district heating tariff and average income per income group.
	2.b.	District heating tariff by region/city
Fuels	3.a.	Average fuel consumption by income level group which use private transport, average end-user fuel price and average income per income group.
	3.b.	Average end-user fuel price and BRENT oil barrel price.
Physical availability	4.a.	Number of newly connected microgenerators to the grid and total installed power of mentioned microgenerators.
	4.b.	Number of newly connected microgenerators to the grid per year
Transport electrification	5.a.	Number of total installed EV chargers and number of total registered EVs.
	5.b.	Total installed power of EV chargers and total charged electric energy

1.1. Electricity and heating energy.

For electricity (1.a. indicator) and heating energy (2.a. indicator) the main indicators are the share of spendings compared to income of households. Neither the Central Statistical Bureau (CSB)[6] of via, nor Eurostat[7] collect energy consumption statistics of households by income groups in the country. In the proposed methodology, the following equations are used for analysis:

$$\frac{E_{\%} = c_{avg.el.} \cdot A_{avg.el.} \cdot 100}{I_{avg.el.}} \quad [1]$$

6 Central Statistical Bureau of Latvia (2022). Available: https://stat.gov.lv/en

7 Eurostat (2022). Available: https://ec.europa.eu/eurostat

where $E_{\%}$ – share of household spendings on electricity compared to average household income, %;
$C_{avg.el}$ – average electricity tariff for households in determined period, EUR/kWh;
$A_{avg.el}$ – average electricity consumption by average household in determined period, kWh/period;
$I_{avg.LV}$ – household average income in Latvia per determined period, EUR/period.

$$H_{\%} = \frac{C_{avg.ht} \cdot A_{avg.ht}}{I_{avg.LV}} \cdot 100 \quad [2]$$

where $H_{\%}$ – share of household spendings on district heating energy compared to average household income; applies only for district heating users;
$C_{avg.ht}$ – district heating tariff for households, EUR/kWh;
$A_{avg.ht}$ – average district heating consumption by the average household (connected to district heating) per country or per region in determined period, kWh/period;
$I_{avg.LV}$ – household average income in certain district area region or in whole country per determined period (depends on aim of the research), EUR/period.

In equation [2] district heating energy can be assumed by regions, only the tariff and average income need to be adjusted accordingly. Electricity tariffs, district heating tariffs and household incomes are estimated in any country and can show the real energy cost pressure on households. Also, a ranking system can be used, which is described further below and demonstrated in the case study.

Additional indicator – percentage of the cost of electricity in the end user tariff (1.b. indicator), could be used both for households and enterprises, it is calculated by [3]. For enterprises, this may not be a representative indicator, since in an open market different customers may receive different price offers from electricity suppliers. This indicator shows how much of the end-user electricity tariff corresponds to the electricity price and how much corresponds to transmission costs, distribution tariff, taxes and various additional components.

$$C_{el.\%} = \frac{100 \cdot C_{spot}}{C_{el}} \quad [3]$$

where $C_{el.\%}$ – percentage of spot electricity price in end tariff, %;
C_{spot} – electricity average spot market price during period under the scope, EUR/kWh;
C_{el} – end user electricity tariff during period under the scope, EUR/kWh.

The additional indicator for district heating is also based on tariffs (2.b. indicator) and should only be analysed regionally as the comparison between different regions is not representative as there are different parameters of the district heating system.

1.1. Fuels

The income of households using private cars and other private transports running on combustible fuels is not reflected in statistics. Authors propose to use as an indicator the average share of household spendings on fuel compared to average household income (3.a. indicator), since there are statistical data on fuel consumption by all households. This indicator is influenced by a number of factors such as total number of cars, efficiency of car engines, overall travel distance per year and others. The idea behind this indicator is to look for a general tendency and compare it to both average mileage per car and average fuel costs to understand why the indicator is increasing or decreasing. To make a calculation of the indicator (4) the following equation is used:

$$F_{\%} = \frac{C_d \cdot l_d + C_{95} \cdot l_{95}}{I_{avg.LV}} \cdot 100 \qquad [4]$$

where $F_{\%}$ – share of household spendings on fuels compared to average household income;

C_d and C_{95} – average diesel and 95 gasoline prices per litre per determined period, EUR/l;

l_d and l_{95} – average diesel and 95 gasoline consumption per determined period, l;

$I_{avg.LV}$ – household average income in Latvia per determined period, EUR/period.

Additional indicator is based on trends which are formed from fuel price statistics and BRENT oil barrel value (3.b. indicator). Average values per determined period are taken to see the general trend. The situation becomes more complicated, if fuel prices do not follow BRENT oil prices, it might be a signal of unfair market or logistics problems. The example is shown in case study.

1.2. Physical availability

As it was mentioned previously electricity is available for 100% of the inhabitants of Latvia. The world is evolving and the ability to connect distributed microgeneration to the electricity grid is essential as more people are interested in locally produced clean energy. It is proposed to analyse the average power of microgenerators connected to the grid (4.a. indicator), which shows the ability of the grid to submit new generating capacities. An additional indicator is the total number of microgenerator installations (4.b. indicator), it shows interest of grid users to install their own microgeneration. Such interest can be high when electricity prices are growing, technology prices are falling, or if the government introduces support mechanisms.

1.3. Transport electrification

In upcoming years, electrification of the transport sector will have the biggest impact on electrification as more and more companies introduce new electric vehicles (EVs). The heating sector is also one of the drivers of electrification, but there are currently no stable trends. To assess the suitability of the infrastructure for the transition to electric vehicles, it is proposed to estimate the number of electric vehicles per one public electric vehicle charger (5.a. indicator), and an additional indicator is the rate of use of EVs public chargers (5.b. indicator). It is hard to imagine a wider use of electric vehicles in the absence of infrastructure, on the other hand, an excessive number of chargers has no commercial justification. The recommendation of Alternative Fuels Infrastructure Directive (AFID)[8] is 10 EV's per one public charger.

1.4. Evaluation approach

For indicators 1.a., 2.a., 3.a. the highest score is given to the year or month with least impact on household income, the lower the share of spendings on energy resources is – the better it is. For indicator 4.a. the situation is opposite, the greater the average power of the microgenerators connected to the network, the better it is, so the highest average value corresponds to the highest score. For indicator 5.a. a scoring system is not used, as it is better to fit the target value. The suggested best score is 100, so if the situation improves in the future this score could be higher than 100.

Additional indicators 1.b., 2.b., 3.b., 4.b. and 5.b. are represented in numerical values, these indicators allow a better understanding of the main indicators and general trends.

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8 Alternative Fuels Infrastructure Directive (2014). Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0094

2. Statistics story about Energy Equity in Latvia

2.1. Electricity and heating energy

The proposed methodology has been applied to the statistics available for Latvia. Data for 1.b. indicator is shown in Fig. 1. shows that the share of electricity cost in the end-user price for households with different levels of consumption during 2012–2020 tends to decrease over the years, this means that electricity in the spot market is getting cheaper or that end-user price includes a high cost of distribution tariffs, taxes and other additional payments. No general statement can be made, which also means that a scoring system for such parameters cannot be applied. In turn, the data in Table 3 shows that the economic impact of electricity costs has changed over the years, with historical data showing the lowest impact in 2020. It can be concluded that electricity tariffs are adequate and do not increase spendings on electricity relative to the average household income.

The availability of data on district heating indicators varies from region to region, and only in the last few years has general data been published for each major Latvian city with district heating. The CSB conducts a survey of the number of households connected to district heating networks once every 5 years, Eurostat does not collect such data at all. Therefore, it is assumed that there are no significant changes for years between the years being estimated.

Since district heating tariffs in 2020 were lower than in 2019, this resulted in lower household heat expenditures, as well as a higher score under the proposed methodology, as household incomes rise steadily over the allotted period (2015 to 20202). As in the case of electricity, the highest score was obtained in 2020, which is the basis for the following results. We see that historically the highest district heating costs were in Daugavpils, reaching 5.56% of the total annual income of an average household in Latgale. In 2020, the city of Liepaja had the worst result, as the tariff was stable there, while in other regions it decreased. Use of both indicators allows us to understand why district heating tariffs affect equity, as we see the relationship between tariff and costs, i.e., spending on district heating compared to average household income by region may decrease if household income rises or tariffs decrease. If better energy efficiency measures are taken, we will see lower spendings on district heating at the same tariff and income levels.

Table 3. Indicator 1.a. score based on historical data

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
Average share of household spendings on electricity compared to average household income, %	3.18	2.92	2.56	2.88	2.85	2.29	2.02	1.94	1.68
Score	52.65	57.35	65.42	58.27	58.82	73.05	82.94	86.58	100.00

Figure 1. Indicator 1.b. results based on historical data (data is provided for each semester, marked on graph as S1 and S2)

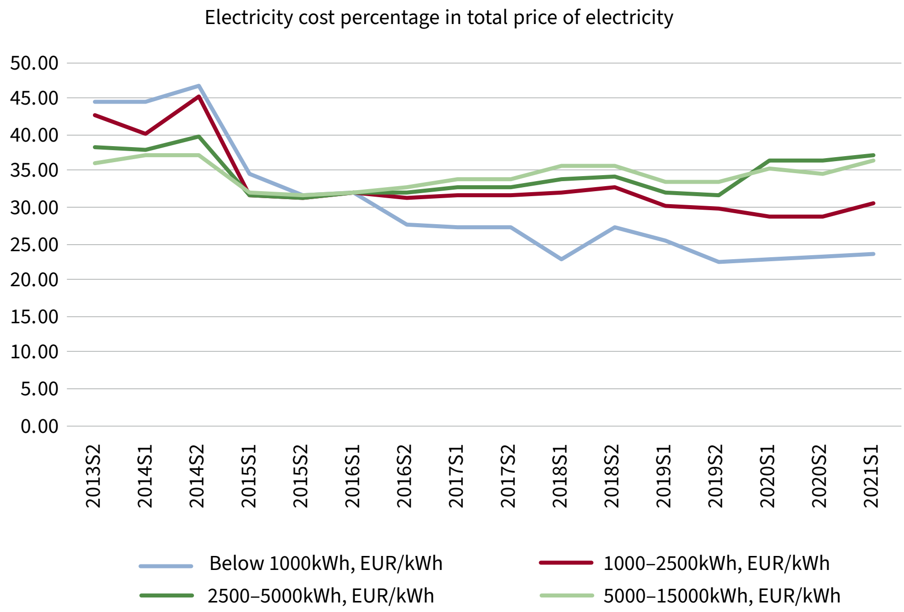
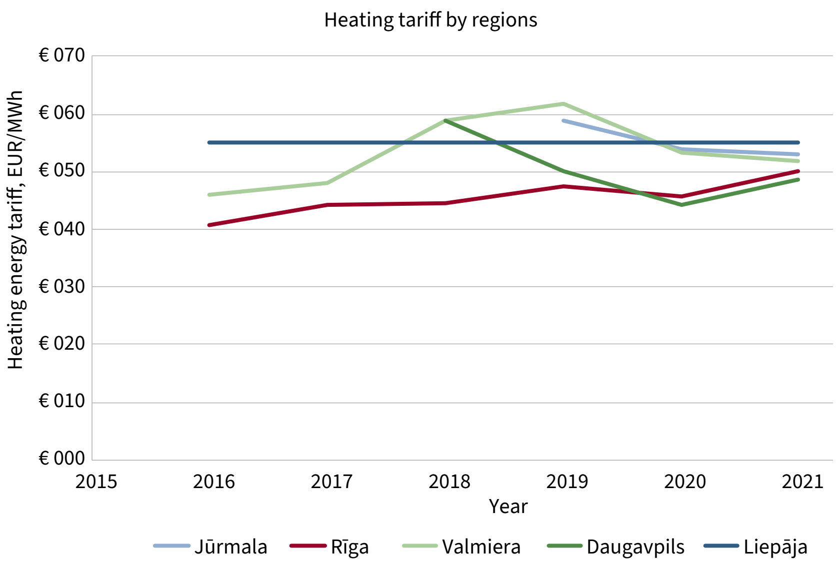


Table 4. **Indicator 2.a. score based on historical data**

Average share of household spendings on district heating compared to average household income by regions, %						
Region/year	2015	2016	2017	2018	2019	2020
Jūrmala	0.00	0.00	0.00	0.00	2.74	2.08
Riga	2.69	2.91	3.01	2.74	2.77	2.05
Valmiera	3.91	4.28	4.08	4.81	4.20	3.11
Daugavpils	0.00	0.00	0.00	5.56	4.22	3.13
Liepāja	4.07	4.54	4.19	3.99	3.74	3.23
Score						
Jūrmala					74.65	98.39
Riga	76.20	70.21	68.10	74.57	73.85	100.00
Valmiera	52.28	47.81	50.20	42.58	48.76	65.80
Daugavpils				36.82	48.46	65.39
Liepāja	50.27	45.09	48.79	51.36	54.73	63.45

Figure 2. **Heating energy tariffs in Latvia by regions**



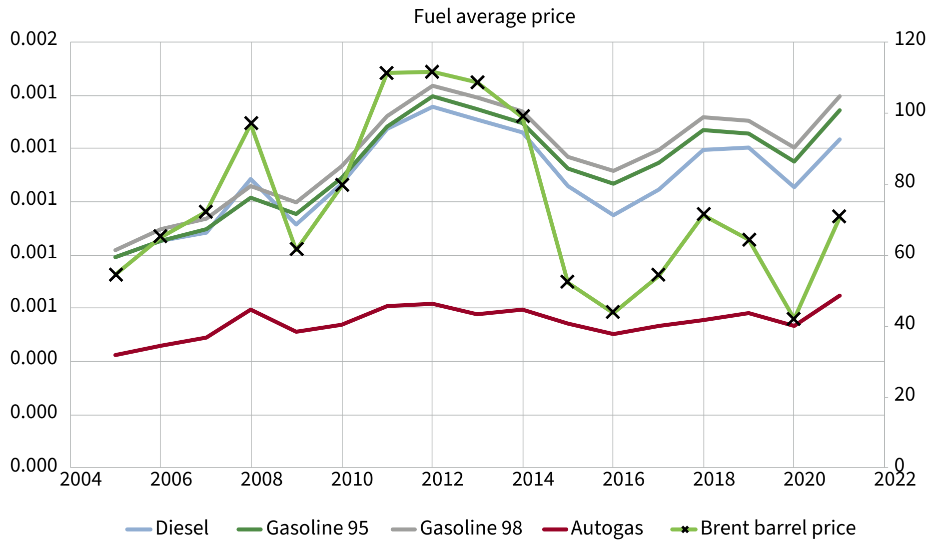
2.2. Fuels

Our study results show that fuel has a much smaller impact on average household spending compared to heating and electricity. It should be noted that due to the lack of statistics, average household fuel consumption was calculated for all households in Latvia, and not only for those which own cars. The results for indicator 3.a. are presented in Table 5. Indicator 3.b. may be more interesting, as it shows the trend of fuel prices in Latvia and the price of a barrel of BRENT oil, the greater the difference between both trends, the more additional fuel costs may appear, so this may be related to the country's environmental goals. The problem appears, if additional taxes have not been applied, but the indicated difference increases. This may indicate a shortage of supply or cartel activity in the market.

Table 5. Indicator 3.a. score based on historical data

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
The average household share of fuel costs comparing to average household income, %	0.45	0.40	0.35	0.27	0.26	0.28	0.32	0.29	0.24
Score	53.28	59.90	68.45	86.94	90.71	84.21	74.50	81.46	100.00

Figure 3. Fuel price and barrel of BRENT oil price graphical comparison for indicator 3.b.



2.2. Physical availability

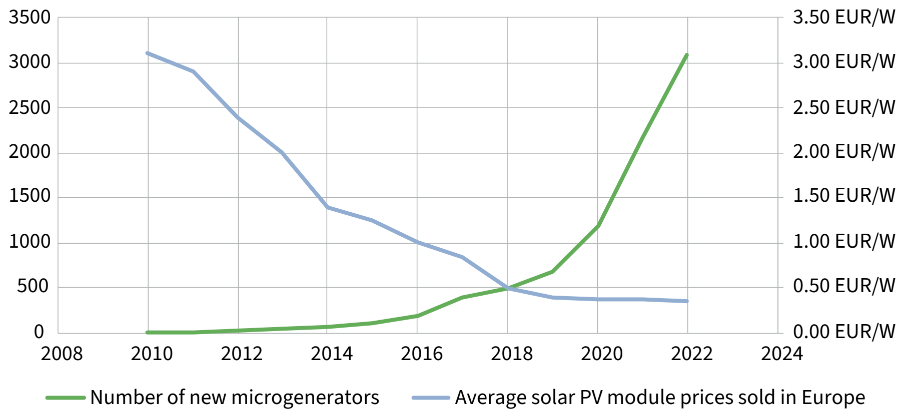
Available statistics show that average installed power of microgenerators is growing year on year with some exceptions, thus, more reliable data is gained starting from 2018 when significant growth of microgeneration installation started in Latvia. Using both 4.a. and 4.b. indicators we can see that more and more microgenerators are installed and the average power also grows.

Table 6. **Indicator 4.a. score based on historical data**

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
The average power rating of installed microgenerators, kW	5.19	4.72	5.90	5.67	6.14	6.66	5.92	6.19	6.37	7.06
Score	73.54	66.80	83.51	80.29	86.90	94.32	83.78	87.60	90.26	100.00

The growth in microgeneration capacity (as seen in Figure 4 below) has kept pace with the reduction in the cost of the technology, making it an economically viable solution. This trend has allowed more people to access private energy sources, indicating an improvement in the Energy Equity.

Figure 4. **Indicator 4.b. results based on historical data and compared to average PV module prices in Europe**



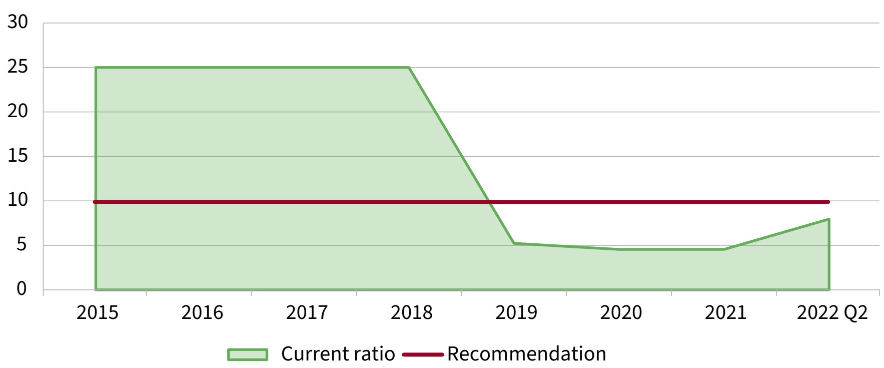
2.3. Transport electrification

There is currently a lack of relevant statistical data for Latvia, especially for indicators 5.b. Results for indicators 5.a. are shown in Fig. 5. Results below target line (the red one in Fig. 5) mean that the EV charging network is developing faster and that EVs are emerging in the country/region. If the indicator rises above the target line, it means that there are not enough EV charge points, so it is more important for this indicator to reach the target value.

The indicator 5.b. represents the percentage of time the chargers are used; a higher percentage indicates a high demand, and in some cases may indicate a lack of EV chargers. If this indicator falls, it indicates inappropriate location of installed EV chargers or too many chargers compared to EVs using public chargers. This indicator might also be used to understand if charging power is sufficient to provide the required charging speed. In 2021, the first data were collected on the consumption of electricity by EVs chargers, which provide data for indicators 5.b. The results of the study show that the percentage of use of chargers in Latvia in 2021 is 1.01%. For Latvia, the first data is available for 2021 and it still has some gaps, average usage rate of public EV chargers is 1.01% of total time.

The results of the case study provide an insight into the Energy Equity situation in Latvia. Average spending on energy sources for average household varies between 4.5–6% with some exceptions. The obtained results characterize the average household in Latvia. When compared across regions, it can be concluded that the percentage of energy expenditure may be higher for some regions compared to the average income in the region, the same is true for households with different income levels. This means that the national averages

Figure 5. Indicator 5.a. results for Latvia starting with 2015



can be quite low, which is good, while for some households paying their electricity and heat bills becomes a real problem, which definitely points to problems with the Energy Equity. For this reason, it is necessary to collect more statistics on the consumption of electricity, heat and fuel, depending on the level of household income. Such an approach could make it possible to study not only general Energy Equity in a country, but also equality. A high level of Energy Equity can only be claimed if high equality is reached.

Conclusion. What can be learned and where to move?

The proposed indicators make it possible to determine Energy Capital within a country or between regions if specific data can be provided for each region, as has been demonstrated for thermal energy in Latvia. The proposed indicators can be used as an additional tool to the WEC methodology to understand the country's progress compared to the previous period.

The main problem is data availability. Authors suggest the type of data for each indicator, for some of which statistics should be collected specifically. For the case study, only officially available data were used, however, they provide a good idea of the processes and changes from year to year, provide a realistic view of the pressure of the energy sector on the average household income, and demonstrate the possibilities of the proposed methodology.

A deeper dive study can be done on the average share of household spendings on electricity compared to average household income, average share of household spendings on district heating compared to average household income by regions and average share of household spendings on fuel compared to average household income indicators, if consumption data are collected by income groups. On the example of district heating, the inequality between regions is indicated. Similar inequalities may emerge if an analysis of different income groups is carried out, this approach will lead to more targeted support mechanisms to increase the country's Energy Equity. The proposed methodology demonstrates the direction in which a country is moving in Energy Equity, and does not simply show comparison with other countries or comparison of region with region. Additional indicators have been introduced to provide a better understanding of key indicators and trends, but do not affect the Energy Equity score.

Indicators of average power rating of installed microgenerators, number of newly connected microgenerators to the grid per year and average PV kW price in EU, number of electric vehicles per one public electric vehicle charger and EV charger usage rate show the real directions of technical development Energy Equity for countries that have already reached the level of 100% electricity technical availability and have a rating of more than 95% access to clean cooking technologies. The proposed technology-focused indicators show the development of microgeneration and electrification in the transport sector as they become increasingly important drivers and indicators of progress that will affect the energy sector in the coming decades. Moving closer to achievement of ESG goals, it is critical to ensure that these technologies are available and accessible to progress towards Energy Equity.

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Life cycle assessment of renewable energy sources towards climate neutrality – Portuguese case study

The global climate emergency has accelerated the energy transition in a worldwide and multilateral effort to mitigate the harmful effects of accentuated anthropogenic use of natural resources. In the Portuguese case, the energy sector represents around 70%[1] of greenhouse gas (GHG) emissions, with its decarbonisation being very relevant and achieved through renewable sources.

The Portuguese Government has been consolidating, at the legislative level, a comprehensive set of public policies oriented toward a strategy of increasing the decarbonisation of the economy, ensuring the penetration of renewable origin or low carbon emissions technologies, underpinning electrification on photovoltaic solar, onshore and offshore wind, hydro and some concentrated solar thermal plants.[2]

National Energy and Climate Plan 2030 (PNEC 2030) is the major national energy and climate policy instrument up to 2030, along with the Roadmap for Carbon Neutrality 2050. Its implementation will allow Portugal to undertake the energy transition, reducing its GHG emissions.[3]

For the goals of the 2030 agenda to be achieved at a global level, a fundamental change in the practices used for resource management must occur. A coordinated strategy is mandatory, within which countries share information and align industrial and trade policies with the Sustainable Development Goals (SDGs).

1 Observatório da Energia, DGEG (2020). Direção Geral de Energia e Geologia, and ADENE – Agência para a Energia. Energia em Números. Edição 2020, Lisboa.

2 Presidência do Conselho de Ministros (2020). Plano Nacional Energia e Clima 2030 (PNEC 2030). Resolução do Conselho de Ministros n.º 53/2020, *Diário da República*, Série I., Vol. 133, pp. 2–158.

3 Ministério do Planeamento (2021). Plano de Recuperação e Resiliência – Recuperar Portugal, Construindo o futuro, Lisboa, Apr.

The financial system should adopt global well-being as its first responsibility and be governed by the "Equator Principles", which include the analysis of environmental and social risks and responsible management.

The paradigm changes in the national energy sector, embodied in the goals of PNEC 2030, entails challenges of economic and operational nature for the several actors involved, which will require an effort by society to ensure the reduction of GHGs between 45% and 55% by 2030 (compared to 2005) and the incorporation of 47% of energy from renewable sources in the gross final energy consumption.

Despite the renewable concept of the new production plants, their impact on the environment is not negligible. This study shows the importance of carrying out a Life Cycle Assessment (LCA) for each technology included in the national investment plan. In this sense, the LCA methodology measures the environmental performance of the main renewable origin technologies recommended in PNEC to leverage the Portuguese energy sector's independence and carbon neutrality. Based on the roadmap for energy mix goals for 2030, the major environmental impacts and benefits of onshore wind, solar photovoltaic, concentrated solar and hydroelectric technologies are quantified in the categories of impact on global warming, use of fossil fuels and mineral resources, use of soil and water consumption.

Although viable strategies for mitigating some of the impacts already exist, such as a symbiosis between agricultural activity and the implementation of photovoltaic power plants, quantifying these mitigation strategies' impact is outside this study's scope. Thus, strategies such as the recovery of waste, circular economy or others that allow the minimization of these impacts were not evaluated.

The LCA allows identifying the potential consequences of the strategy outlined for 2030, making it possible to include this data in future decision-making process on pollution prevention and optimising resource use for the 2050 horizon.

1. Methodology

LCA, standardized by ISO 14040 and 14044, is a methodology which allows quantifying potential environmental impacts of systems (product, process, services, etc.) throughout their life cycle or part of it.[4] In this study, first, the environmental performance of onshore wind, solar photovoltaic, concentrated solar and hydroelectric technologies is analysed and compared to natural gas in the combined cycle gas technology (CCGT), which corresponds to the reference scenario to produce

4 Rebitzer, G., et al. (2004). Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment International, 30*(5), 701–720. https://doi.org/10.1016/j.envint.2003.11.005

1 MWh of electricity. Then, the impacts considering renewable sources installations recommended in PNEC 2030 are evaluated[5] and compared to the 2020 energy mix (Table 2).

1.1. Impact analysis

The environmental impact categories under analysis are listed in Table 1. In addition to the calculation units for each category, the way in which environmental impacts are quantified in the life cycle is also presented. The impacts have been disaggregated by phase – Construction, Operation and Decommissioning – or total lifecycle impact.

Table 1. Impact categories

Impact category	Unit	Life cycle
Global warming	kg $CO_{2\,eq.}$	By life cycle phase (construction, operation, decommissioning)*
Use of fossil resources	kg $oil_{eq.}$	
Use of mineral resources	kg $Cu_{eq.}$	
Use of the soil	$m^2 \times_{eq.}$ year agricultural soil	Life cycle total[2]
Water consumption	$m^3{}_{eq.}$ water consumed	

* Except for the mineral resource use category of the Concentrated Solar technology
** The decommissioning phase is not considered in natural gas technology

The environmental impacts quantification has been carried out considering the following studies.

1) Kabayo et al.[6]

This study is contextualized for the national scenario. It quantifies the impacts for various technologies and stages: production, construction, and dismantling phases, except for solar concentrated technology. Land use and water consumption are not considered in this study.

5 Presidência do Conselho de Ministros (2020). Plano Nacional Energia e Clima 2030 (PNEC 2030). Resolução do Conselho de Ministros No. 53/2020, *Diário da Répúblic*a, Série I, Vol. 133, pp. 2–158.

6 Kabayo, J., Marques, P., Garcia, R., and Freire, F. (2019). Life-cycle sustainability assessment of key electricity generation systems in Portugal. *Energy, 176*, 131–142. https://doi.org/10.1016/j.energy.2019.03.166

2) Heath e Turchi.[7]

In this study, the solar concentrated technology is addressed, excluding land use, water consumption and mineral resources.

3) Šerešová et al.[8]

The breakdown of impacts in the construction and decommissioning phases of the study by Kabayo et al. is done through this article, where the impacts in these life cycle stages of the technologies under analysis are presented, but for the Czech Republic's context. Thus, the same proportions of impacts are assumed throughout the life cycle phases and extrapolated to the total in Kabayo et al.

4) Ecoinvent, ReCiPe, SimaPro.[9]

For the identified limitations the impacts of the various technologies on land use and water consumption, the ecoinvent database, delimited for the national context, the ReCiPe method, and the SimaPro software were used.

1.2. Reference scenario

The reference scenario was characterized by the energy mix of 2020. However, this study did not consider coal, since the last coal-fired plant to operate in Portugal was decommissioned in 2021.

This study does not consider neither the contribution of imported electricity, nor the impact of its production sources. To estimate the impacts of the energy mix recommended in PNEC 2030, the power and generation corresponding to 2020 were used and linearly extrapolated to the expected capacity to be installed by 2030. According to data published by the General Directorate of Energy and Geology[10], the 2020 energy mix had the following values:

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7 Burkhardt, J. J., Heath, G. A., and Turchi, C. S. (2011). Life cycle assessment of a parabolic trough concentrating solar power plant and the impacts of key design alternatives. *Environmental Science & Technology, 45*(6), 2457–2464. https://doi.org/10.1021/es1033266; Whitaker, M. B., Heath, G. A., Burkhardt, J. J., and Turchi, C. S. (2013). Life cycle assessment of a power tower concentrating solar plant and the impacts of key design alternatives. *Environmental Science & Technology, 47*(11), 5896–5903. https://doi.org/10.1021/es400821x

8 Šerešová, M., Štefanica, J., Vitvarová, M., Zakuciová, K., Wolf, P., and Kočí, V. (2020). Life cycle performance of various energy sources used in the Czech Republic. *Energies, 13*(21). https://doi.org/10.3390/en13215833

9 Moreno Ruiz, E. et al. (2020). Documentation of changes implemented in ecoinvent. Available: https://ecoinvent.org/wp-content/uploads/2021/01/change-report_v3-7-1_20201217.pdf.

10 Direção-Geral de Energia e Geologia (2020). Produção anual e potência instalada; Direção-Geral de Energia e Geologia (2021). Potência Instalada nas Centrais Produtoras de Energia Elétrica (1995–2020); Direção-Geral de Energia e Geologia (2021). Produção de Energia Elétrica a partir de FER (1995–2020).

Table 2. **Energy mix in 2020**

Technology	MW	GWh
Natural gas	5021	17599
Hydropower	7129	13633
Wind	5502	12299
Photovoltaic	1076	1691
Concentrated Solar	0	0

Table 3. **Energy mix forecast to 2030**

Technology	MW	GWh
Natural gas	3800	13319
Hydropower	8200	15681
Wind	9000	20118
Photovoltaic	9000	14144
Concentrated Solar[11]	300	696

Assuming a linear extrapolation for the installed power in PNEC 2030, considering the production values of 2020, the values presented in Table 3 were obtained. The capacity factor of the solar thermal production plant in Almeria (Spain) was considered to estimate the expected production for the 300 MW recommended in PNEC 2030.[12]

2. Results

This section analyses the LCA results applied to the several electricity production technologies, considering the defined impacts, first presented with normalization by the total MWh along the life cycle of each technology and later extrapolated to the expected MWh produced in the 2030 energy mix.

11 Direção-Geral de Energia e Geologia (2020). Produção anual e potência instalada; Direção-Geral de Energia e Geologia (2021). Potência Instalada nas Centrais Produtoras de Energia Elétrica (1995–2020); Direção-Geral de Energia e Geologia (2021). Produção de Energia Elétrica a partir de FER (1995–2020).

12 Gómez-Calvet, R., and Martínez-Duart, J. M. (2019, April). On the Assessment of the 2030 Power Sector Transition in Spain. *Energies, 12*(7), 1369. https://doi.org/10.3390/en12071369

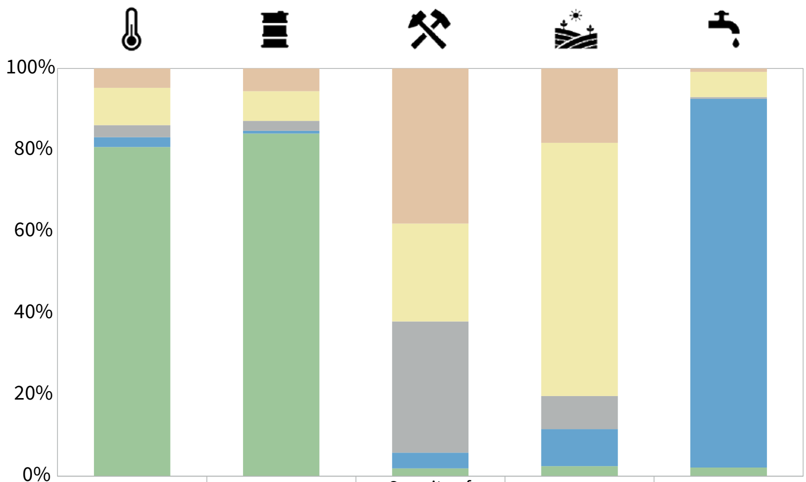
2.1. Overall impacts

The assessment of the relative total impacts throughout the life cycle of each technology allows an overview of their impact in each category, which are presented in Figure 1.

Since it was not possible to disaggregate the impacts of land use and water consumption by the three life cycle phases (Construction, Operation and Decommissioning), these indicators were not analysed in the following subsections.

In Figure 1, solar photovoltaic technology shows a greater impact on arable land use (within the operation phase), corresponding to an impact of 41.2 m²/MWh. The second technology with the greatest impact on land use is concentrated solar with 12.0 m²/MWh. As mentioned previously, impact mitigation strategies such as the combination of farming activities with the installation of photovoltaic plants, which will significantly decrease the potential impact of this technology on land use, are not quantified.

Figure 1. Total impacts of the various production technologies



	Global warming potential [kg $CO_{2\,eq.}$/MWh]	Scarcity of fossil resources [$kg_{eq.}$/MWh]	Scarcity of mineral resources [kg $Cu_{eq.}$/MWh]	Land use [$m^2_{eq.}$/MWh]	Water consumption [m^3/MWh]
Concentrated solar	26.0	10.3	1.4	12.0	0.3
Solar PV	50.3	13.4	0.9	41.2	2.0
Onshore wind	16.2	4.4	1.1	5.4	0.1
Hydro	13.5	1.3	0.1	6.0	29.3
Natural gas	443.7	154.8	0.1	1.6	0.7

For water consumption, the technology with the most significant impact throughout the life cycle is hydroelectricity, far surpassing all other technologies. It is important to emphasize that hydroelectric power plants, during the operation phase, allow the conversion of waterpower potential into electrical energy, being, therefore, a use of water without contamination and not effective water consumption. Natural gas concentrated solar and onshore wind are the technologies with the most negligible impact on water consumption.

Considering the potential for global warming and consumptions of fossil resources, natural gas is the technology with the most significant impact, having into account the evaluated technologies.

In the category of use of mineral resources, among the compared technologies, concentrated solar is the one with the greatest impact, with 1.4 kg of copper equivalent per MWh produced (kg $Cu_{eq.}$/MWh), essentially due to the use of mined nitrates which are used in the thermal storage system. New CSP technologies use synthetic salts instead of mined ones, thus considerably reducing their impact.

2.2. Natural gas

Natural gas is analysed as the fossil-based baseline scenario. In Portugal, this energy vector represents a volume of energy conveyed, essentially, for electric generation in combined cycle power plants and distribution networks. Combined cycle power plants constitute a very relevant part of the dependable power capacity in the electricity production system, complementing variable renewable production (solar and wind) as well as the hydropower plants.

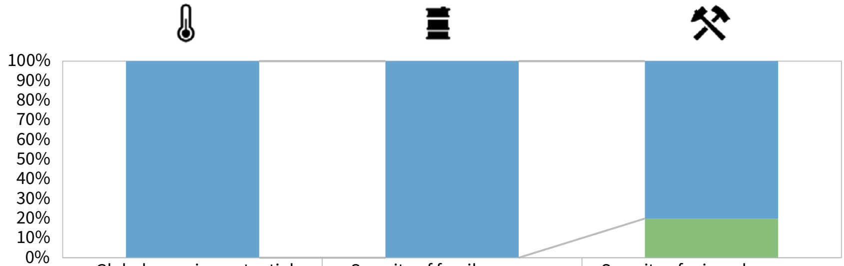
In 2020, Portugal had a gas-fired combined cycle installed capacity of 4.6 GW, responsible for 17.6 TWh of electricity generated that year.[13] It should be noted that, of the installed capacity, 3.8 GW refer to combined cycle power plants (Lares, Pego, Ribatejo and Tapada do Outeiro – Turbogás), and the remaining units are decentralized cogeneration plants by the National Gas System.

1) Impacts of each life cycle per unit of production

Analysing the weight of the impacts in the global warming potential and the use of fossil resources by life cycle phases, it is noted that the most significant phase is the operation phase – 443.4 kg $CO_{2\ eq.}$/MWh and 154.7 kg of oil equivalent per MWh produced (kgoe/MWh) – with the construction and decommissioning phases having merely residual impacts.

13 Redes Energéticas Nacionais (REN) (2021). Dados Técnicos 2020 (Eletricidade e Gás Natural). Lisboa, Jan.

Figure 2. **Natural gas technology – impacts of each life phase per MWh**



	Global warming potential [kg $CO_{2\,eq.}$/MWh]	Scarcity of fossil resources [$kg_{eq.}$/MWh]	Scarcity of mineral resources [kg $Cu_{eq.}$/MWh]
Decommission	0.0	0.0	0.0
Operation	443.4	154.7	0.1
Construction	0.3	0.1	0.0

The use of mineral resources is negligible for this technology, having only expression during the construction phase, with an impact of 0.1 kg $Cu_{eq.}$/MWh. Figure 2 shows the impacts of each life phase per MWh.

2) Extrapolation of impacts on the energy mix of 2020 and 2030

With a forecasted reduction from 5 GW to 3.8 GW between 2020 and 2030, the impact of global warming is predicted to decrease from 7.9 Mton $CO_{2\,eq.}$ to 5.9 Mton $CO_{2\,eq.}$, and the use of fossil resources will be reduced from 2.7 tons of oil equivalent (toe) to 2.0 toe. On the other hand, the impact on mineral resources will be mitigated from 1.2 kg $Cu_{eq.}$ to 0.9 kg $Cu_{eq.}$ Table 4 presents the forecast for 2030 of the total impacts of natural gas technology based on 2020.

Table 4. **Forecast of the total impacts of natural gas technology to 2030, based on 2020**

Year	Potential global warming [kton $CO_{2\,eq.}$]	Fossil resources [kgoe]	Mineral resources [ton $Cu_{eq.}$]
In 2020	7807.9	2724.6	1.2
Forecast to 2030	5909.2	2062.0	0.9

2.3. Hydropower

By the end of 2020, hydropower represented 49% of the total installed power capacity from renewable sources (7129 MW)[14], with a growth outlook of 1 GW by 2030.

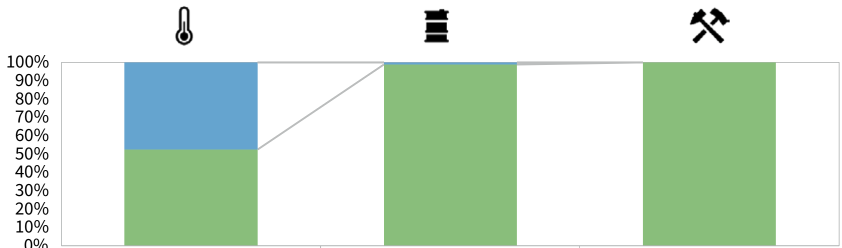
In compliance with the objectives outlined by PNEC 2030, the exploitation enhancement of the national hydroelectric capacity will be achieved through the conclusion of the Alto Tâmega hydroelectric complex, with three hydroelectric power plants: Gouvães, Alto Tâmega and Daivões.

This new hydrographic system will contribute with a 1158 MW of power production and a pumping storage capacity of 880 MW, which will contribute for improving the security of supply, through its energy storage potential.

1) Impacts of each life cycle phase per unit of production

The construction and operation stages have the greatest impact on the global warming potential, with the construction process being the unique responsible for use of fossil and mineral resources impacts. Compared with the fossil reference technology, natural gas, hydropower has much lower impacts in the operation phase, corresponding to 6.4 kg $CO_{2\ eq.}$/MWh, about 1.5% of the impact of natural gas. As for fossil resources, only the construction phase has a potential impact (1.3 kgoe/MWh), representing 0.8% of the total impact of using fossil natural gas resources. The total impact of mineral resources is identical for both technologies (0.1 kg $Cu_{eq.}$/MWh). Figure 3 represents the impacts of each life phase per MWh.

Figure 3. Hydropower technology – impacts of each life phase per MWh



	Global warming potential [kg $CO_{2\ eq.}$/MWh]	Scarcity of fossil resources [$kg_{eq.}$/MWh]	Scarcity of mineral resources [kg $Cu_{eq.}$/MWh]
Decommission	0.0	0.0	0.0
Operation	6.4	0.0	0.0
Construction	7.1	1.3	0.1

14 Direção-Geral de Energia e Geologia (2021). Potência Instalada nas Centrais Produtoras de Energia Elétrica (1995–2020).

2) Extrapolation of impacts on the energy mix of 2020 and 2030

Since the prospects for 2030 increase from 7.1 to 8.2 GW of installed power capacity, the impacts will also rise. Thus, the global warming potential will ascend by 184 kton $CO_{2\ eq.}$ to 212 kton $CO_{2\ eq.}$, and the use of fossil resources from 17.4 to 20 kgoe. The impacts on mineral use will increase from 1.9 to 2.2 ton $Cu_{eq.}$ between 2020 and 2030.

Table 5. **Forecast of the total impacts of hydropower to 2030, based on 2020**

Year	Potential global warming [kton $CO_{2\ eq.}$]	Use of fossil resources [kgoe]	Use of mineral resources [ton $Cu_{eq.}$]
In 2020	183.9	17.4	1.9
Forecast to 2030	211.5	20.0	2.2

2.4. Onshore wind

Considering the installed capacity in 2020, 65% came from renewable sources (14609 MW), with wind representing 25% of the total power capacity (5502 MW)[15]. The evolution perspective of the installed capacity to produce electricity by onshore wind in Portugal, on the horizon of 2030, is 9.3 GW.

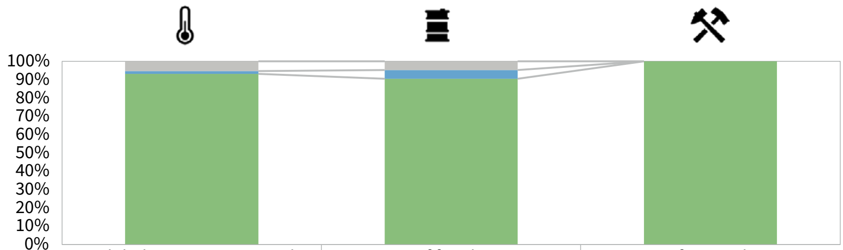
The country still has significant unexplored wind potential, not neglecting the current wind farms. There are strategies to reinforce existing wind farms, taking advantage of the already set up grid infrastructure to increase installed power capacity. For this purpose, the strategy to strengthen onshore wind power will involve over-equipment and power reinforcement, fostering the necessary conditions for these options' feasibility and offering favourable conditions for this technology to become more competitive (PNEC 2030).

1) Impacts of each life cycle per unit of production

Although the purpose of wind farms is to generate electricity through a renewable resource, it does not imply that it occurs without negative impacts on the environment, similarly to what happens in conventional power plants. As shown in Figure 4, a significant part of the environmental impacts of onshore wind power are associated with the Construction phase, corresponding to approximately 15.1 kg $CO_{2\ eq.}$ per MWh produced. This is due to the energy and materials required during this phase, including the extraction of raw materials and their transport to the installation site. However, the impacts are significantly reduced in

15 Direção-Geral de Energia e Geologia (2021). Potência Instalada nas Centrais Produtoras de Energia Elétrica (1995–2020).

Figure 4. Onshore wind technology – impacts of each life phase per MWh



	Global warming potential [kg $CO_{2\,eq.}$/MWh]	Scarcity of fossil resources [$kg_{eq.}$/MWh]	Scarcity of mineral resources [kg $Cu_{eq.}$/MWh]
Decommission	0.9	0.2	0.0
Operation	0.2	0.2	0.0
Construction	15.1	4.0	1.1

Table 6. Forecast of the total impacts of onshore wind to 2030, based on 2020

Year	Potential global warming [kton $CO_{2\,eq.}$]	Use of fossil resources [kgoe]	Use of mineral resources [ton $Cu_{eq.}$]
In 2020	199.1	54.3	14.1
Forecast to 2030	325.6	88.9	23.1

the later phases, namely in Operation and Decommissioning, with the Operation phase having minimum values. Figure 4 represents the impacts for each life phase per MWh.

This technology has higher impacts than natural gas technology in the Construction phase, namely 15.1 ton $CO_{2\,eq.}$ compared to 0.3 ton $CO_{2\,eq.}$ and 4.0 kgoe compared to 0.1 kgoe for natural gas per MWh produced. However, natural gas production technology has significantly higher impacts in the operation phase than onshore wind technology, namely 443.4 ton $CO_{2\,eq.}$ compared to 0.2 ton $CO_{2\,eq.}$ and 154.7 kgoe compared to 0.2 kgoe from onshore wind for each MWh produced.

2) Extrapolation of impacts on the energy mix of 2020 and 2030

Considering the evolution of the installed capacity of this technology according to PNEC2030, in 2030, onshore wind will correspond to 9 GW, which translates into total impacts of 325.6 kton $CO_{2\,eq.}$, 88.9 kgoe and 23.1 ton $Cu_{eq.}$ Table 6 presents the forecasted impacts to 2030 for the onshore wind technology.

The projected rise of installed wind capacity from 9 GW to more than 20 GW in 2030 will increase the impacts, albeit at a slower rate than the growth rate of the installed capacity. The global warming potential will rise by 199 kton $CO_{2\,eq.}$ to 326 kton $CO_{2\,eq.}$, the use of fossil resources will increase from 54.3 to

88.9 kgoe and impacts on mineral use will grow from 14.1 to 23.1 ton $Cu_{eq.}$ between 2020 and 2030.

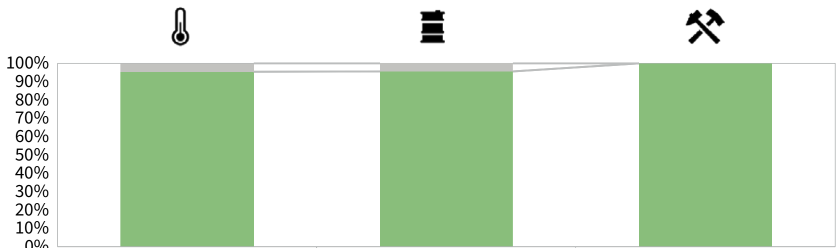
2.5. Solar photovoltaic

PNEC 2030 aims to increase the capacity of photovoltaic solar plants installed in Portugal from 1.1 GW to 9 GW. The significant reduction in costs and Portugal's extraordinary potential for harnessing the sun as a source for electricity production make this technology play a strategic role in meeting PNEC2030's objectives. The two main tools to accelerate the development of solar capacity in Portugal will be: (1) grid injection capacity allocation auctions; and (2) the possibility for promoters, together with the network operator, to provide network reinforcements when there is no reception capacity (ideally for large projects)[16].

1) Impacts of each life cycle per unit of production

The impacts of photovoltaic technology in the different life cycle phases are presented in Figure 5.

Figure 5. Solar photovoltaic technology – impacts of each life phase per MWh



	Global warming potential [kg $CO_{2\,eq.}$/MWh]	Scarcity of fossil resources [$kg_{eq.}$/MWh]	Scarcity of mineral resources [kg $Cu_{eq.}$/MWh]
Decommission	2.3	0.6	0.0
Operation	0.0	0.0	0.0
Construction	48.0	12.8	0.9

The phase with the most significant impact is Construction, where the global warming potential is 48 kg $CO_{2\,eq.}$/MWh, using fossil resources of 12.8 kgoe/MWh and mineral resources of 0.9 kg $Cu_{eq.}$/MWh.

16 Presidência do Conselho de Ministros (2020). Plano Nacional Energia e Clima 2030 (PNEC 2030). Resolução do Conselho de Ministros n.º 53/2020, *Diário da República*, Série I., Vol. 133, pp. 2–158.

The impact of the global warming potential and use of fossil resources is considerably lower than the reference technology, natural gas, corresponding to 9.5% and 8.7% of its impacts, respectively. However, the use of mineral resources has a nine times greater impact on photovoltaic technology when compared to natural gas technology.

The operation phase has virtually no impact, as it is a technology that requires little maintenance, and decommissioning only slightly impacts the global warming potential and the use of fossil resources.

2) Extrapolation of impacts on the energy mix of 2020 and 2030

In 2020, photovoltaic technology was responsible for an output of almost 1.7 TWh. At the life cycle level, it was responsible for a global warming potential of more than 86 kg $CO_{2\ eq.}$ and nearly 23 kgoe of fossil resource use. The impact on the use of mineral resources was 1.5 kg $Cu_{eq.}$ Table 7 presents the forecasted impacts to 2030 due to solar photovoltaic technology.

Table 7. **Forecast of the total impacts of solar photovoltaic to 2030, based on 2020**

Year	Potential global warming [kton $CO_{2\ eq.}$]	Use of fossil resources [kgoe]	Use of mineral resources [ton $Cu_{eq.}$]
In 2020	85.1	22.6	1.5
Forecast to 2030	711.7	189.1	12.2

2.6. Concentrated solar

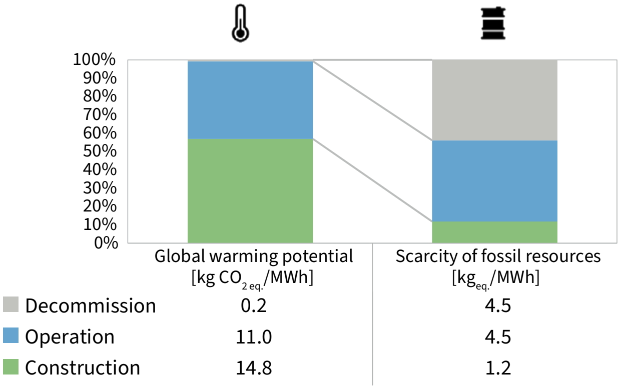
Concentrated solar power technologies use solar radiation to heat a fluid that can be stored in a thermal energy storage system or used in a thermodynamic cycle to produce electricity. PNEC 2030 considers the promotion of pilot projects based on Concentrated Solar Thermal technologies as a technology which allows energy storage, with the installation of 300 MW expected in the next decade.

1) Impacts of each life cycle per unit of production

Compared to the reference scenario (natural gas), concentrated solar significantly reduces global warming potential (27 kg $CO_{2\ eq.}$/MWh). The Construction phase is responsible for the greatest impact, with the production of the parabolic mirror system, the thermal transmission fluid and the salts used in the storage system being the main contributors to an impact of 14.8 kg $CO_{2\ eq.}$/MWh[17]. It

17 Garvin Heath, P. A., Turchi, C. S., and Burkhardt, J. J. III (2011). Life Cycle Assessment of a Parabolic Trough Concentrating Solar Power Plant and Impacts of Key Design Alternatives: Preprint. https://doi.org/10.1021/es1033266.

Figure 6. **Concentrated photovoltaic technology – impacts of each life phase per MWh**



should be noted that synthetic salts, as an alternative to mined salts, have a positive impact of 52% on the global warming potential during the Construction phase.[18] During operation, the global warming potential is 11 kg $CO_{2\ eq.}$/MWh, essentially due to electricity grid energy use to satisfy the consumption of auxiliary systems, whenever the plant is not producing thermal energy. The global warming potential during operation depends on the energy mix of the electrical grid in the region where the unit is installed. On fossil resources use, concentrated solar technology presents values considerably lower than the base scenario (natural gas).

2) Extrapolation of impacts on the energy mix of 2020 and 2030

There are currently no electricity production plants in Portugal using concentrated solar technology. Although in the past, attempts have been made to promote pilot projects, none of them was pursued, due to the lack of economic feasibility, ending up as solar photovoltaic projects. However, if PNEC 2030 objectives are reached, the technologies' total impacts are presented in Table 8.

Table 8. **Forecast of the total impacts of concentrated solar to 2030, based on 2020**

Year	Potential global warming [kton $CO_{2\ eq.}$]	Use of fossil resources [kgoe]	Use of mineral resources [ton $Cu_{eq.}$]
In 2020	0.0	0.0	0.0
Forecast to 2030	18.1	7.1	0.9

18 Garvin Heath, P. A., Turchi, C. S., and Burkhardt, J. J. III (2011). Life Cycle Assessment of a Parabolic Trough Concentrating Solar Power Plant and Impacts of Key Design Alternatives: Preprint. doi: 10.1021/es1033266.

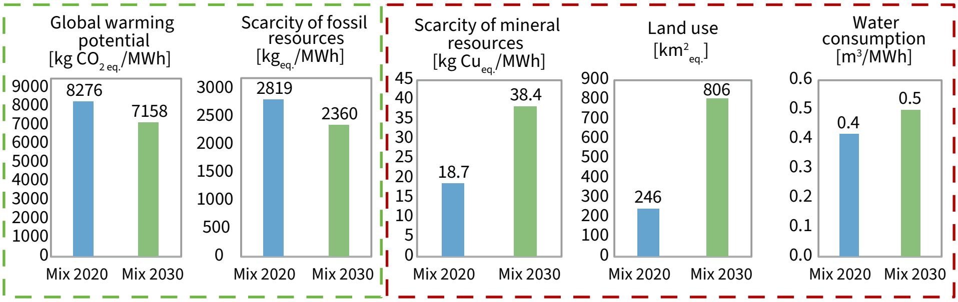
3. Strategic analysis

Renewable production sources integration into the national electricity system presents a set of strategic advantages for the security of supply, energy independence, and decarbonization of the energy sector. The objectives outlined in PNEC 2030 are aligned with this strategic framework, reinforcing the penetration of renewable origin sources over fossil-origin conventional sources. The present study allows us to conclude that renewable origin technologies have considerably lower impacts on the global warming potential and use of fossil resources during the Operation Phase compared to natural gas technology. Figure 7 shows the total impact values of the energy mix for 2020 and 2030 for the five impact categories under analysis. Figure 8 shows the values of environmental impacts for the reference scenario – the 2020 energy mix – and the extrapolated scenario for the 2030 energy mix, using equivalent units to enable the interpretation and results communication.

Figure 7 shows that the projection made for 2030s energy mix presents a decrease of 14% and 16% for the global warming potential and use of fossil resources, respectively. However, in terms of the use of mineral resources, land use, and water consumption, the addition of renewable origin sources in 2030 causes an impact increase of around 105% (predominantly wind, photovoltaic and concentrated solar), 227% (mainly solar photovoltaic) and 20% (primarily hydroelectric), respectively. The impact on water consumption does not increase significantly, as in the other two categories, and is mainly caused by hydropower, which is not the technology with the greatest growth planned in PNEC 2030 (only a hydroelectric plant). The use of mineral resources is mainly affected by onshore wind, concentrated solar, and photovoltaics. These impacts require closer attention since solar photovoltaic and wind are expected to prevail in the coming decades. The impacts associated with the construction phase, with relevance to the extraction of raw materials, are, therefore, significant.

The raw materials necessary for the technologies' construction are mostly imported, so they have a component associated with transport, which increases the impact. It is imperative to apply circular economy measures, particularly technological solutions which allow the recovery of these minerals at the end of the assets' life and must be improved and widely implemented to guarantee the technologies' sustainability, considering the potential scarcity of raw materials or the change of import policies that can occur. Regarding land use, the most impactful technology is solar photovoltaics, so the installation of large solar plants should be prioritized in locations where land use does not compete with other types of use (e.g., agricultural and agroforestry) as well as installation in buildings. However, it is necessary to consider its location in geographic points in line with the local electrical and electrical network's needs.

Figure 7. Total impacts for the 2020 and 2030 energy mix



Using indicators of general perception with equivalent magnitudes, the positive impacts correspond to the avoided emissions of 1.7 million cars driven annually and the extraction of 18 million barrels of oil. However, its negative impacts can be compared to 9 megatons of soil extracted from mines, with the equivalent of 500 000 swimming pools filled with fresh water and 538 km^2 of occupied agricultural land.

It is concluded that, regarding the political guidelines for climate and energy independence, PNEC 2030 promotes carbon neutrality and independence from the fossil base. However, the large-scale insertion of renewable origin technologies must consider mitigating environmental impacts on mineral resources, land use, and water consumption. For these impact categories, four possible impact mitigation solutions are presented:

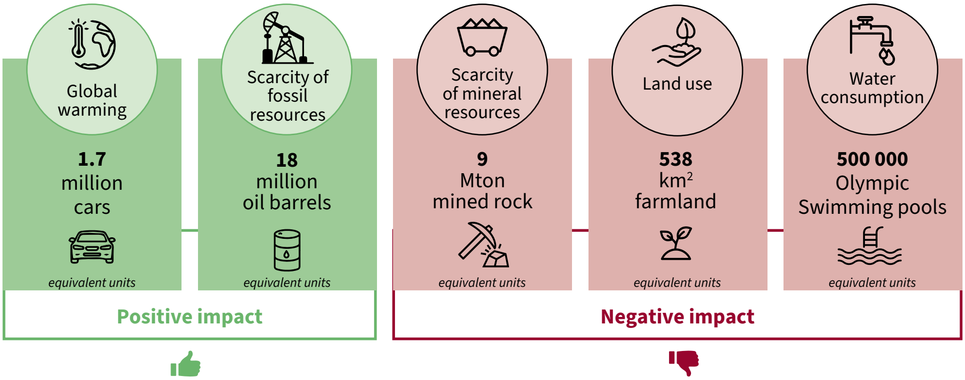
Solution 1 – Preferential integration of solar photovoltaic production in buildings and non-productive land. When in agricultural soil, it must be coordinated with crops compatible with shading or allowing sun entry in the appropriate periods.

Solution 2 – Hybridization of energy production systems, namely hydropower and floating photovoltaic, in a symbiosis that reduces evaporation water losses from the reservoir and takes advantage of the available space with no other use for the installation of photovoltaic panels.

Solution 3 – Setting material recovery programs during the dismantling phase, thus reducing external dependence on raw materials. At the same time, grant support for inspection and social responsibility measures for mining activity in the various exploration countries.

Solution 4 – Implementation of energy efficiency strategies in the several phases of the life cycle of renewable sources technologies, and on the consumption side.

Figure 8. **Estimation of potential annual environmental savings based on the targets recommended in PNEC2030 for the national energy mix in 2030 compared to 2020**



1 car travels an average of 20 000 km per year (4.2 ton $CO_{2\ eq.}$).[19]
1 barrel of oil has 5858 MJ of primary energy (1 kg oil – 41 MJ).[20]
1 kg Cu mined corresponds to 500 kg of tailings.[21]
1 Olympic pool has 2 500 m^3 of water.[22]

Conclusion and recommendations

Guidelines promoting the carbon neutrality of the Portuguese energy sector must ensure that sustainable development and circular economy approaches are hand in hand in the planning of renewables' 2050 goals. One of the critical factors identified is the importance of environmental impacts in the life cycle of the different electrical production technologies (from raw material extraction to dismantling).

The present study identified the environmental impacts that may arise from the goals established in PNEC 2030. In this sense, it is recommended that strategic policies in the energy sector consider solutions that minimize these impacts, promoting the rational and efficient use of electricity. Additionally, the analysis of other sustainability impact indicators – social and economic – is recommended, allowing for a more in-depth quantification of the impacts of these technologies, speeding up the transition to an effective green, sustainable, and fair economy.

19 Calculation Tools | Greenhouse Gas Protocol (2011).
20 Convert barrels of oil equivalent to megajoules – energy converter (2021).
21 Santos, J. (2017). Recuperação e Reabilitação de Áreas Degradadas pela Mineração. UAB; SEAD.
22 Just in Tools, Olympic Size Swimming Pool.

Finally, it is highly recommended that energy development policies be cross-sectoral, drawn up in conjunction with the various national economic development plans, seeking synergies that allow leveraging the development of circular economy policies, enhancing the sustainability of the Portuguese energy system.

Part IV

Case studies of transition-related fields

Felipe Bastarrica, Lorena Di Chiara, Ignacio Estrada, Federico Ferrés, Gonzalo Irrazabal, Juan Manuel Mercant, Alejandro Perroni, Ariel Álvarez

Emerging green hydrogen economy and Uruguay as a case study

This paper aims to discuss the potential role of green hydrogen in decarbonizing energy systems, and present Uruguay as a case study. Firstly, a brief introduction to hydrogen is given, presenting its basic characteristics, current and projected market, investments, and electrolysis technologies. Subsequently, potential uses of hydrogen are discussed, together with policy priorities, and the international agenda, mentioning bilateral agreements, announced roadmaps and megaprojects. Finally, Uruguay's successful first energy transition is depicted, and its potential to produce green hydrogen is briefly described, bringing forward its national strategy, and analysing projected investments, costs, and potential market.

1. Brief introduction to hydrogen

1.1. Basic characteristics

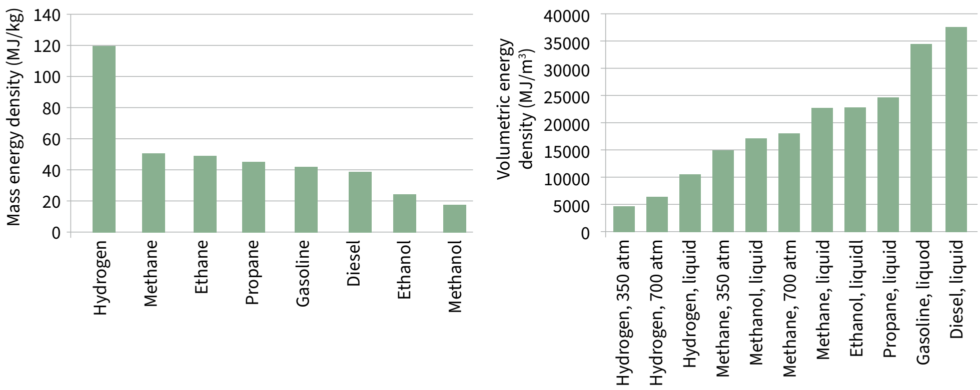
Hydrogen is the lightest, simplest, and most abundant element in the universe. Notwithstanding, hydrogen in its molecular form (i.e., two atoms bonded together, from now on H_2) is scarce, and on earth is naturally present solely in combination with other atoms, such as oxygen in the case of water (H_2O) or carbon in the case of methane (CH_4)[1].

Like electricity, hydrogen is an energy carrier, which allows energy to be transported in a usable form, requiring a primary source of energy to be produced[2].

1 Florence School of Regulation (2020). Hydrogen in the Energy Transition. Available: https://fsr.eui.eu/hydrogen-in-the-energy-transition/

2 U.S. Energy Information Administration (2022). Hydrogen explained. Available: https://www.eia.gov/energyexplained/hydrogen/

Figure 1. Hydrogen mass and volumetric energy density



Source: Centro Nacional de Hidrógeno, 2021[3]

Thus, the energy released when burned is lower than the energy required to produce it.

It is a highly inflammable gas, of exothermic, clean and invisible combustion. The word Hydrogen derives from a Greek word meaning 'maker of water'[4]. The etymology derives from the fact that it releases water vapor (combined with Oxygen) when burned, instead of Carbon Dioxide (CO_2), like fossil fuels do.

H_2 contains a high amount of energy per unit of mass (approximately 3 times more than gasoline), but a low energy content per unit of volume compared to other gases and fuels (approximately 4 times less than gasoline), as portrayed in the figure below.

1.2. Colour spectrum

Even though hydrogen is a colourless (and odourless) gas, it became popular to metaphorically assign a colour to the carrier, according to the energy source used to produce it.

The figure below provides an illustration of such characterization, where green and pink hydrogen, have the lowest impact in terms of Green House

3 Centro Nacional de Hidrógeno (2021). Curso Introductorio sobre Tecnologías del Hidrógeno y las Pilas de Combustible. Available: https://www.fing.edu.uy/owncloud/index.php/s/5a0k505xVvnINZT#pdfviewer

4 Britannica website. Hydrogen chemical element. Available: https://www.britannica.com/science/hydrogen

Figure 2. Hydrogen colour spectrum

	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind, Solar, Hydro, Geothermal, Tidal	Minimal
	Purple/Pink Hydrogen		Nuclear	
	Yellow Hydrogen		Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS gasification + CCUS	Natural gas, coal	Low
	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
	Grey Hydrogen	Natural gas reforming		Medium
	Brown Hydrogen	Gasification	Brown coal (lignite)	High
	Black Hydrogen		Black coal	

*GCG footprint given as a general guide but it is accepted that each category can be higher in some cases.
Source: Global Energy Infrastructure, 2021[5]

Gas (GHG) emissions. These are produced by water electrolysis using renewable energy sources and nuclear energy respectively. Mid-range lies blue hydrogen, which involves fossil fuels (usually natural gas) adding Carbon Capture Usage and Storage (CCUS) technologies.

On the other end of the spectrum, black and brown hydrogen have the highest GHG footprint, where hydrogen is produced by gasification of coal or lignite.

In the literature it is common to find references to clean hydrogen. In the case of the European Union, clean hydrogen is a synonym of renewable hydrogen, which is defined, as follows:

> *Renewable hydrogen is hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources. The full life-cycle greenhouse gas emissions of the production of renewable hydrogen are close to zero. Renewable hydrogen may also be produced through the reforming of biogas (instead of natural gas)*

5 Global Energy Infrastructure (2021). Hydrogen – data telling a story. Available: https://globalenergyinfrastructure.com/articles/2021/03-march/hydrogen-data-telling-a-story/

or biochemical conversion of biomass, if in compliance with sustainability requirements.
(European Commission, A hydrogen strategy for a climate-neutral Europe, 2020[6])

Even though blue hydrogen is not considered to be clean hydrogen in the EU, there is no international consensus on a definition of clean hydrogen. Other institutions do consider blue hydrogen to be clean hydrogen (see, for example, World Economic Forum, 2022[7]). Notwithstanding, some studies argue that blue hydrogen emits more GHG than burning coal or natural gas burned to produce heat, questioning its 'cleanness' (see, for example, Howarth and Jacobson, 2021[8]).

1.3. Current production and demand

Annual hydrogen demand increased by 50% in the 2000–2020 period, reaching approximately 90 million tons (Mt) by the end of the period[9]. In addition, 30 Mt are present in waste gases from industrial processes (heat and electricity). Approximately 96% of this hydrogen derives from fossil fuels (grey hydrogen).

The figure below portrays annual hydrogen demand by sector in the period 2000–2020, showing that the chemicals and refining industries are currently the largest consumers.

China is currently the largest hydrogen consumer (approximately 24 Mt per year), followed by the United States (11 Mt), India (7.2 Mt), Russia (6 Mt) and the European Union (6 Mt), as portrayed in the map below.

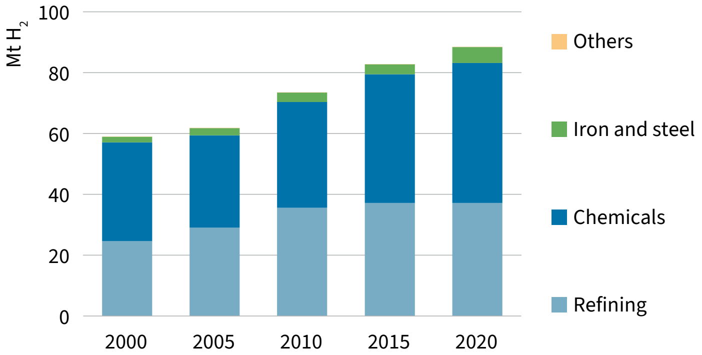
6 European Commission (2020). A hydrogen strategy for a climate-neutral Europe. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0301&from=EN

7 World Economic Forum (2022). Clean Hydrogen & its Uses. Available: https://initiatives.weforum.org/accelerating-clean-hydrogen-initiative/cleanhydrogenanditsuses

8 Howarth, R. W., and Jacobson, M. Z. (2021). How green is blue hydrogen? Available: https://onlinelibrary.wiley.com/doi/10.1002/ese3.956

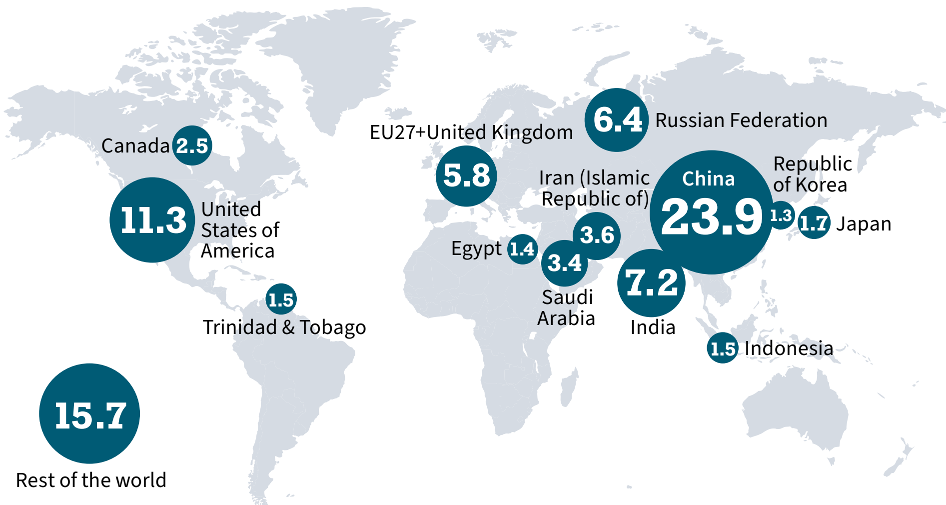
9 IEA (2021). Global Hydrogen Review 2021. Available: https://iea.blob.core.windows.net/assets/5bd46d7b-906a-4429-abda-e9c507a62341/GlobalHydrogenReview2021.pdf

Figure 3. Annual hydrogen demand by sector, 2000–2020



Source: IEA 2021

Figure 4. Hydrogen consumption in 2020, million tons



Source: IRENA, 2022[10]

10 IRENA (2022). Geopolitics of the Energy Transformation. The Hydrogen Factor. Available: https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen

2. The emerging green hydrogen economy

2.1. Decarbonisation potential

Green hydrogen has gained particular attention in recent years in the context of worldwide commitments to reduce GHG emissions under the Paris Agreement and the recommendations of the Intergovernmental Panel on Climate Change (IPCC).

One of the main arguments brought forward by green hydrogen advocates is that it has a strong potential to decarbonise hard to abate sectors, which include mainly heavy industry and long-distance transport (air, maritime and land). Most energy experts agree that electricity produced with renewable energy sources is the most efficient substitute to fossil fuels. However, electricity is not a viable substitute for sectors requiring high energy contents, at least with current technologies. This is the gap green hydrogen, and its derivatives (ammonia, methanol, green kerosene and other green fuels) are arguably set to bridge.

Another attribute brought forward is that hydrogen could act as long-term and large-scale storage capacity to further integrate non-conventional renewable sources into electricity systems (i.e., wind, solar, geothermal, tidal, among other). The intermittency of these sources does not currently allow them to self-sufficiently source entire systems, so different storage technologies are being introduced to help supply meet demand when these sources are not producing enough. In addition, hydrogen and its derivatives can be transported at larger distances than electricity.

The expectation of lowering costs is also one of the arguments that make green hydrogen a compelling case. Current estimates suggest that the increase in the scale of electrolysers coupled with lowering renewable electricity costs will reduce hydrogen generation costs by 30% by 2030[11].

Last but not least, hydrogen's versatility also makes it particularly attractive, with a vast range of uses. These include feedstock applications, for example in the petrochemical industry, or combining it with other gases, for example ammonia synthesis (combining hydrogen with nitrogen[12]) and fertilizers production (further combining with liquid carbon dioxide[13]) or to produce methanol (combining hydrogen with carbon monoxide[14]). Furthermore, hydrogen can be used as a fuel, given that it can reach temperatures of 1000°C when burned, and in fuel cells to

11 IEA (2019). The Future of Hydrogen: Seizing today's opportunities. Available: https://www.iea.org/reports/the-future-of-hydrogen

12 Britannica website. Ammonia chemical compound. Available: https://www.britannica.com/science/ammonia

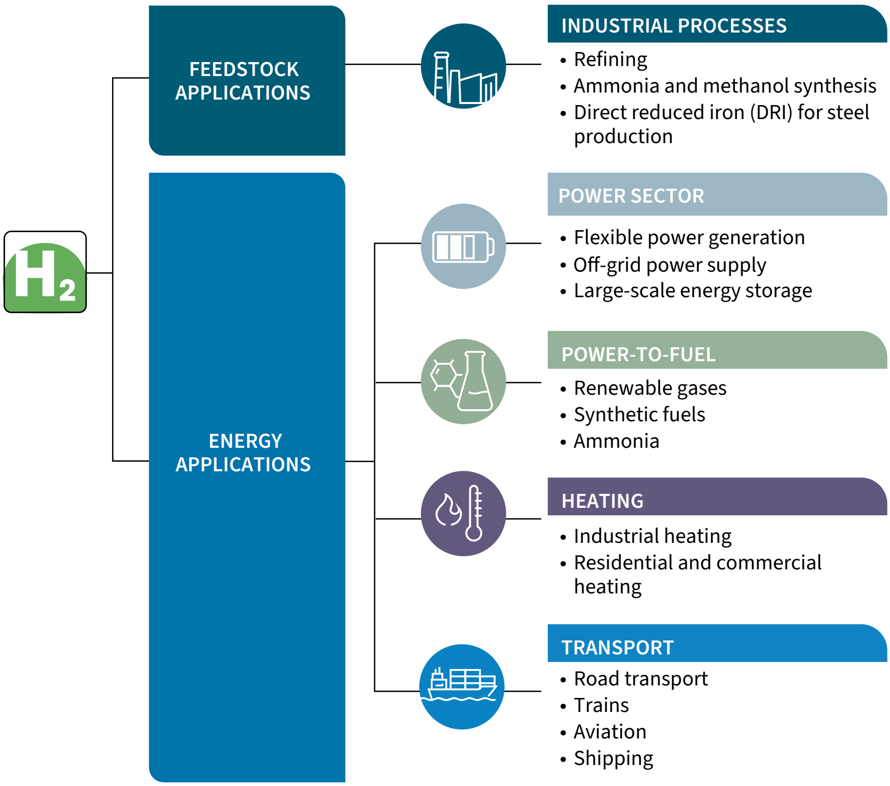
13 Ibid. Urea chemical compound. Available: https://www.britannica.com/science/urea

14 Ibid. Methanol chemical compound. Available: https://www.britannica.com/science/methanol

produce electricity without emitting any pollutants or greenhouse gases, just water vapor.

The figure below portrays potential uses of green hydrogen by sector, including uses in industrial processes (feedstock applications), the power sector, power-to-fuel, heating, and the transport sector.

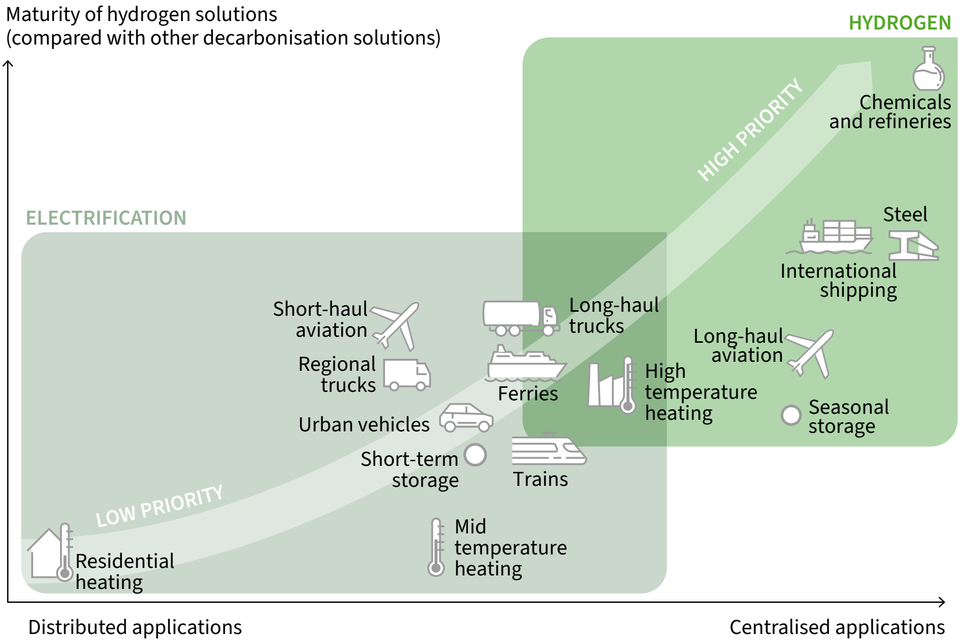
Figure 5. Potential uses of green hydrogen



Source: International Renewable Energy Agency (IRENA), 2022[15]

15 IRENA (2022). Geopolitics of the Energy Transformation. The Hydrogen Factor. Available: https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen

Figure 6. Green hydrogen policy priorities



Source: IRENA, 2022

Some of these uses are gaining policy priority given the maturity of the solutions, and that electrification is not a possible substitute. These include the chemicals industry, refineries, steel production and international shipping, among others.

2.2. Electrolysis

2.2.1. Technologies

As noted before, green hydrogen is produced by water electrolysis. Electrolysis is the process of separating the elements of a compound by means of electricity, using an electrolyser. In this process, electrons are released by anions at the anode (oxidation) and electrons are captured by cations at the cathode (reduction).

Electrolysis technologies include:

- **Alkaline**: a mature and commercial technology developed in the 1920s, particularly to produce hydrogen for the fertilizer and chlorine industries. The operating range of the alkaline electrolyser is from a minimum load of 10% up to design capacity. Alkaline electrolysis is characterized by relatively low capital costs compared to other electrolyser technologies, as it does not require the use of precious metals. The pressure of the hydrogen produced is in the range of 1–30 bar.

- **Proton Exchange Membrane (PEM):** first introduced in the 1960s by General Electric to overcome some of the operational drawbacks of alkaline electrolysers. They are relatively small in terms of size, potentially making them more attractive than alkaline electrolysers in dense urban areas. They can produce highly compressed hydrogen for refuelling stations at 30–60 bar without an additional compressor, and up to 100–200 bar in some systems. Furthermore, they offer flexible operation, with capacity to provide frequency reservation and other network services. It is possible to overload the electrolyser in the short term if the plant and power electronics have been designed accordingly (operating range 0% to 160% of design capacity). On the other hand, the catalysts are usually precious metals, the membrane material is expensive, the lifetime is currently shorter than that of alkaline electrolysers.
- Solid Oxide Electrolyser Cell (SOEC): technology under development. The process uses ceramic as electrolyte and thus have low material costs. It operates at high temperatures and with a high degree of electrical efficiency. It requires steam in the electrolysis process, requiring a source of heat.

The table below provides a comparison of basic characteristics of these technologies.

Table 1. **Comparison of basic characteristics of electrolysers**

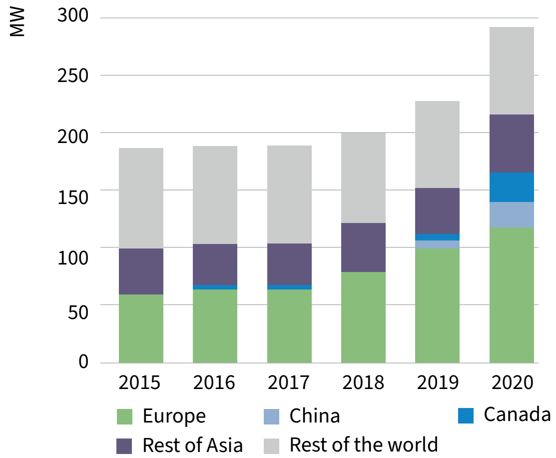
	Alkaline	PEM	SOEC
Efficiency (%)	63–70	56–60	74–81
CAPEX (USD/kW) – current	500–1400	1100–1800	2800–5600
CAPEX (USD/kW) – long term forecast	200–700	200–900	500–1000
Temperature (°C)	60–85	50–80	800–1000
Pressure (bar)	< 30	< 35	1–5
Useful life (hours)	> 95 000	55 000–75 000	Under research
Advantages	Mature technology. Greater durability and lower cost	Small size and high operating range	Low electricity consumption
Disadvantages	Subsequent H_2 purification required	High cost of catalysts and membranes	High operating temperatures

Source: own elaboration based on International Energy Agency, 2019 and IRENA, 2020

2.2.2. Installed capacity

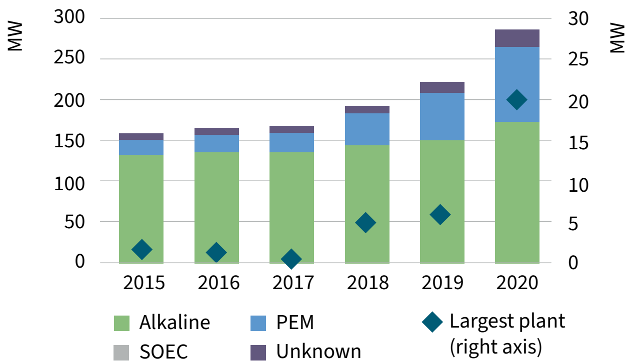
In the period spanning 2015–2020, the global installed electrolyser capacity increased by approximately 70% (see the figure below)[16]. As of 2020, more than half of the installed capacity is based in Europe, China and Canada.

Figure 7. Installed electrolyser capacity by region, 2015–2020



Source: IEA, 2021

Figure 8. Electrolysis installed capacity by technology, 2015–2020



Source: IEA, 2021

16 Britannica website. Hydrogen chemical element. Available: https://www.britannica.com/science/hydrogen

As shown in the figure, alkaline electrolysers are the leading technology in installed capacity. Notwithstanding, PEM electrolysis is gaining popularity, given lowering costs and its versatility in responding to the intermittency of renewable energy sources.

2.3. Projected investments

In the 2016–2020 period, investments in electrolysers have increased 8-fold and fuel cell electric vehicles (FCEVs) 20-fold. Currently, global investments in these technologies total USD 700 million per year, as portrayed in the figure below.

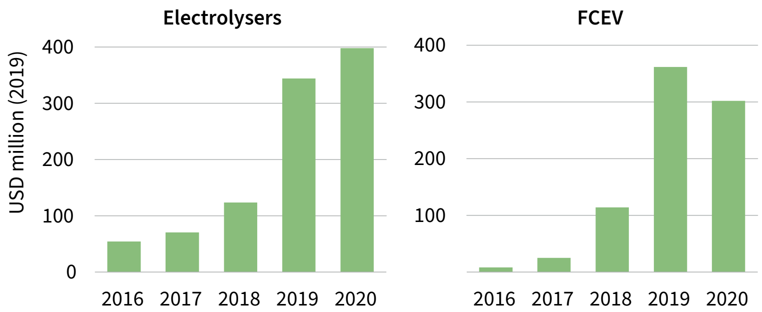
Although investments, as showcased above, have increased significantly in the past few years, they could grow exponentially in the coming decades considering current government climate ambitions.

For example, IEA constructed two scenarios for future expected investments:

- **Announced Pledges Scenario (APS)**: which considers all governmental commitments announced and is based on the premise that these commitments will be fully met in a timely manner;
- **Net Zero Emissions (NZE)**: which is based on the premise that carbon neutrality will be achieved by 2050, and thus considers larger investments and greater commitments from governments than current pledges.

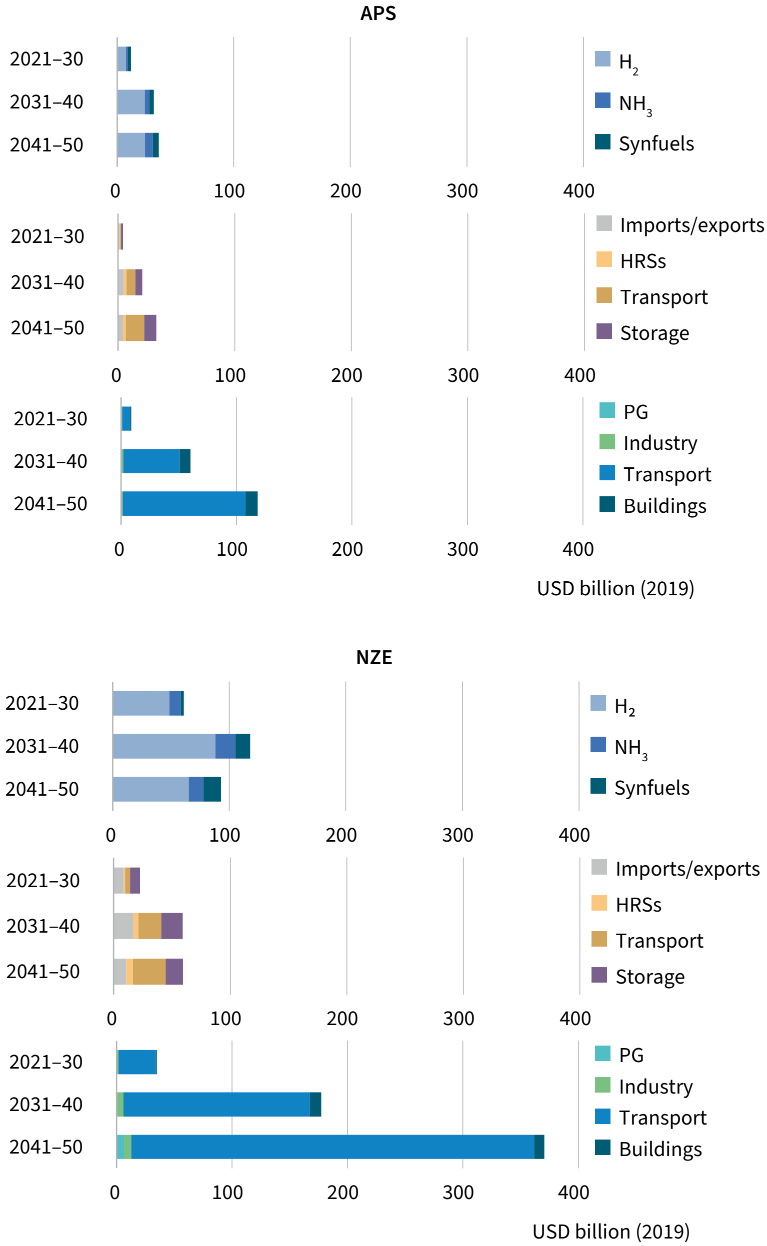
Under the APS scenario, investments of USD 250 billion are expected for the 2020–2030 decade, and cumulative USD 3.2 trillion by 2050. On the other

Figure 9. Annual investments in electrolysers and fuel cell electric vehicles, 2016–2020



Note: FCEV = fuel cell electric vehicle.
Sources: Based on IEA Hydrogen Project Database and annual data submission of the AFC TCP to the IEA Secretariat.
Source: IEA, 2021

Figure 10. Investments required in the Announced Pledges and Net Zero scenarios



Notes: APS = Announced Pledges Scenario. NZE = Net zero Emissions Scenario. HRSs = hydrogen refuelling stations. PG = power geneation.
Source: IEA, 2021

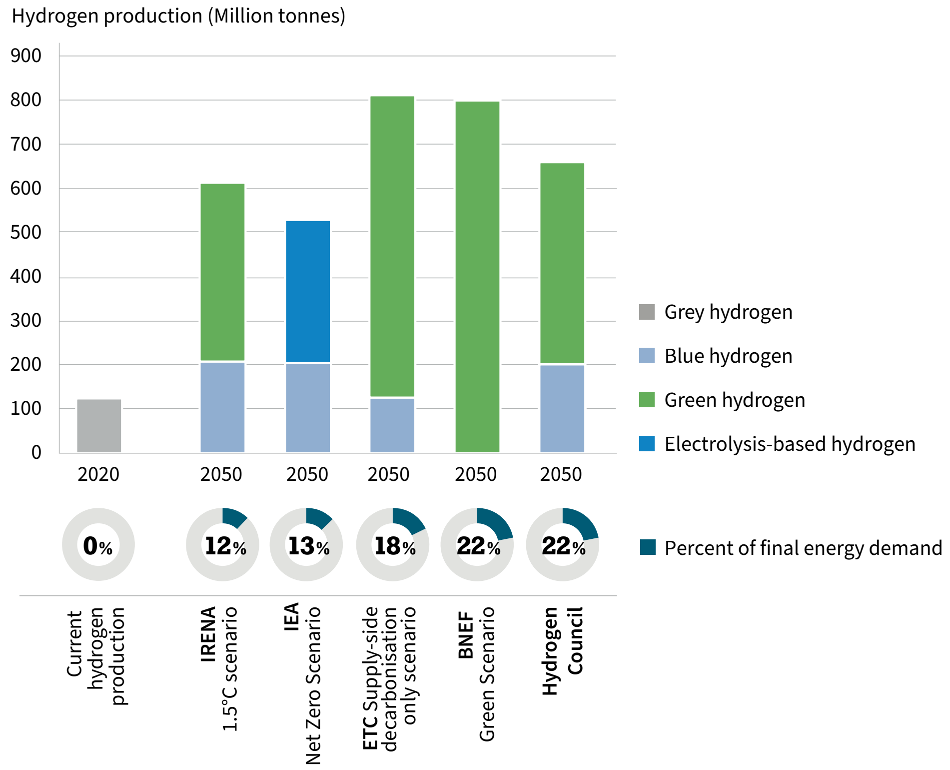
hand, the NZE scenario would require cumulative global investments to increase to USD 1.2 trillion by 2030 and USD 10 trillion by 2050.

The figure above disaggregates these investments by sector, showing that the largest share corresponds to end-use technologies (60% of cumulative investment needs by 2050), followed by developing production capacity (between 25–27%).

2.4. Production projections

Hydrogen production is expected to increase 5 to 8-fold, and its share of final energy demand to soar from 0% up to 22% by 2050, as portrayed in the figure below.

Figure 11. Projected hydrogen production by 2050 according to different organizations

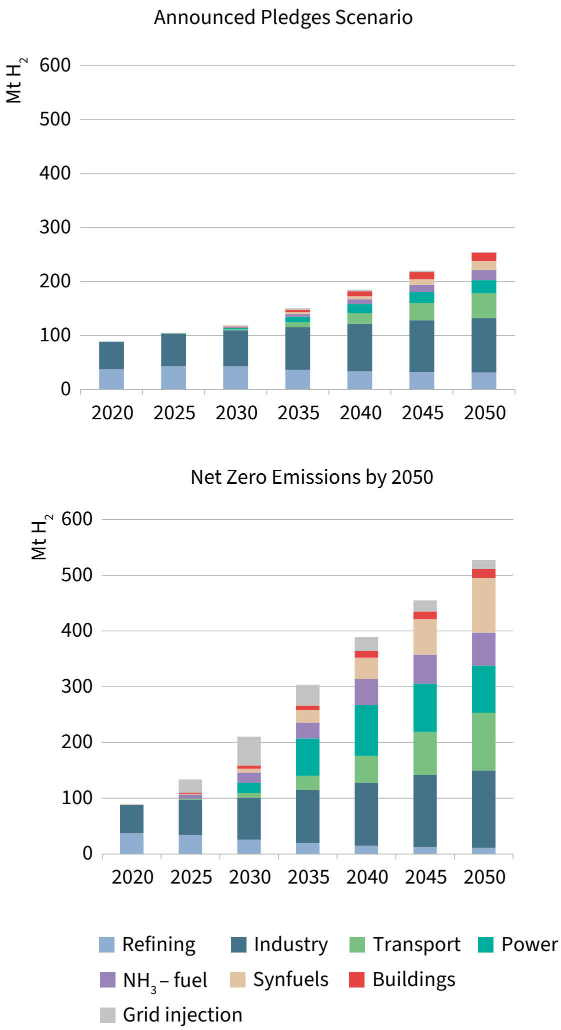


Note: IEA classifies hydrogen produced by fossil fuels with carbon capture and storage as blue, and hydrogen produced by electrolysis as yellow, which is equivalent to green if the energy is renewable, which is the expectation for 2050.
Source: IRENA, 2022

Furthermore, by 2050 grey hydrogen is expected to be fully displaced by green and to a lesser extent blue hydrogen.

The figure below provides the comparison of hydrogen demand between the APS and NZE scenarios of IEA in the period 2020–2050, showing that demand under the latter doubles the former.

Figure 12. Hydrogen demand in Announced Pledges and Net Zero scenarios, 2020–2050



Notes: "NH_3 – fuel" refers to the use of hydrogen to produce ammonia for its use as a fuel. The use of hydrogen to produce ammonia as a feedstock in the chemical subsector is included within industry demand.
Source: IEA, 2021

2.5. Announced roadmaps, bilateral agreements and mega-projects

Several countries have recently published or are in the process of developing green (or clean) hydrogen roadmaps and strategies and signed bilateral agreements.

The table below summarises efforts as of mid-2021. As discussed in the next section, Uruguay has recently published its national roadmap.

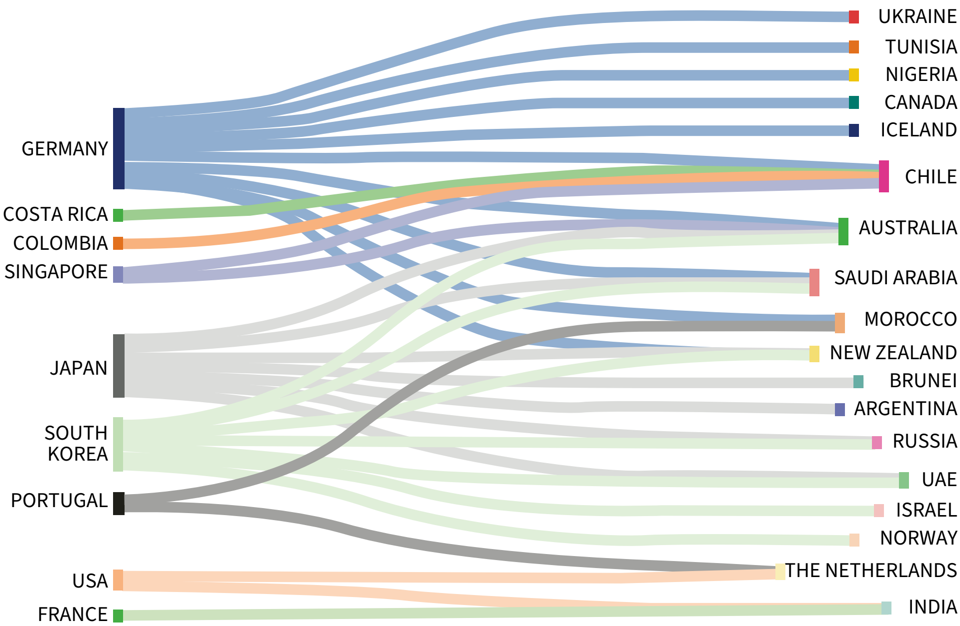
Table 2. Countries activities towards developing a hydrogen strategy

	Policy discussions, official statements, initial demonstration projects			Strategy in preparation	Strategy available
Africa	Cape Verde Burkina Faso	Mali Nigeria	South Africa Tunisia	Egypt Morocco	
Asia	Bangladesh	Hong Kong, China	India	China New Zealand Singapore Uzbekistan	Australia (2019 Japan (2017) South Korea (2019))
Europe	Bulgaria Croatia Czech Republic Denmark Estonia Finland Georgia	Greece Iceland Latvia Lithuania Luxembourg Malta	Romania Serbia Slovenia Switzerland Turkey Ukraine	Austria Belgium Italy Poland Russian Federation Sweden Slovakia United Kingdom	European Union (2020) France (2020) Germany (2020) Netherlands (2020) Norway (2020) Portugal (2020) Spain (2020) Hungary (2021)
Latin America & the Caribbean	Argentina Bolivia Costa Rica	Panama Paraguay	Peru Trinidad and Tobago	Brazil Colombia Uruguay	Chile (2020)
Middle East and Gulf States	Israel	United Arab Emirates		Oman Saudi Arabia	
North America	Mexico	United States of America			Canada (2020)

Source: World Energy Council (WEC), 2021[17]

17 World Energy Council (2021). Hydrogen on the Horizon: Ready, Almost Set, Go? Available: https://www.worldenergy.org/assets/downloads/Working_Paper_-_National_Hydrogen_Strategies_-_September_2021.pdf

Figure 13. Bilateral partnerships



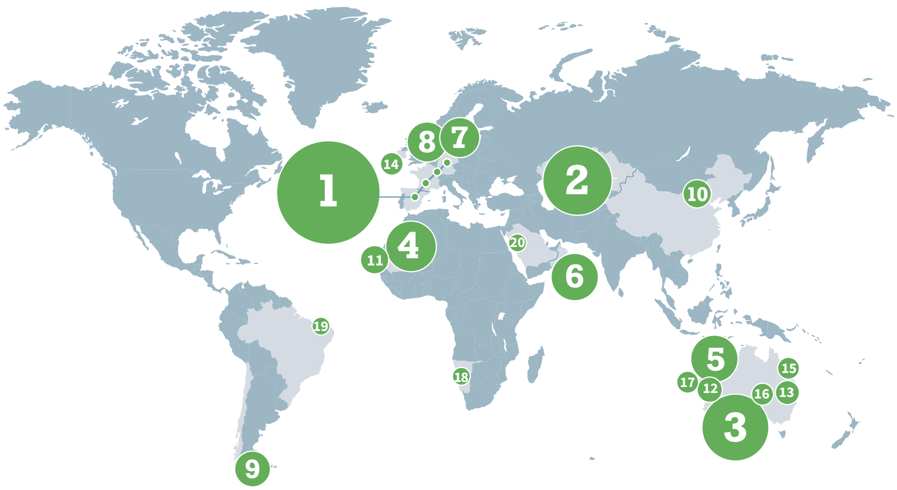
Source: WEC, 2021[18]

In addition, several countries have signed bilateral agreements to jointly develop research programs, explore harmonising standards, and encourage the emerging world hydrogen trade. As portrayed in the figure below, Germany is currently a world leader in this regard.

The figure below depicts the 20 largest announced green hydrogen production mega-projects in the world. As portrayed, Europe and Australia are leading in terms of installation of megaprojects.

18 Howarth, R. W., and Jacobson, M. Z. How green is blue hydrogen? Available: https://onlinelibrary.wiley.com/doi/10.1002/ese3.956

Figure 14. World's 20 largest green hydrogen mega projects announced



1	**HyDeal Ambition (67GW)**	Western Europe
2	**Unnamed (30GW)**	Kazakhstan
3	**Western Green Energy Hub (28GW)**	Australia
4	**AMAN (16GW)**	Mauritania
5	**Asian Renewable Energy Hub (14GW)**	Australia
6	**Oman Green Energy Hub (14GW)**	Oman
7	**AquaVentus (10GW)**	Germany
8	**NorthH2 (10GW)**	Netherlands
9	**H2 Magallanes (8GW)**	Chile
10	**Beijing Jingneng (5GW)**	China
11	**Project Nour (5GW)**	Mauritania
12	**HyEnergy Zero Carbon Hydrogen (4GW)**	Australia
13	**Pacific solar Hydrogen (3.6GW)**	Australia
14	**Green Marlin (3.2GW)**	Ireland
15	**H2-Hub Gladstone (3GW)**	Australia
16	**Moolawatana Renewable Hydrogen Project (3GW)**	Australia
17	**Murchison Renewable Hydrogen Project (3GW)**	Australia
18	**Unnamed (3GW)**	Namibia
19	**Base One (2GW)**	Brazil
20	**Helios green Fuels Project (2GW)**	Saudi Arabia

Source: IRENA, 2022

3. Uruguay as a case study

3.1. Energy transition

Uruguay can be considered as a success story in terms of the first energy transition.

The electricity mix of the country was historically composed of thermal and hydroelectric capacity, with a strong dependence on hydrological conditions, which led to high supply costs in dry years, particularly aggravated when occurring in conjunction with high international prices of oil and its derivatives.

During the decade 2010–2020, there was a strong penetration of Non-Conventional Renewable Energy (NCRE) sources: wind, solar photovoltaic and biomass. These have diversified the system with autochthonous sources, increasing its resilience, stabilizing costs and lowering its environmental impact.

As portrayed in the figure below, NCRE installed capacity soared from 7% of Uruguay's total installed capacity in 2007, to 45% in 2021. In terms of electricity production, the renewable share averaged 97% in the period 2017–2020[19], becoming the second country in the world in terms of wind and solar share in the electricity mix, after Denmark.

Table 3. Integration of NCRE

	Total installed capacity (MW)	NCRE (% of total)	Hydro (% of total)	Fossil fuels (% of total)
2007	2406	7	64	29
2014	3716	24	41	34
2021	4912	45	31	24

Source: authors' elaboration based on data from MIEM[20]

The first energy transition had a significant impact on Uruguay's economy. Investments in renewable energy in the past decade exceed USD 8 billion[21],

19 Ministerio de Industria, Energía y Minería (MIEM) (2022). Green Hydrogen Roadmap in Uruguay. Available: https://www.gub.uy/ministerio-industria-energia-mineria/sites/ministerio-industria-energia-mineria/files/documentos/noticias/Green%20Hydrogen%20Roadmap%20in%20Uruguay.pdf

20 MIEM website. Series estadísticas de energía eléctrica. Available: https://www.gub.uy/ministerio-industria-energia-mineria/datos-y-estadisticas/datos/series-estadisticas-energia-electrica

21 Uruguay XXI (2022). Renewable energies in Uruguay. Available: https://www.uruguayxxi.gub.uy/uploads/informacion/df0a21ae89dff9e9729dd824da45eede094ef414.pdf

which corresponds to roughly 14% of the country's current Gross Domestic Product (GDP)[22].

It is beyond the scope of this article to deep dive into all the factors that have enabled the first energy transition in Uruguay, yet it is worth listing a few fundamental enablers:

- Support from the political system (2005–2030 Energy Policy signed by all political parties) with a clear long-term definition of NCRE promotion and penetration targets;
- High participation of the private sector through power purchase agreements (PPA) with adequate standards for access to financing, and transparent bidding processes;
- Tax exemptions and clear investment promotion framework for the incorporation of NCRE;
- Auto-dispatch of NCRE at zero marginal cost;
- Promotion of self-producing industrial consumers and distributed generation;
- Creation of an Energy Efficiency Trust;
- A favourable starting point:
  - ✓ Robust transmission system with new generation connection capacity in dispersed locations;
  - ✓ Prior assessment of wind resources;
  - ✓ Storage capacity to manage the intermittency of NCRE with hydroelectric reservoirs and back-up thermal generation;
  - ✓ Strong interconnection capacity with neighbouring countries (Argentina and Brazil) for occasional exchanges;
  - ✓ Institutional stability, transparency, macroeconomic balance and a positive sovereign credit rating (investment grade);
  - ✓ Absence of fossil resources made it not only environmentally and socially desirable to increase the participation of NCRE, but also to be the best economic alternative for the expansion of the electricity system.

Having virtually completed successfully the first energy transition, the country has outlined various objectives and policies for the second energy transition to be as successful as the first, in order to tackle the approximately 40% of energy needs still sourced from fossil fuels[23].

Given that the transport and industry sectors are the main consumers of fossil fuels, the target is being set on the electrification of small/medium-scale transport vehicles and industry feedstocks and processes, and the introduction of green

22 World Bank (2022). GDP (current US$) – Uruguay. Available: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=UY

23 MIEM (2022). Balance preliminary 2021. Available: https://ben.miem.gub.uy/

hydrogen for large-scale transportation, green fertilizer, and other derivatives (e.g., methanol and green ammonia) production and export.

3.2. Favourable conditions for green hydrogen production

As discussed further above in this article, green hydrogen is produced through water electrolysis, provided that the electricity was produced with renewable energy sources; in particular, non-conventional sources such as wind and solar.

In Uruguay, there are strong synergies between wind and solar resources, both daily and annually, which allow for high-capacity factors for electrolysers (i.e., actual electricity produced / theoretical maximum)[24].

The top graph of the figure below illustrates power production and demand during a typical summer day in Uruguay (January). As portrayed, wind power reaches its minimum around midday (green line), which coincides with the period of maximum output of solar energy (yellow line).

The bottom part of the figure portrays the annual (seasonal) synergy between wind (green line) and solar (yellow line), and also how they complement hydro power (blue line), which acts as a "natural power battery" in the country due to reservoirs.

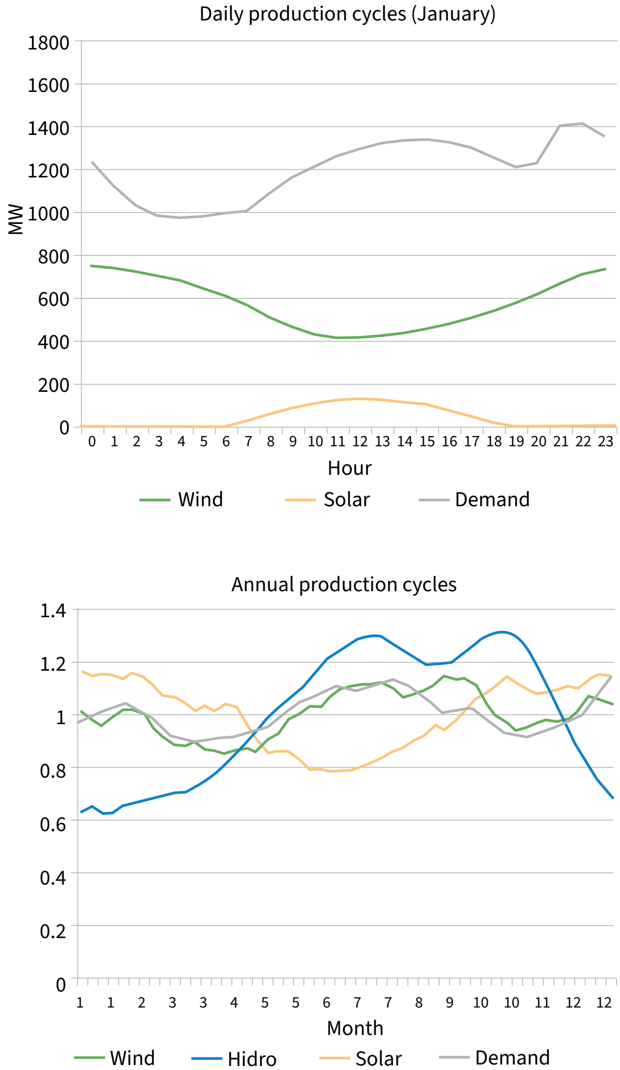
Summertime (December, January and February) is typically a dry period, and thus hydro power is at its lowest production, but this is complemented by the fact that solar power reaches its maximum in those months. Winter months (June, July, August) are typically rainy and when peak demand occurs in Uruguay (there might be isolated days in summer close to peak-demand due to air conditioning when high temperatures occur). In these months, solar reaches its minimum power production, which is complemented by the fact that wind and hydro reach their peak output.

Furthermore, Uruguay has a strong growth potential for further wind and solar deployment. Wind installed capacity could potentially increase from 1.5 GW (currently solely onshore) to 306 GW (30 GW onshore and 276 GW offshore) and solar capacity from 0.23 GW to 450 GW.

The low density of population of the country (20 inhabitants/km^2) allow for these projects to be installed in the country easier than in countries with higher population density (e.g., West Europe).

24 Port of Rotterdam and MIEM (2021). Uruguay – Port of Rotterdam Hydrogen Supply Chain. Available: https://www.gub.uy/ministerio-industria-energia-mineria/sites/ministerio-industria-energia-mineria/files/documentos/noticias/Hydrogen%20-%20Uruguay%20%26%20Port%20of%20Rotterdam.pdf

Figure 15. Daily and annual production cycles of wind and solar energy in Uruguay



Source: Port of Rotterdam and MIEM, 2021

Furthermore, Uruguay has water availability and biogenic CO_2 as a by-product of pulp production, which is needed to produce hydrogen derivatives such as ammonia.

3.3. National green hydrogen strategy and roadmap

On June 2022, the Government of Uruguay presented its Green Hydrogen Roadmap[25], developed with support from consultancy firm McKinsey, and financing from the Inter American Development Bank (IADB). The process involved participation and consultation of public and private companies, the academic sector and civil society.

Uruguay's green hydrogen roadmap aims to position the country as a world leader in the production and export of green hydrogen. In order to achieve this ambitious goal, the roadmap structures the development of the national sector in three stages:

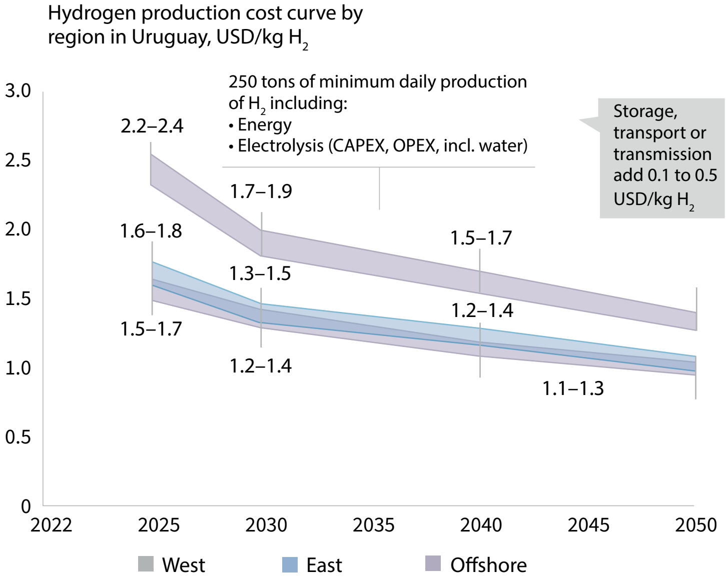
- **First stage (2022–2024)**: will seek to boost the domestic market and pave the way for the first export projects. During this stage, it is expected that 1 or 2 small-scale projects will be developed, which could arise with the support of the Green Hydrogen Sector Fund convened by the national agency of research and innovation of Uruguay (ANII, acronym in Spanish). In this stage specific regulation will be implemented, infrastructure built, and fiscal incentives granted, among others.
- **Second stage (2025–2029)**: will seek to increase the scale of the domestic market and also start the operation of initial export projects. These could be hydrogen derivatives such as green methanol or ammonia. Projections for this stage include 3–4 medium-scale projects and 1–2 large-scale projects.
- **Third stage (2030–2040)**: the roadmap estimates the installation of 20 GW of renewable energy and 10 GW of electrolysers. The installation of 20 GW of electricity generation from non-conventional renewable sources (i.e., wind and solar), would imply installing 10 times the current capacity of these sources in Uruguay. Although this is substantial, the potential is even greater, considering offshore resources.

3.4. Projected costs, investments, and market

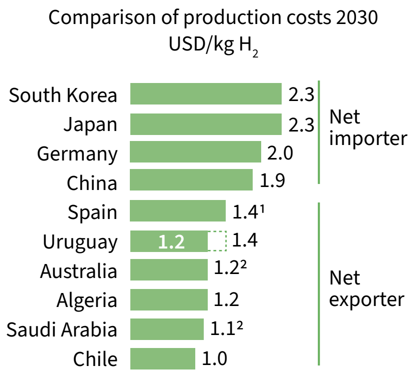
According to the green hydrogen roadmap, by 2030 the Levelised Cost of Hydrogen (LCOH) in Uruguay would range between 1.2 and 1.4 USD/kg in the west of the country, and between 1.3 and 1.5 USD/kg in the east (see figure below), for a project scale superior to 500 MW. These production costs would allow Uruguay

25 Howarth, R. W., and Jacobson, M. Z. How green is blue hydrogen? Available: https://onlinelibrary.wiley.com/doi/10.1002/ese3.956

Figure 16. Cost of hydrogen projection in Uruguay, 2020–2050



Sorce: McKinst & Company in accordance with contract C-RG-T3777.P001 entered into with the IADD: Hyrdogen Council Hydrogen Insights Report 2021



[1] Benchmark taken from HyDeal ad for production costs at scale, excludes transportation and distributions costs.
[2] Benchmark taken from Hydrogen Council projections, xcludes transportation and distributions costs 3. WACC Chile 6%, Australia 5.4%, Saudi Arabia 5.3%, Spain 5%.

Source: Uruguay XXI, 2022

to compete with net exporting countries such as Chile, Saudi Arabia, Oman, Namibia or Australia.

By 2040, green hydrogen (and its derivatives) could generate revenues of USD 2 100 million per year for Uruguay (domestic market plus exports), as well as the creation of 35 000 jobs considering construction, operation and maintenance phases, among other. These would be direct positions; thousands of indirect jobs would also be created.

The above-mentioned Port of Rotterdam study estimated accumulated investments required to build the Uruguayan Hydrogen supply chain under three scenarios (Conservative / Medium / Ambitious). In the early stage of development (2020s), investment would range between USD 1.7 and 3.3 billion between scenarios. In the mid-stage (2030s), additional USD 1.5–3 billion would be required, whereas in the long-term (2040s), the lowest investment would be USD 2.6 billion, and the ambitious scenario would require USD 39 billion.

Conclusion

Green hydrogen has gained international momentum as a key decarbonisation enabler, as economies around the world diversify their energy needs away from fossil fuels in the context of the Paris Agreement. This is particularly true for hard to abate sectors, including heavy industry and long-distance transport (air, maritime and land), where electrification is not possible. In addition, its versatility would allow a vast number of uses across several other sectors as mentioned throughout this article.

Furthermore, green hydrogen would allow to further integrate non-conventional renewable sources (especially wind and solar) by providing long-term and large-scale storage capacity, bridging the gap produced by their intermittency.

The green hydrogen economy could require cumulative investments of up to USD 10 trillion by 2050 (approximately 10% of the world's current GDP), and hydrogen could represent up to 22% of final energy demand (soaring from the current 0%).

This enormous potential has lead dozens of countries around the world to develop national strategies and roadmaps, and sign bilateral agreements to jointly develop research programs, explore harmonising standards, and foster the green hydrogen market and economy overall.

Uruguay, a country that has successfully completed its first energy transition, and benefits from favourable conditions to produce green hydrogen competitively, is aiming to position itself as a leader in the green energy economy. By 2040, this may require cumulative investments of USD 39 billion for the country (roughly 66% of its current GDP).

In 1874, science fiction author Jules Verne wrote:

[…] water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable. Someday the coal-rooms of steamers and the tenders of locomotives will, instead of coal, be stored with these two condensed gases, which will burn in the furnaces with enormous calorific power.

(Jules Verne, Mysterious Island, 1874)

At the time of writing this paper, Germany announced the first train line running exclusively on hydrogen close Hamburg[26], after having announced in 2018 the world's first hydrogen-powered train[27]. Needless to say, whether or not green hydrogen will become "an inexhaustible source of heat and light" as envisioned almost 150 years ago in a science fiction classic, allowing economies to decarbonise their energy needs by 2050, remains unknown. Notwithstanding, its chances are higher now than ever before.

26 DW (2022). German train line switching fully to hydrogen. Available: https://www.dw.com/en/german-train-line-switching-fully-to-hydrogen/a-62907198

27 The Guardian (2018). Germany launches world's first hydrogen-powered train. Available: https://www.theguardian.com/environment/2018/sep/17/germany-launches-worlds-first-hydrogen-powered-train

Kaushal Kishore

Energy transition in India and emergence of electric vehicles: Opportunities and challenges ahead

The Paris agreement on climate change and COP26 summit have made the countries of the world to think seriously on uses of various sources of energy to achieve economic growth and development. The economic growth and consumption of energy resources are having direct linkages. Higher the growth, higher the demand of energy resources, leading to higher the emission. So, the challenges are clear and complex.

The developing countries including India have set up their own target to support climate neutrality without compromising the economic prosperity. To achieve such a target, a lot of effort is required, which is not easy to do. The rise of crude prices and gas prices made the Indian government and stakeholders think on reducing dependence on fossil fuel to renewable energy. These alternate energies are environmentally friendly and also support the economy to backing the mission of Energy Transition.

The Energy Transition in India and globally is also driven by various policies formulation and implementation including the adoption of E-Vehicles. The present paper is an attempt to share a perspective based on the experiences and expertise developed as to how the Indian Economy has accepted the challenges of adopting renewable energy and EVs to support the energy transition. The secondary source of information available in the forms of reports from governments, consulting firms and other stakeholders have added value to the discussions. The articles published in the leading newspapers and articles published in the journals are of great help. The study may help the stakeholders to understand the importance and process of energy transition and make them change their mind-sets in adopting according to the need of the hour.

1. Ideation

Since 2010, India's energy sector has observed phenomenal changes. Starting from deregulation of pricing of petrol in the 2010 followed by deregulation of pricing of Diesel in the 2014 have changed the overall scenario in the energy domain. Deregulation of fuel prices helped the government and oil companies to control over the losses and under recovery due to the subsidies provided on these fuels. The market driven prices of fuel have improved the efficiency in terms of its usage and economy at large has benefited in the long run.[1] Such reforms have given the opportunities to private players and Multinational Companies (MNCs) to engage themselves in the downstream businesses in India actively. Since then, the scenario of Fuel Retailing has changed a lot in many aspects.

Theme Report on Energy Transition: Towards the Achievement of SDG 7 and NET-ZERO Emissions[2] has been the torch bearer for writing this paper. The UN suggested eleven recommendations for achieving the SDG7 goals and decarbonized energy system by 2050. The first recommendation was to increase the contribution of renewable energy to 8000 GW. The second one was to improve the energy efficiency from 0.8% to 3%. The third recommendation was to invest in physical infrastructure to enable the energy transition. The fourth one as OECD countries should phase out coal by 2030 and non-OECD countries should phase out by 2040. The fifth one, to mainstream energy policies into industrial, labour, economic, social strategies and education. The sixth one was to boost sustainable economic growth, formalising the integrated energy policies. The seventh one, to promote regional energy markets. The eight one was to intensify international co-operation to support the energy transition. The ninth one was the development of sustainable road transport roadmaps. The tenth one, to Tailor labour and social protection policies. And finally, the eleventh one was to make the energy transition as a participatory enterprise.

The initiatives of UN on addressing several global challenges specially on climate change has made the countries of world to re-think and re-strategies the way energy is being consumed and wastage at the cost of compromising with sustainable growth. Indeed, it would be interesting to see how the countries of the world are adapting themselves to support sustainable growth through the energy transition. It would be more interesting to observe the role of developed countries of the world for their strategies to move towards the suitability and time taken for such a move.

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1 Kishore, K. (2016). Petro-Retailing in the Future. *DEW: The Complete Energy Journal*, *25*(12), 65–70.

2 United Nations (2021). Theme Report on Energy Transition: Towards the Achievement of SDG 7 and NET-ZERO Emissions. Department of Economic and Social Affairs. Available: https://www.un.org/sites/un2.un.org/files/2021-twg_2-062321.pdf

2. India's commitment for sustainability and energy transition

"Energy transition refers to the global energy sector's shift from fossil-based systems of energy production and consumption including oil, natural gas and coal to renewable energy sources like wind and solar, as well as lithium-ion batteries".[3]

In the COP26 summit in Glasgow, the Prime Minister of India presented the following five nectar elements Panchamrit, to deal with the challenge of global warming. The first one is India to reach its non-fossil energy capacity from approximately 160 GW to 500 GW by 2030. The second commitment is interesting in many ways as India aims to meet 50% of its energy requirements from renewable energy by 2030 which is currently close to 39% of overall installed power capacity. The third Panchamrit as, India to reduce total projected carbon emissions by one billion tonnes from now onwards until 2030. The fourth one, as of 2030, India will reduce the carbon intensity of its economy by less than 45%. And finally, by year 2070, India will achieve the target of Net Zero.[4]

India's annual CO_2 emissions have risen to become the third highest in the world though the per capita CO_2 emissions in India is almost at the bottom of the list of world's CO_2 emitters. The targets for 2030 as set up by the Government of India, for reducing the emissions intensity of its economy by 45%, and reducing a billion tonnes of CO_2.[5] Indian government is committed to support the world in achieving the sustainable goal with the help of focused and sector specific approaches.

India is the third largest energy market in the world and also takes the third place in global emission. However, the per capita energy consumption is much lower than global standards. A lot of efforts are being made by the government to improve socio-economic status of the society and economy in addition to improving the basic infrastructure. In achieving such gigantic tasks, a lot of energy resources are required, which may lead to higher emissions. However, the initiative and commitments are loud and clear, as a lot of emphasis is given on taking renewable energy to the next level in the overall energy basket.

In addition to faster adoption of renewable energy, the focus is on improving the efficiencies from all sectors. In the recent past, the refineries and automobile sectors of India have upgraded themselves from BS-IV to BS-VI to match with

3 S&P GLOBAL (2020, February 20). What is Energy Transition? Available: https://www.spglobal.com/en/research-insights/articles/what-is-energy-transition

4 PPAC (2021). India's Oil & Gas Ready Reckoner: Oil Industry Performance at a Glance. New Delhi: Petroleum Planning & Analysis Cell, Ministry of Petroleum & Natural Gas, Government of India.

5 IEA-1 (2022, January 10). India's clean energy transition is rapidly underway, benefiting the entire world. Available: https://www.iea.org: https://www.iea.org/commentaries/india-s-clean-energy-transition-is-rapidly-underway-benefiting-the-entire-world

Euro-VI standards. Such an upgrade indeed asked for huge investment and fortunately the stakeholders could manage it successfully. Even the customers are okay with paying higher prices for the automobile to support innovation and sustainability. The scrapping policy has been brought by the Government of India for automobile sectors, in which old vehicles having high emission can go for scrapping the vehicle to gain some incentives to buy new bikes/cars and to support the sustainability. The utilities companies are diversifying more towards generating more power from renewable sources and also cutting down the dependencies on coal etc. They are also working hard on reducing Transmission and Distribution (T&D) losses. Overall, it looks like that everyone is sinking with achieving the mission of sustainability.

The investment in Energy Transition depends on understanding of energy and its resources and by the investors.[6] The investors are now prioritising environmental, social and governance and Energy transition is going to be an important factor of investment.[7] Energy Transition is an opportunity for the economy like India in fostering higher growth. Green hydrogen, renewable batteries and other low-carbon technologies can create an $80 billion market for India by 2030. India may need $160 billion per year from today till 2030 to reach net zero emission by 2070 and it is important for developed countries of the world to support the mission.[8] The price rise of fossil fuel, the global energy crisis and commitments to support the sustainability are silently giving the opportunities for Nuclear power to come back strongly.[9] The usage of technologies to improve energy efficiency, energy storage are driving the initiates of Energy Transitions in addition to producing the power from renewable energy.

6 Bain & Company (2022). Global Energy and Natural Resources Report 2022. Bain & Company. Available: https://www.bain.com/globalassets/noindex/2022/bain_report_global-energy-and-natural-resources-2022.pdf

7 S&P GLOBAL (2020). What is Energy Transition? February 20. Available: https://www.spglobal.com/: https://www.spglobal.com/en/research-insights/articles/what-is-energy-transition

8 IEA-1 (2022, January 10). India's clean energy transition is rapidly underway, benefiting the entire world. Available: https://www.iea.org: https://www.iea.org/commentaries/india-s-clean-energy-transition-is-rapidly-underway-benefiting-the-entire-world

9 IEA-2 (2022). Nuclear power can play major role in clean energy transition: IEA. India: Investing.com. Available: https://in.investing.com/news/nuclear-power-can-play-major-role-in-clean-energy-transition-iea-3258513

3. Scenario of EVs in India

Road transport currently accounts for nearly three quarters of transport CO_2 emissions.[10] India imports more than 80% of crude oil, 54% of natural gas and 24% of coal requirements from the rest of the world. These heavy imports also affect the financial health of the economy. India's oil import bill for the financial year 20 was close to US$ 101.4 billion.[11] India's target to reduce its carbon emission to net-zero by the year 2070 also depends on how EVs emerge to join the mainstream of the transportation system. By 2030, 80% of two and three-wheelers, 70% of commercial vehicles and 30% of private cars will be as EVs as the goal set up by India.[12] The growth of EVs in India is significant and it is expected that in a couple of years the number can go up to 3 crores (30 million) from the current status of 12 lakhs (1.2 million).[13] India's share in EVs are negligible globally though it is the largest 3W and 2W amongst the top five in passenger cars segment and commercial vehicles.[14]

The Government of India has reduced the Taxes/GST (GST or Goods and Services Tax, is an indirect tax imposed on the supply of goods and services) on electric vehicles from 12% to 5% and the GST rate on charger or charging stations for Electric vehicles reduced from 18% to 5%.[15] Additionally, to promote the EVs, there is exemption of paying the registration fee of vehicles, provision of providing the specific parking slots are interesting incentives given the government to promote the EVs in India under the Faster Adoption and Manufacturing of

10 United Nations (2021). Theme Report on Energy Transition: Towards the Achievement of SDG 7 and NET-ZERO Emissions. Department of Economic and Social Affairs. Available: https://www.un.org/sites/un2.un.org/files/2021-twg_2-062321.pdf

11 Ernst & Young (2022). Unlocking India's hydrogen ambitions. India. Available: https://www.ey.com/en_in/energy-resources/how-can-india-unlock-its-green-hydrogen-ambitions

12 Livemint (2022, February 16). Electric Vehicles in India; miles covered and miles to go. *Livemint*. Available: https://www.livemint.com/auto-news/electric-vehicles-in-india-miles-covered-and-miles-to-go-11644845581284.html

13 The Hindu (2022. May 7). Number of Electric Vehicles in India to reach 3 crore in two years, says Gadkari. *The Hindu*. Available: https://www.thehindu.com/business/Industry/number-of-electric-vehicles-in-india-to-reach-3-crore-in-two-years-says-gadkari/article65390856.ece

14 Livemint (2022, February 16). Electric Vehicles in India; miles covered and miles to go. *Livemint*. Available: https://www.livemint.com/auto-news/electric-vehicles-in-india-miles-covered-and-miles-to-go-11644845581284.html

15 Press Information Bureau, GoI (2019). GST rate on all Electric Vehicles reduced from 12% to 5%. New Delhi: Press Information Bureau, Ministry of Finance, Government of India. Available: https://pib.gov.in/newsite/PrintRelease.aspx?relid=192337

(Hybrid) and Electric Vehicles in India (FAME) – II.[16] Government also announced 0% customs duty on nickel core-a key component of lithium ion batteries, which was earlier 5%. The incentive for purchasing an EV (2W or 4W) on loan is exciting, the tax exemption of up to Rs.1 50 000 (US$ 1 960) under section 80EEB of income tax is also provided to buyers.[17] Such policies are very much similar to the home loans benefits provided to home buyers and because of this real estate business in India has grown multi fold. The buyers were encouraged to buy to get benefits from the policies and owned a house.

The supply chain disruptions may hurt the movement of battery storage, renewable energy and EV growth due to non-availability or poor supply of manufacturing components to critical materials and minerals.[18] Sharma, Sinha, & Kautish suggested government to bring stringent policy for the protection of environment and also incentivised the consumption of renewable energy.[19] The EVs market in India is evolving very fast with sales up 168% Year on Year (YoY) in 2021 as almost 0.32% vehicles are sold in comparison to the last year. Globally, EVs has 8.3% share in 2021 in compare to 4.2% in 2020 with 6.75 million vehicles on the road.[20]

The energy transition is a pivotal enabler of sustainable development and climate resilience. The European Union and 31 other countries have set net-zero targets of 2050 (United Nations, 2021).[21] Hero Electric (36%), Okinawa (21%) and Ather Energy (11.1%) commands the electric two-wheeler market in India with a collective market share of 64%. In the passenger vehicle segment, Tata Motors is leading with 71% of market share in the passenger vehicle segment led by their two key models, Nexon and Tigor EV. MG Motors with MG EZS provides 439 KM range on a single charge, holding the second highest market share in India.[22]

16 Deloitte (2020). Indian Electric Vehicle segment might continue to draw investments. Deloitte Touché Tohmatsu India LLP. Member of Deloitte Touché. Available: https://www2.deloitte.com/content/dam/Deloitte/in/Documents/finance/in-fa-ev-covid-noexp.pdf

17 IBEF (2022). Electric Vehicles Market in India. I. B. Foundation, Producer. Available: https://www.ibef.org/blogs/electric-vehicles-market-in-india

18 Deloitte Insights (2021). Renewable transition: Separating perception from reality. Deloitte Development LLC. Available: https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/us-renewable-energy-transition.html

19 Sharma, R., Sinha, A., & Kautish, P. (2020). Does renewable energy consumption reduce ecological footprint? Evidence from eight developing countries of Asia. *Journal of Cleaner Production, 285.* https://doi.org/10.1016/j.jclepro.2020.124867

20 IBEF (2022). Electric Vehicles Market in India. I. B. Foundation, Producer. Available: https://www.ibef.org/blogs/electric-vehicles-market-in-india

21 United Nations (2021). Theme Report on Energy Transition: Towards the Achievement of SDG 7 and NET-ZERO Emissions. Department of Economic and Social Affairs. Available: https://www.un.org/sites/un2.un.org/files/2021-twg_2-062321.pdf

22 IBEF (2022). Electric Vehicles Market in India. I. B. Foundation, Producer. Available: https://www.ibef.org/blogs/electric-vehicles-market-in-india

Electric mobility can provide a lift to industrial and economic competitiveness by attracting a lot of investments in the country. EVs come with zero or ultra-low tailpipe emission and noise pollution is also negligible.[23] The overall scenario for EVs in India and globally looks promising in many ways.

4. Opportunities and Challenges for EVs in India

India is an emerging market for the EVs and EVs are environment friendly when comparing the vehicles running on internal combustion engine (ICE) vehicles.[24] The availability of a good number of public charging infrastructure facilities, incentives for vehicle purchase, providing dedicated parking facilities and technological advancement can uptake the EVs in India.[25]

EVs in India are facing challenges like 'Range Anxiety', High Purchase cost for customers, lack of charging infrastructure, battery technologies, service & maintenance etc.[26] The EVs companies in India and in the world must address these challenges to make the transition meaningful.

To make a smooth movement of adoption of EVs in India 'Political will' is an important factor. The existing vehicles-ICE have been a great source of revenue to the state and central government. In the last 4 years, the efforts made by the government is indeed appreciable. A lot of incentives are being provided by the government to the consumers for buying EVs. The incentives include exemption of paying the registration fee in addition to other benefits. The Demand side incentives to the consumers of EVs will motivate them to think of buying EVs.

Technological improvement is required to bring down the cost of EVs in India. Though the majority of population is sensitive in their consumption, affordability is a concern, not just only in India but in all such developing and poor countries. Once the price of EVs will be at par with ICE, the uptake of EVs will be faster. The government has cut down the taxes to create the ecosystem to support the EVs companies to foster the culture of innovation and technological improvements.

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23 Bureau of Energy Efficiency, GoI (2022) E-Mobility. Bureau of Energy Efficiency, Ministry of Power, Government of India. Available: https://beeindia.gov.in: https://beeindia.gov.in/content/e-mobility

24 Trivedi, J. P., & Kishore, K. (2020). Investigating the factors influencing consumers' purchase intention for electric cars: an emerging market perspective. *Int. J. Economics and Business Research, 20*(2), 117–137.

25 Goel, S., Sharma, R., & Rathore, A. K. (2021). A review on barriers and challenges of electric vehicle in India and vehicle to grid optimisation. *Transportation Engineering, 4*. https://doi.org/10.1016/j.treng.2021.100057

26 Kumar, R., Jha, A., Damodaran, A., & Bangwal, D. (2021). Addressing the challenges to electric vehicle adoption via sharing economy: an Indian perspective. *Management of Environmental Quality, 32*(1), 82–99. https://doi.org/10.1108/MEQ-03-2020-0058

Such supply side incentives will encourage the manufacturers of EVs in India to expedite the process of producing more at the better price.

Range anxiety and battery life are indeed a point of concern for the buyers as well as sellers. A lot of efforts are required to improve the range and battery life. All leading EVs companies in India like Tata Motors, MG, Mahindra & Mahindra, Hero Motors, Okinawa and Ather Energy are working on the challenges of range anxiety and life of a battery.

The charging infrastructure at the public place and at the residence are important aspects to the faster adoption of EVs in India. As of now, approximately 1800 charging stations are there in India, which is not sufficient enough to take care of growing demands of EVs. Hence, it is important to encourage Public sector companies, Private sector companies and start-ups to join hands together to achieve the mission of sustainability and energy transition. The EVs companies can offer a long-term guarantee on batteries of EVs that will help them to sell out more EVs in a shorter span of time. In today's scenario, the ICE vehicles when going to a gas station/petroleum retail outlet to buy fuel (Petrol/Diesel), it takes 3–4 minutes to get the work done. In case of EVs, for battery charging facilities the time varies from minutes to hours. A lot of efforts are required to bring down the challenges of charging batteries at the charging stations. EVs can think of working on swapping the battery then charging, but what about compatibility of battery. EVs can work on bringing the commonality with batteries across different types of vehicles so that battery swapping may be possible.

India is the 5th largest automobile market in the world. In India, 22 people out of a thousand own a car, while in the US 980, UK 850, New Zealand 774, Australia 740, Canada 662, Japan 591, and China has 164.[27] On the other hand, India is improving on macroeconomic indicators like GDP, Per capita income, household income, more importantly, the aspirations of society keep on rising. The women are competing with men in the journey of job, career and businesses. The villages are becoming smart villages and towns are moving towards sustainable consumption. In all such scenarios, the future of automobile companies in India is huge and it is going to be interesting to observe who gets the bigger pie of market share in EVs in days to come.

In India, two wheelers and three wheelers are leading in the EV segment. The four-wheeler vehicles are slowly but steadily growing and EVs companies are excited about it. The government and company can play an important role in making public transport comfortable, convenient and sustainable. The public

27 Abbas, M. (2018, December 12). India has 22 cars per 1000 individuals: Amitabh Kant. *Economic times*. Available: https://auto.economictimes.indiatimes.com/news/passenger-vehicle/cars/india-has-22-cars-per-1000-individuals-amitabh-kant/67059021#:~:text=NEW%20DELHI%3A%20India%20has%20a,top%20government%20official%20Wednesday%20said

transport system in India requires a huge support from the government as the number of fleets are less and the quality of roads need to be improved across the country. EVs buses can be deployed faster on the road for public transport in India across all cities and hence it is the high time for the government and other stakeholders to expedite the process.

Conclusion and future outlook

EVs in India are supporting the movement of energy transition with open arms. The biggest challenges before the society and economy are known as how existing skills, labours and enterprises are accommodating themselves in the transition period. They all need to upgrade themselves to remain relevant else they all will struggle for existence. The companies and government should address these challenges in a better manner as what best they can do to keep such people, organisation relevant. The simple example to support the argument is if an ICEVs plant decides to shift from existing technology to EVs, what will happen to those workers who are working there for long. Will the shift from ICEVs to EVs absorb all the workers of the plant? If not, then what are the alternative plans the companies and government are having to engage them?

Like Norway and other countries of the world, government and local authorities can think of designing a special lane for EVs on road in addition to providing the parking facilities for EVs car holders without charging much. Such policies may motivate the consumer to go with EVs.

The majority of India's population lives in the villages. The half of the two-wheeler demands are coming from rural India. The rising income of the rural population due to the opportunities created by the government, makes these inhabitants the target customers for automobile companies. The villages of India now have access to electricity, clean drinking water 24 × 7 The roads and railway infrastructure are connecting them from the villages to the nearest market in a shorter time. EVs companies should think of engaging franchisee/dealers/collaborators for EV charging stations in rural India as well. The adoption of EVs in rural India will bring lots of opportunities for EVs companies in the days to come.

The Society of Indian Automobile Manufacturers[28] is a giving sufficient indications that the sales of vehicles in the Indian market is growing at the right pace. The export of vehicles from India to the rest of world is also growing. The 'Make in India' campaign which offers a lot of incentives to investors in all

28 SIAM (2022). Automobile Domestic Sales Trends. Society of Indian Automobile Manufacturers (SIAM). Available: https://www.siam.in/statistics.aspx?mpgid=8&pgidtrail=14

sectors including the automobile and EVs, may further increase the production, consumption and exports of all commodities including the EVs.

Certainly, as of now, it appears that the Indian economy and government is committed to maintain the balance with growth without compromising with sustainability. Of course, the developed countries of the world must make a point in achieving net zero emission by 2050 so that poor and developing countries will follow their path. India as a representative of 'Global Champions of Energy Transition' of the world is guiding others to achieve economic and social prosperity without hurting the ecology and environment.

The NITI Aayog's intentions are to reach EV sales penetration of 30% for private cars, 80% for two and three-wheelers, 70% for all commercial cars, 40% for buses by 2030.[29] The adoption of EVs in India depends on various factors. Though everyone wants to have their own vehicles/cars but they are not ready to pay the higher price. Hence, it is important for EVs companies globally to bring down the price of cars/vehicles closer to the ICEVs so that shifts can be easier and faster. Secondly, the charging facilities for EVs should be more and more to address the concern of charging stations and range anxiety. Thirdly, the companies must think on addressing the compatibility issues of the batteries for EVs, that will strengthen the idea of 'Battery Swapping' at the charging stations or any other relevant locations. The concerns of employees, labourers who are working with the ICEVs plants, should be trained so that they can continue contributing to the sectors. The start-ups and entrepreneurs can do wonders in the domain and hence, government and policymakers may encourage them through various schemes to get into the business of EVs. Overall, it appears that India, an emerging market of the world, is moving in the right direction to meet carbon neutrality by 2070. Renewable energy is going to play a vital role in achieving this gigantic task. Thus, the EVs in India are going to make the transportation system more efficient, affordable and sustainable.

29 IBEF (2022). Electric Vehicles Market in India. I. B. Foundation, Producer. Available: https://www.ibef.org/blogs/electric-vehicles-market-in-india

Olegs Krasnopjorovs

Is Riga a green city? Measuring a perceived quality of the environment in Riga compared to other European cities

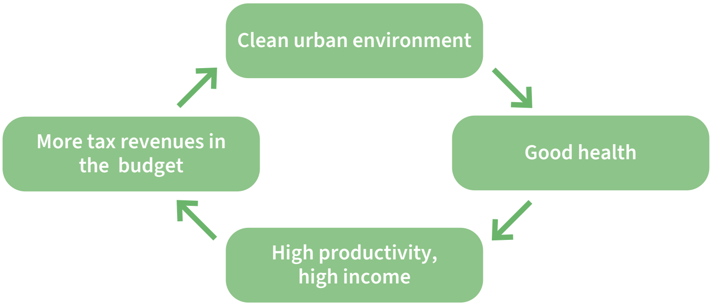
This paper assesses a perceived quality of urban environment in Riga both over time and compared to other European cities. It finds that perceived environmental quality in Riga is still slightly above the European average, but in several dimensions Riga lags behind Tallinn and Vilnius. Particularly, residents of Riga are less satisfied with the air quality, drinking water quality, waste disposal, and the general cleanliness of the city. The author documents a lack of progress with perceived quality of urban environment in Riga over the recent years, and discusses the links between the urban environmental quality and people's health, economic development and the overall life satisfaction.

1. Literature review

Quality of urban environment is one the key areas of urban life satisfaction. Rich cities are usually less polluted than poor ones – this is unlikely to be a coincidence. The urban environment is an important element of the quality of life, affecting health, life expectancy and overall life satisfaction. Longer healthy life expectancy tends to raise labour productivity and, thus, income. Higher incomes, in turn, mean higher tax revenues for the city budget, providing an opportunity to further improve the urban environment. Globally, the most polluted cities are located in India, which are also poor. Environmental pollution is likely to be one of the causes and consequences of this poverty. In turn, the cities of Northern Europe are both clean and rich. This anecdotal evidence is in line with the Environmental Kuznets Curve hypothesis, suggesting that after a certain income threshold more economic growth goes hand-in-hand with better environment. Wealth allows for environmental cleanliness, but a clean environment promotes wealth (Figure 1).

Air and noise pollution are recognised as two most important environmental problems in the European cities.

Figure 1. Theoretical model of urban environment, population health and economic growth



Source: author's elaboration.

Air pollution is negatively related with life satisfaction, health and life expectancy. For instance, Ferreira et al.[1] point to a robust negative relation between air pollution (measured by sulphur dioxide concentrations) and self-reported life satisfaction in the European countries. Jorgenson et al. (2021)[2] reveal that in a global cross-country setup this relation is stronger for countries with higher income inequality, which might intensify a segregation of lower-income groups to areas with high air pollution. Branis and Linhartova[3] present an evidence from the Czech Republic that residents of large cities are exposed to high levels of traffic-related air pollution. Rodriguez-Alvarez[4] documents a negative relation between air pollution and life satisfaction for a sample of European countries, pointing out that especially particulate matters with a diameter of less than 2.5 μm are detrimental to the life expectancy. Due to its small size, PM2.5 can remain in the air for a long

1 Ferreira, S., Akay, A., Brereton, F., Cuñado, J., Martinsson, P., Moro, M., Ningal, T. F. (2013). Life satisfaction and air quality in Europe. *Ecological Economics, 88*, 1–10. https://doi.org/10.1016/j.ecolecon.2012.12.027

2 Jorgenson, A. K., Thombs, R. P., Clark, B., Givens, J. E., Hill, T. D., Huang, X., Kelly, O. M., Fitzgerald, J. B. (2021). Inequality amplifies the negative association between life expectancy and air pollution: a cross-national longitudinal study. *Science of the Total Environment, 758*, 143705. https://doi.org/10.1016/j.scitotenv.2020.143705

3 Branis, M., Linhartova, M. (2012). Association between unemployment, income, education level, population size and air pollution in Czech cities: evidence for environmental inequality? A pilot national scale analysis. *Health & Place, 18*(5), 1110–1114. https://doi.org/10.1016/j.healthplace.2012.04.011

4 Rodriguez-Alvarez, A. (2021). Air pollution and life expectancy in Europe: Does investment in renewable energy matter? *Science of The Total Environment, 792*, 148480. https://doi.org/10.1016/j.scitotenv.2021.148480

time and enter the bloodstream after inhalation. Khomenko et al.[5] claim that air pollution in European cities above World Health Organization (WHO) upper thresholds is responsible for more than 50 thousand premature deaths annually. The highest mortality burden due to air pollution was recorded in Northern Italy, Poland and the Czech Republic, while the lowest – in northern Europe, with Riga showing relatively high nitrogen dioxide (traffic) emissions comparing to the other cities in the region.

There is also well-established negative link between noise pollution and health outcomes. The main source of noise pollution in the European big cities is road traffic noise, followed by rail and air traffic, recreational activities and industry. Majority of European city residents are exposed daily to ambient noise levels above 55 dB – exceeding this threshold is recognized to be undesirable[6]. Veber et al.[7] document a considerable negative health effects of noise pollution, particularly from road traffic, in two Estonian cities, Tallinn and Tartu. They recognize transport noise as being important factor for cardiovascular diseases (hypertension, myocardial infarction and stroke), mental disorders, diabetes, obesity, breast cancer and adverse birth outcomes. Overall, noise pollution in European cities can cause around 12 thousand premature deaths per year. European Environment Agency data confirm that the biggest source of noise in Riga is road transport – it exposes 526 thousand people to noise pollution (5 out of 6 city residents; moreover, 38 thousand people in Riga are exposed to railway noise and 13 thousand – to industrial noise).

A detrimental impact of air and noise pollution is not always fully recognized. Moreover, this recognition is likely to differ substantially across European cities, and might correlate with the stage of economic development. For instance, Chiarini et al.[8] show that many people living in Central and Eastern European countries have a high tolerance towards urban air pollution even it is high as measured by the hard data. Such an adaptation towards high air pollution may reflect a situation when growth-driven pollution is not perceived as harmful. Note that this is in

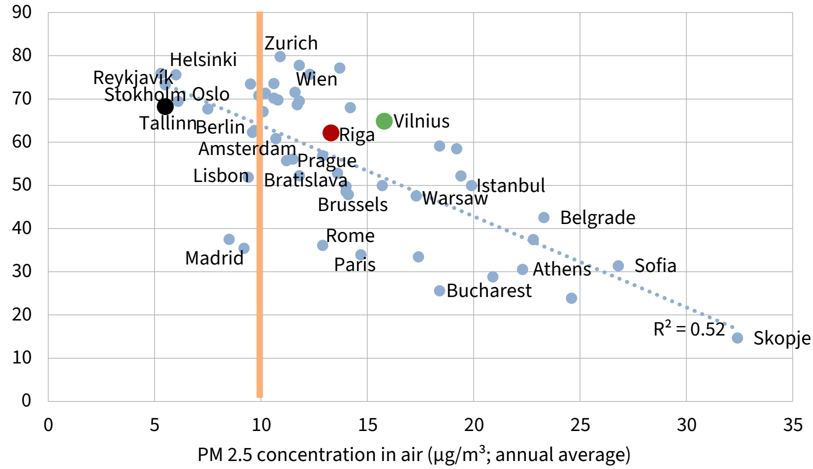
5 Khomenko, S., Cirach, M., Pereira-Barboza, E., Mueller, N., Barrera-Gómez, J., Rojas-Rueda, D., de Hoogh, K., Hoek, G., Nieuwenhuijsen, M. (2021). Premature mortality due to air pollution in European cities: A health impact assessment. *The Lancet Planetary Health, 5*(3), e121–e134. https://doi.org/10.1016/S2542-5196(20)30272-2

6 Lawrence, R. J. (2013). Urban health challenges in Europe. *Journal of urban health: bulletin of the New York Academy of Medicine, 90*(1), 23–36. https://doi.org/10.1007/s11524-012-9761-z

7 Veber, T., Tamm, T., Ründva, M., Kriit, H. K., Pyko, A., Orru, H. (2022). Health impact assessment of transportation noise in two Estonian cities. *Environmental Research, 204*, Part C, 112319. https://doi.org/10.1016/j.envres.2021.112319

8 Chiarini, B., D'Agostino, A., Marzano, E., Regoli, A. (2021). Air quality in urban areas: Comparing objective and subjective indicators in European countries. *Ecological Indicators, 121*, 107144. https://doi.org/10.1016/j.ecolind.2020.107144

Figure 2. **Concentrations of PM2.5 in the air and public satisfaction with air quality in European cities (in 2019)**



Note. The orange line represents the World Health Organization threshold for airborne concentrations of PM 2.5 (particulate matter less than 2.5 microns in diameter) of 10 µg / m³. Satisfaction with air quality in the city: the balance of replies is recalculated on a 0–100 point scale, where "0" is very unsatisfied, "100" is very satisfied).
Source: author's calculations based on Eurobarometer and *IQ Air (World's most polluted cities)* data.

line with López-Ruiz et al.[9] showing that environmental dimension (compared to economic and social) is still unappreciated by many European citizens. For instance, in Riga and Vilnius people's satisfaction with air quality is higher than the level which corresponds to the actual concentrations of PM2.5 in the air. Riga and Vilnius have similar PM2.5 air concentrations as Paris, Brussels or Rome, while enjoying relatively higher people's satisfaction with air quality (Figure 2). The World Air Quality report reveals that cities from Central and Eastern Europe represent 88% of the most polluted places in Europe. Apart from private car transport congestions, this could be attributed to the insufficient use of renewables in the energy sector and combustion of solid fuels in the household sector.[10]

This article systematically assesses a perceived quality of urban environment in the European cities, particularly focusing on Riga. Riga is the economic, political and cultural capital of Latvia, and the most populous city within a radius of 400 kilometres.

9 López-Ruiz, V.-R., Alfaro-Navarro, J.-L., Nevado-Peña, D. (2019). An Intellectual Capital Approach to Citizens' Quality of Life in Sustainable Cities: A Focus on Europe. *Sustainability, 11*(21), 6025. https://doi.org/10.3390/su11216025

10 Karpinska, L., Śmiech, S. (2020). Invisible energy poverty? Analysing housing costs in Central and Eastern Europe. *Energy Research & Social Science, 70*, 101670. https://doi.org/10.1016/j.erss.2020.101670

2. Data and methods

Urban environmental quality could be assessed via hard and soft data. The former consists of pollution amounts recorded at the monitoring stations, while the latter is based on surveys conducted among the city residents. Both data sources have its merits and drawbacks. On the one hand, hard data are largely affected by destination of the monitoring stations and weather effects, which distorts comparison both across countries and time periods. Although hard data provide a measure, for instance, regarding the prevalence of different particulate matters in the air, these data are difficult to aggregate in a single variable which would reflect an overall environmental quality in a city. On the other hand, survey data reflect the subjective perception of the respondents compared to the imagined ideal situation. Residents of different cities tend to have different understandings about the latter, and it is likely to change over time. Also, respondents' satisfaction may decline if improvement in a given area is slower than expected.

This article follows the most recent literature analysing the environmental aspects of the quality of life by employing mainly the soft data. In a world displaying a plethora of information, composite social and economic indicators have become extremely popular as a way to aggregate different dimensions in a single index, dimensions that would otherwise be difficult or impossible to compare.[11] Two soft data sources used extensively in this article are European Commission Perception Survey on the Quality of Life in European Cities (hereafter – Eurobarometer) and Numbeo survey data. Moreover, data for Riga city is supplemented by SKDS survey data.

The most recent wave of Eurobarometer survey was conducted in 2019 and consists of 83 European cities. In each city 700 respondents were surveyed; the structure of respondents by age and gender is in line with the structure of general population in a given city. Respondents rated different aspects of the quality of life, with some questions related to the quality of urban environment – particularly, satisfaction with air quality, noise level, green areas and cleanliness of the city. Each respondent was asked to rate each of these aspects on a 5-point Likert scale (very satisfied; rather satisfied; rather unsatisfied; not at all satisfied; do not know). Eurostat provides the percentage of respondents in each category as separate variables. This article follows Okulicz-Kozaryn and Valente[12] to create one variable per every question in a given city.

11 Goerlich, F. J., Reig, E. (2021). Quality of life ranking of Spanish cities: A non-compensatory approach. *Cities, 109*, 102979. https://doi.org/10.1016/j.cities.2020.102979

12 Okulicz-Kozaryn, A., Valente, R. R. (2019). Livability and Subjective Well-Being Across European Cities. *Applied Research in Quality of Life, 14*, 197–220. https://doi.org/10.1007/s11482-017-9587-7

The following transformation was used:
Variable used here = (very satisfied ∗ 1) + (rather satisfied ∗ 0.75) +
+ (don't know ∗ 0.5) + (rather unsatisfied ∗ 0.25) + (very unsatisfied * 0) [1]

The respective variable ranges between a theoretical "0" when everybody is very unsatisfied with environmental quality, to "+100" when everybody is very satisfied.

Numbeo runs continuous survey of internet users summarized biannually. Each biannual release consists of replies recorded over the recent 36 months. Sample of cities could vary from one to another biannual release, which makes it harder to compare results between cities over time. Although self-selection of respondents means that structure of respondents by age and gender might not correspond to the general population of a city, and technically it is possible to participate in Numbeo survey without residing in a respective city, a mechanism is employed by Numbeo to drop out irrelevant answers (outliers). While each respondent rates different quality of life areas in a 5-point Likert scale, Numbeo reports only aggregate value of a particular area on a 0–100 points scale (see equation [1]).

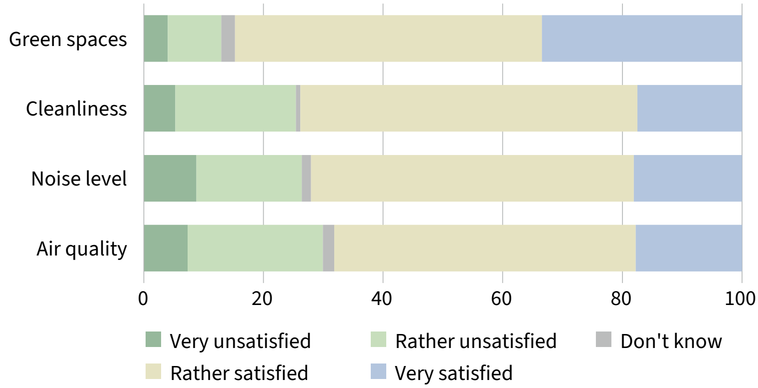
SKDS survey assesses public evaluation of different Riga City Council activities and is regularly published at the Riga City Council website. SKDS survey runs quarterly as from 2011, with some questions available even from 1997. Each quarter sample consists of several hundred respondents, which allows SKDS to disentangle public perceptions by gender, age group, education level, language spoken at home, citizenship, employment status, income quartile and even a particular city district. Results of SKDS survey are weighted and therefore are representative of Riga population. SKDS respondents express their views in a 5-point Likert scale; in this article, it was recalculated to a 0–100-point scale according to equation [1].

3. Empirical results and discussion

The most recent Eurobarometer data (5^{th} wave of the survey, conducted in 2019) reveal that although majority of Riga residents are rather satisfied with the quality of urban environment, there is a non-negligible share of unsatisfied respondents. The share of unsatisfied Riga residents varies from 13% on green spaces to 30% on air quality (Figure 3).

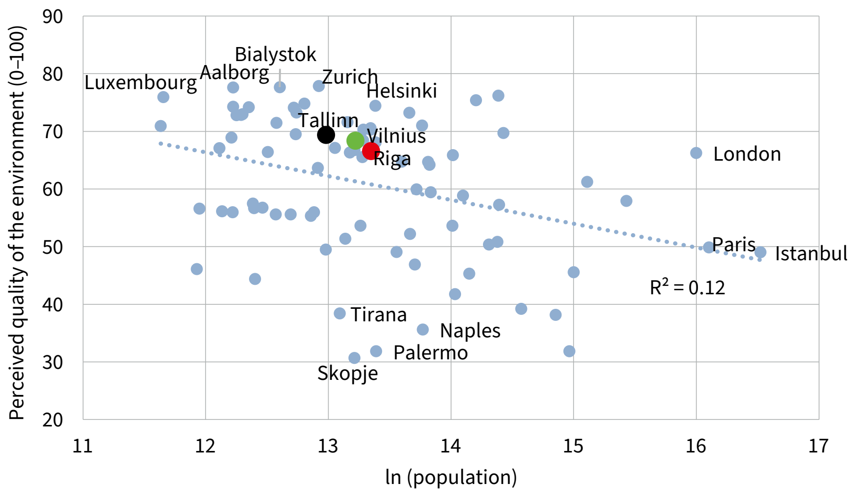
Perceived environmental quality in Riga is slightly above the European average. Partly this reflects rather small city size. There is a weak, albeit a statistically significant negative relationship across the European cities between the city size (measured by population) and perceived quality of the environment

Figure 3. Satisfaction of Riga residents with the quality of urban environment (%; in 2019)



Source: Eurobarometer survey data.

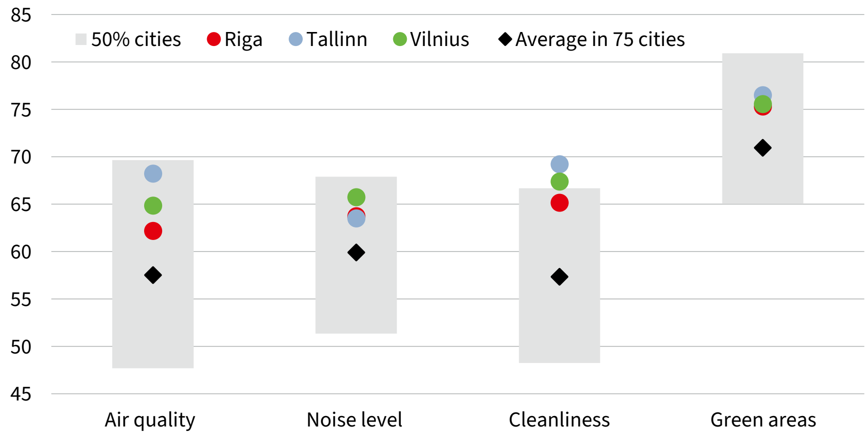
Figure 4. Perceived quality of the environment and city population across European cities (in 2019)



Note. Perceived quality of the environment reflects the average satisfaction with the following four environmental dimensions: air quality, noise level, cleanliness, green areas. Balance of replies was recalculated to 0–100 point scale where 0 means very unsatisfied, 100 – very satisfied.

Source: Eurobarometer survey data, author's calculations.

Figure 5. Perceived quality of urban environment in Riga, Tallinn and Vilnius compared to other European cities (0–100 point scale; in 2019)



Note: balance of replies was recalculated to 0–100 point scale where 0 means very unsatisfied, 100 – very satisfied. 75 cities considered in this figure belong to the EU countries as well as UK, Iceland, Norway and Switzerland.
Source: Eurobarometer survey data, author's calculations.

in a given city. In other words, it is more difficult for large cities to maintain high environment satisfaction among its residents. Note, however, that the quality of environment in Riga is perceived to be slightly better than in many European cities of similar size, which is reflected by a position of Riga city slightly above the regression line (Figure 4).

Eurobarometer survey also reveals that in several urban environmental quality dimensions, particularly in the areas of cleanliness and air quality in the city, Riga lags behind Tallinn and Vilnius (Figure 5). Numbeo survey further confirms that Riga lags behind Tallinn and Vilnius in several dimensions of urban environmental quality. In particular, residents of Riga are less satisfied with air quality, drinking water quality, garbage disposal, and the general cleanliness of the city (Table 1).

One striking fact about the perceived environmental quality in Riga is the lack of progress over time. Ten years ago the quality of the environment in Riga was perceived as being the best among the Baltic capital cities. This is evidenced by the fact that Riga residents were more satisfied in all four environmental dimensions: satisfaction with air quality, noise level, cleanliness of the city and green areas. Since then, Tallinn and Vilnius have made significant progress, while environmental improvements in Riga have been modest. Thus, currently Riga lags behind Tallinn and Vilnius in almost all dimensions of environmental quality (Figure 6).

Table 1. **Environment and pollution perceptions in Riga, Tallinn and Vilnius (balance of replies; 0–100 point scale)**

	Riga	Tallinn	Vilnius
European Commision survey (2019):			
Satisfaction with air quality	62.2	68.2	64.9
Satisfaction with noise level	63.7	63.5	65.7
Satisfaction with cleanlines	65.1	69.2	67.4
Satisfaction with green spaces	75.3	76.5	75.6
Numbeo survey (2022):			
Air pollution	62.6	82.0	76.3
Drinking water pollution and inaccessibility	74.0	86.7	90.9
Satisfied with garbage disposal	64.6	74.7	65.5
Clean and tidy	68.0	74.8	81.0
Noise and light pollution	58.1	62.4	71.0
Water pollution	68.4	82.1	79.2
Satisfied with green spaces and parks	85.7	75.3	89.2

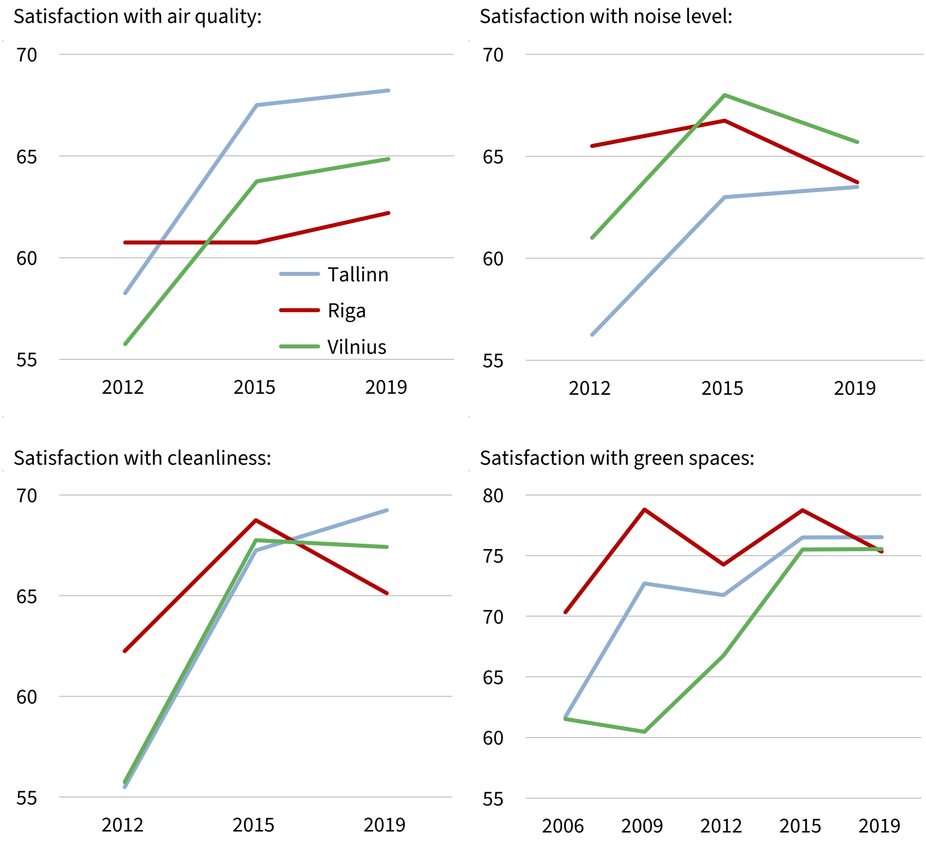
Note. Cell's colour reflects the place of a particular city among Baltic capital cities: green: the 1st place (best); yellow: the 2nd place; gray: the 3rd place (worst). Eurobarometer survey (2019): number of respondents is 700 in each city. Numbeo survey (2022): number of respondents – 126 in Riga, 103 in Tallinn, 95 in Vilnius.
Source: Eurobarometer and Numbeo survey data, author's calculations.

Moreover, SKDS survey data show a downward trend among Riga residents in the satisfaction with cleanliness, waste management and green areas over the last three years. For instance, Riga residents currently are satisfied with cleanliness of the city similarly as they were 20 years ago. Satisfaction with waste disposal, on the other hand, is now lower than ever since regular surveys began in 1997. Also, the satisfaction of Riga residents with the green areas in the city deteriorated recently – currently it is similar to the level recorded about ten years ago (Figure 7).

A recent slowdown in a satisfaction with waste management may be partly attributed to growing payments for removal of household waste. However, growing expenses are not likely to be the only reason behind a downward satisfaction trend, as satisfaction with cleanliness and green areas of the city decreased at the same time. Likewise, Covid-19 pandemics is unlikely to be the major factor of decreased satisfaction since perceived cleanliness started to decline even before the outbreak of the virus.

It should be noted that the use of soft data to assess the environmental quality in a city is not without limitations. What is measured in surveys like Eurobarometer, Numbeo and SKDS, is subjective perception of respondents compared to the imagined ideal situation. Residents of different cities tend to have

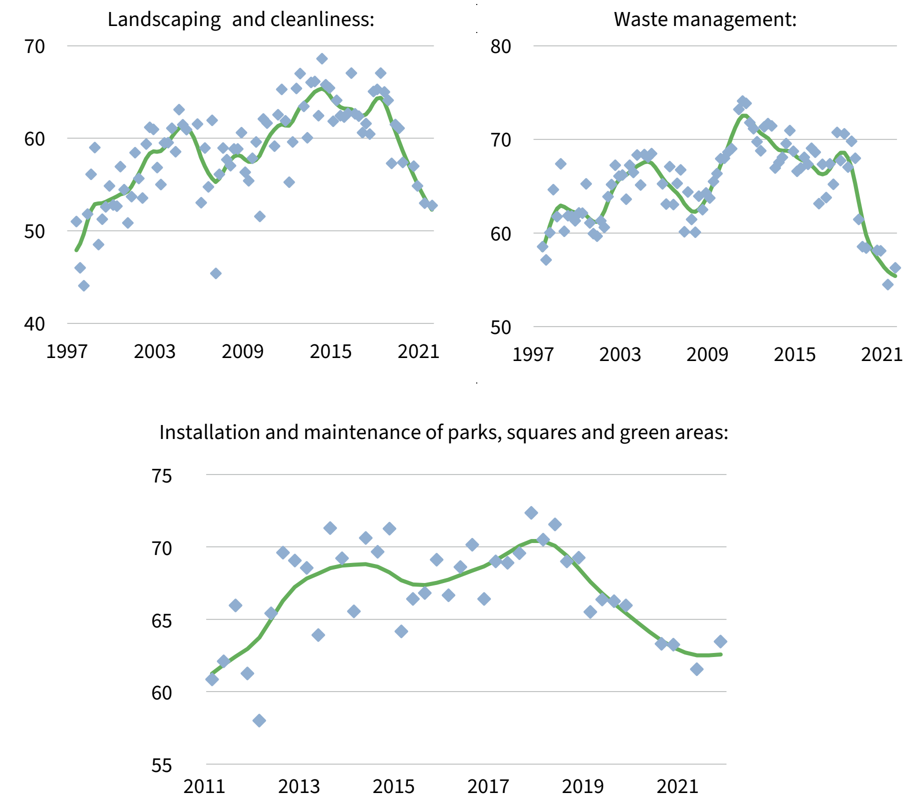
Figure 6. Environmental quality changes in Riga, Tallinn and Vilnius (0–100 point scale)



Note. The balance of replies to each question was recalculated on a 0–100 point scale, where 0 – very dissatisfied, 100 – very satisfied.
Source: Eurobarometer survey data, author's calculations.

different understandings about the latter, and it is likely to change over time. For instance, respondents' satisfaction may decline if improvement in a given area is slower than expected; in this case, perceived environmental quality may be biased downwards. At the contrary, perceived quality of the urban environment might be biased upwards if detrimental impact of air and noise pollution is not fully recognized in a given city.

Figure 7. **Satisfaction of Riga residents with the cleanliness of the city, green areas and waste removal (0–100 point scale; over 1997–2021)**



Note. The balance of replies is recalculated on a 0–100 point scale, where "0" means completely unsatisfied, "100" means completely satisfied. The blue dots represent the data of the SKDS quarterly survey. The green line reflects the trend filtered by the Hodrick-Prescott filter (lambda = 10). In some quarters (including due to Covid-19 restrictions) the survey was not conducted – the relevant data were interpolated.
Source: SKDS survey data, author's calculations.

Conclusion

1. Perceived environmental quality in Riga is slightly above the European average, which only partly reflects rather small city size.
2. In several environmental quality dimensions Riga lags behind Tallinn and Vilnius. Particularly, residents of Riga are less satisfied with the air quality, drinking water quality, garbage disposal, and the general cleanliness of the city.
3. Perceived quality of urban environment in Riga lacks progress over time. For instance, Eurobarometer 2012 survey reveals that Riga residents were

the most satisfied with the environment compared to residents in Tallinn and Vilnius, while in 2019 Riga residents were the least satisfied with the environment.

4. Perceived quality of the environment in Riga deteriorated over the period of Covid-19 pandemics. SKDS survey data point to a considerable decrease in the satisfaction with cleanliness, waste management and green areas in the city. Alternatively, this trend might reflect a growing demand for improvement of environmental quality in a city, which is yet to be satisfied.

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The monograph

TOWARDS CLIMATE NEUTRALITY: ECONOMIC IMPACTS, OPPORTUNITIES AND RISKS

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FOREWORD

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INTRODUCTION

Prof. Inna ŠTEINBUKA

PART I: SCENE SETTING

Minister for Climate and Energy Raimonds Čudars in interview with Olga Bogdanova

Raimonds ČUDARS was born in 1974 in Riga. Graduated from the Faculty of Law of the University of Latvia, practiced as an attorney of law. Since 2001, a council member of Salaspils municipality. From 2009 to 2022, he held the position of chairman of Salaspils municipality council. For many years, he has ensured governance of the municipality with the "backbone" of Latvia's energy sector – Riga Hydroelectric Power Plant and Combined Heat and Power Plant TEC2. In 2022, he was elected to the Parliament of the Republic of Latvia from the political party New Unity (Latvian: *Jaunā Vienotība*, JV). Since 14 December 2022, he holds the position of Minister for Climate and Energy in the second Cabinet of Ministers headed by Krišjānis Kariņš.

Europe's energy policy – from short-term solutions to the crisis to long-term outlook

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PART II: ENERGY POLICY AND ECONOMY

Long-term macroeconomic trends affecting the Latvian energy sector

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Factors affecting energy costs: Green Deal impact

Olga BOGDANOVA

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The role of natural gas in energy transition

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Substitution elasticity of energy and other production factors: An empirical estimation for 27 EU Member States and other major economies

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PART III: FINDING THE BEST BALANCE OF ENERGY TRILEMMA

Latvia's energy supply and security

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Latvia's environmental sustainability and green energy development in terms of the WEC Energy Trilemma Index Tool

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Energy equity: Story about equality. Equity common analysis

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Life cycle assessment of renewable energy sources towards climate neutrality – Portuguese case study

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PART IV: CASE STUDIES OF TRANSITION-RELATED FIELDS

Emerging green hydrogen economy and Uruguay as a case study

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Energy transition in India and emergence of electric vehicles: Opportunities and challenges ahead

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Is Riga a green city? Measuring a perceived quality of the environment in Riga compared to other European cities

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Abbreviations

ADF	Augmented Dickey Fuller
AFC TCP	Advanced Fuel Cells Technology Collaboration Programme
AFID	Alternative Fuels Infrastructure Directive
ANII	National Agency of Research and Innovation of Uruguay
APEC	Asia-Pacific Economic Cooperation
APS	Announced Pledges Scenario
ARDL	Auto-Regressive Distributed Lag
AST	Augstsprieguma tīkls, JSC
BECCS	Bioenergy with Carbon Capture and Storage
BNEF	Bloomberg New Energy Finance
BP	British Petroleum
BRELL	Belarus, Russia, Estonia, Latvia, Lithuania energy system
BS	Bharat Stage
CAP	Common Agricultural Policy
CAT	cap and trade
CBAM	Carbon Border Adjustment Mechanism
CCGT	Combined Cycle Gas Technology
CCS	carbon capture and storage
CCUS	carbon capture usage and storage
CEER	Council of European Energy Regulators
CEPSA	Compañía Española de Petróleos, S.A.U. (Spanish Petroleum Company)
CES	Constant Elasticity of Substitution
CEF	Connecting Europe Facility
CGE	Computable General Equilibrium
CH_4	methane
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2 eq.	carbon dioxide equivalent
COP	Conference of the Parties
COP28	The 28th session of the Conference of Parties to the UNFCCC
COVID-19	Coronavirus disease 2019
CPRICE	carbon price-based scenario
CSB	Central Statistical Bureau of Latvia
CSIS	Centre for Strategic and International Studies
Cu eq.	copper equivalent
dB	decibel
DNV GL	an international accredited registrar and classification society headquartered in Høvik, Norway
DSO	distribution system operator
EC	European Commission

ECM	Error Correction Model
ECM – GH	Error Correction Model – Gregory and Hansen
EE	Estonia
EIA	U.S. Energy Information Administration
EMFF	European Maritime and Fisheries Fund
ENTSO-E	European Association of Transmission System Operators for Electricity
EPC	Council's Economic Policy Committee
ERDF	European Regional Development Fund
ETC	Energy Transition Commission
ETS	Emissions Trading System
EU	European Union
EU ETS	European Union Emissions Trading System
Eurostat	Statistical Office of the European Union
EV	electric vehicle
FAME	Faster Adoption and Manufacturing of Electric and Hybrid Vehicles
FCEV	fuel cell electric vehicle
FELPT	Future Energy Leaders Portugal Programme
FGLS	Feasible Generalized Least Square
FI	Finland
GDP	Gross Domestic Product
GECF	Gas Exporting Countries Forum
GHG	greenhouse gas emissions
GIPL	Gas interconnection Poland-Lithuania
H_2	hydrogen
H_2O	water
HES	Hicksian Elasticity of Substitution
HF Center	United States Center for Data Analysis Heritage Foundation
HPP	hydro power plant
HRS	hydrogen refueling station
IADB	Inter-American Development Bank
ICE	internal combustion engine
ICEV	internal combustion engine vehicle
IEA	International Energy Agency
IEEJ	Institute of Economics
IPCC	Intergovernmental Panel on Climate Change
IPS	Im, Pesaran, Shin
IRENA	International Renewable Energy Agency
IT	information technologies
ITER	international thermonuclear experimental reactor
JB	Jarque–Bera
kgoe	kilogram oil equivalent
KLE	Capital, Labour and Energy

KLEM	Capital, Labour, Energy and Material
LCA	Life Cycle Assessment
LCOH	Levelised Cost of Hydrogen
LIAA	Latvian Investment and Development Agency
LLC	Levin, Lin, Chu
LM	Lagrange Multiplier
LNG	liquefied natural gas
LOHCs	liquid organic hydrogen carriers
LPG	liquefied petroleum gas
LULUCF	Land Use, Land-Use Change and Forestry
LV	Latvia
MIEM	Ministry of Industry, Energy and Mining of Uruguay
MNCs	multinational companies
MSCI	Morgan Stanley Capital International
Mtoe	million tonnes of oil equivalent
NARDL	non-linear auto-regressive distributed lag
NCRE	non-conventional renewable energy
NDICI	Neighbourhood, Development and International Cooperation Instrument
NEKP	Latvian National Energy and Climate Plan 2021–2030
NGFS	Network of Central Banks and Supervisors for Greening the Financial System
NGVs	natural gas vehicles
NH_3	ammonia
NOx	nitrogen oxide
NZE	Net Zero Emissions
OCT	overseas countries and territories
OECD	Organisation for Economic Co-operation and Development
oil eq.	oil equivalent
OLS	Ordinary Least Squares
OLS – FD	Ordinary Least Squares – First Difference
OPEC +	Organization of the Petroleum Exporting Countries
PEM	proton exchange membrane
PG	power generation
PM	particulate matter
PNEC 2030	National Energy and Climate Plan 2030
PP	Phillips–Perron
PPA	Power Purchase Agreement
PV	photovoltaic system
R&D	research and development
REG	Regulation-Based Scenario
RES	renewable energy sources
RRF	Recovery and Resilience Facility

SDG	Sustainable Development Goals
SKDS	Latvian private and independent company, which conducts public opinion research
SME	small and medium-sized enterprises
SOEC	solid oxide electrolyser cell
THE	Germany's Trading Hub Europe
TSO	transmission system operator
TTF	Title Transfer Facility
T&D	transmission and distribution
UGS	underground natural gas storage
UK	United Kingdom
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USD	United States dollars
WEC	World Energy Council
WHO	World Health Organization
WIOD	World Input-Output Database
YoY	year on year
ZTP	Belgium's Zeebrugge Trading Point

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Monogrāfija "Virzība uz klimata neitralitāti: ietekme uz ekonomiku, iespējas un riski" (*Towards Climate Neutrality: Economic Impacts, Opportunities and Risks*)

Kopsavilkums

Šīs monogrāfijas ideja ir prezentēt dažādu valstu zinātnieku starpdisciplinārus enerģētikai veltītus pētījumus, lai atbalstītu politikas veidotājus, zaļās transformācijas procesu pētniekus un jebkuru iesaistīto sabiedrības locekli izaicinājumiem bagātajā ceļā uz klimata neitralitāti.

Monogrāfijas galvenais mērķis ir veicināt Eiropas Savienības (ES) klimata neitralitātes sasniegšanu līdz 2050. gadam. Pētījumi ir veikti saskaņā ar Parīzes nolīgumu klimata pārmaiņu jomā, Eiropas Zaļo kursu, stratēģisko redzējumu "Tīra planēta visiem" un citu ES prioritāšu īstenošanu klimata pārmaiņu mazināšanas, enerģētikas, vides ilgtspējības un mobilitātes jomā. Savos pētījumos autori adekvāti reaģējuši uz pandēmijas krīzes sekām un globālā enerģijas tirgus darbības traucējumiem, ko izraisīja Krievijas iebrukums Ukrainā. Autoru ieteikumi var būt noderīgi ES atveseļošanas un noturības plāna Eiropai un *REPowerEU* plāna īstenošanā Latvijā un citās ES dalībvalstīs.

Pētījums labi atbilst Latvijas stratēģijai klimata neitralitātes sasniegšanai līdz 2050. gadam un Latvijas Nacionālajam enerģētikas un klimata plānam 2021.–2030. gadam, kas akcentē pāreju uz ilgtspējīgu energosistēmu, kā arī drošas un pieejamas enerģijas izšķirošo nozīmi.

Ievērojama atkarība no fosilajiem energoresursiem, kā arī Krievijas energoresursu importa būtisks īpatsvars ES tirgos, diversifikācijas un enerģētikas sektora izturētspējas trūkums rezultējās ar nepieredzēti augstu elektroenerģijas cenu līmeni 2022. gadā. Situācija kļuva kritiska pēc Krievijas iebrukuma Ukrainā, izaicinot ES rīkoties izlēmīgi ārkārtas situācijas apstākļos. ES bija spiesta uzņemties samazināt Krievijas gāzes piegādes par divām trešdaļām līdz 2022. gada beigām, meklēt alternatīvus piegādātājus, ieviest naftas embargo, kā arī paredzēt naftas cenas griestus. Ieviešot ārkārtas risinājumus, tika nodrošināts nepieciešamais energoresursu piegāžu drošības līmenis, lai gan gala lietotāji bieži vien apšauba tirgus mehānisma spēju nodrošināt pietiekamu energoapgādi par saprātīgām cenām. Meklējot iespējas paātrināt enerģētikas sektora ilgtspējīgu pāreju, tādējādi stiprinot energoapgādes drošību un enerģijas fizisko un ekonomisko pieejamību, autori pētījumos izceļ tādus svarīgus instrumentus kā energoefektivitāte, elektrifikācija, e-mobilitāte un dekarbonizācija, kā arī pievēršas nākotnes perspektīvāko tīrās enerģijas tehnoloģiju potenciālam. Būtiska nozīme pārmaiņu vadībā ir iesaistīto subjektu lokam klimata neitralitātes sasniegšanā, nodrošinot gan publiskā sektora (arī pašvaldību), gan komerciālā sektora, gan gala lietotāju proaktīvu iesaisti. Turklāt dekarbonizācija, izmaksu lietderība un pieejamība, piegādes drošība un tīkla stabilitāte, kā arī citi tīras enerģijas pārveidošanas mērķi ir atkarīgi

no efektīvas tīkla pārvaldības un tā optimizēšanas. Virzība uz klimatneitralitāti kā jebkura lielo pārmaiņu procesu pārvaldīšana ir saistīta ar riskiem. Tieši šo risku apzināšana un vieda rīcība, tos mazinot, būs noteicoša pārmaiņu veiksmīgai norisei.

Monogrāfijā ir četras nodaļas. Pirmajā nodaļā Latvijas klimata un enerģētikas ministrs Raimonds Čudars un Eiropas Komisijas izpildviceprezidents Valdis Dombrovskis iezīmē kopējo politisko noskaņojumu Latvijā un ES, risinot enerģētikas jomas izaicinājumus. Otrā nodaļa ir veltīta enerģētikas politikai un tās ietekmei uz tautsaimniecības attīstību. Monogrāfijas trešās nodaļas autori apskata optimālā Enerģijas trilemmas līdzsvara risinājumus. Ceturtajā nodaļā pētnieki analizē Urugvajas, Indijas un Latvijas pieredzi, koncentrējoties uz dažādām ar pāreju uz klimata neitralitāti saistītām jomām. Monogrāfijas tapšanā piedalījušies 45 pētnieki no septiņām valstīm.

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