Energy markets in transition

Economy. Climate. Technology. Regulation

Scientific seminars – School of Energy

The project manager: Grażyna Wojtkowska-Łodej

Project implemented from 1 October 2020 to 31 September 2022
within Ministry grant SONP/SP/469426/2020

https://energia.sgh.waw.pl/

Co-financed from the programme of the Minister of Education and Science
“Social Responsibility of Science”

Table of contents

Foreword **5**

Aleksandra Gawlikowska-Fyk

Chapter I. Trends in Global Energy Demand and Supply 8

Introduction 8

1. GDP and demography – increased energy demand factors 9
2. Forecasting uncertainty 9
3. Impact of the pandemic on the energy sector 11
4. Electrification 14
5. CO_2 emissions 15

Conclusions 16

Dariusz Michalski

Chapter II. Green Transition Financing Management 18

1. Systemic risk for financial institutions caused by climate change 19
2. Role of finance in the green transition 22
3. Impact of climate change risk on the performance of financial institutions 26
4. Selected activities of financial institutions related to climate change 27
5. Selected elements of green finance 32

Conclusions 36

Honorata Nyga-Łukaszewska

Chapter III. International Energy Markets and the Continuity of Energy Supply in the Era of the COVID-19 Pandemic 38

Introduction 38

1. Energy security in the 21st century 40
2. Impact of the COVID-19 pandemic of the selected fuel markets 40
3. Impact of the COVID-19 pandemic on the energy security 43

Conclusions 45

Paweł Wróbel

Chapter IV. Model of Energy Transition in the European Union 48

Introduction 48

1. Integration of the energy system 49
2. What is the role of hydrogen technologies? 49
3. Costs and benefits of sector integration 50
4. “Renovation wave” – a new model of modernisation of buildings 52
5. Transition financing 53

Conclusions 54

Ewa Mataczyńska
Chapter V. Energy Sector Transition as a Way to Accelerate Decarbonisation 56
1. Background of the issue and major targets of implementation 56
2. Sector coupling as a response to changes on the energy market 57
3. Major assumptions of the energy system integration and their significance 60
   3.1. Close circuit/energy efficiency 60
   3.2. Direct electrification 62
   3.3. Renewable fuels/hydrogen 63
   3.4. Multidirectional system/active customer 64
4. Opportunities, challenges and barriers 65
Conclusions 66

Katarzyna Stala-Szlugaj
Chapter VI. Is Carbon-Neutral Poland Feasible in the Perspective of 2050? 69
Introduction 69
1. Balance of coal in Poland 71
2. Major directions of climate and energy policy 73
3. Forecast of coal consumption in Poland 75
Conclusions 77

Dorota Niedziółka
Chapter VII. Determinants and Barriers to the Development of Green Energy in Poland 79
Introduction 79
1. Concept of green energy 80
2. Determinants of green energy development 81
3. Limitations to the development of green energy in Poland 82
4. Energy transition 84
5. Characterstics of the Polish electric energy market 85
Conclusions 88

Józef Paska
Chapter VIII. Renewable and Distributed Energy Sources in the National Power System – Determinants and Challenges 90
1. Definitions and classification 90
2. Technologies of renewable and distributed energy sources 91
3. Renewable and distributed energy sources and the power system 94
4. Economic aspects of renewable and distributed energy sources in the power system 101
Conclusions 103

Tomasz P. Wiśniewski

Chapter IX. **Energy Transition and Technological and Socio-Economic Progress** 105

Introduction 105

1. Energy transitions 106
2. Technological determinants of energy transitions. A historical approach 107
3. Technological determinants of the current energy transition 108

Conclusions 110

Hanna Bartosiewicz-Burczy, *Filip Schraube*

Chapter X. **Technical and regulatory approaches to enhance the renewable energy capabilities to take part actively in the electricity services markets – DRES2Market**................................... 112

Introduction 113

1. Barriers to the development of renewable sources of energy... 113
   - 1.1. Technological barriers 116
   - 1.2. Economic barriers... 117
   - 1.3. Social and environmental barriers 118
2. Company infrastructure 119
3. Analysis in PowerFactory (digSilent) – Test Case 1 – Analysing the impact of RES large penetration for grid congestions 124
4. Analyses in PowerFactory (digSilent) – Test Case 2 – Analysing the impact of self – consumption and storage on grid congestions 129
5. Targets of the DRES2Market project 134

Krzysztof Zagrajek

Chapter XI. **Electric Vehicles as Mobile Energy Storage Facilities. A Proposal of New Energy Services** 136

Introdution 137

1. Legal framework to create energy services using electric vehicles.. 139
2. Concept of an energy service programme using electric vehicles.. 143

Conclusions 145

Notes on the Authors 148

Foreword

The presented texts are related to the Ministry of Science and Higher Education grant: *A series of seminars – School of Energy* (SONP/SP/469426/2020) implemented at the Warsaw School of Economics in the period from 1 October 2020 to 31 September 2022. They cover the issues of theoretical and practical aspects of energy management on the global market, building a low-carbon economy in Europe in the perspective of 2050, energy and climate policy of the European Union, its consequences for Poland and the issue of the role of technological progress in the transformation of the energy sector. At the same time, they result from the participation of authors in the project and complete and/or extend the contents presented as part of the seminars.[1]

The Series of Seminars – School of Energy coincided with exceptional events that occured in the global economy, in the region of Central and Eastern Europe, namely the COVID-19 epidemic and the conflict in Ukraine. These events have a huge impact on energy management and implementation of regional development strategies, providing the supply of hydrocarbons to the countries of the region to meet the growing demand. While the time of the pandemic is inscribed in the substantive considerations planned in the grant, the events after 24 February 2022 and their impact on the energy market are not the subject of detailed analyses, although in the last module of seminars, carried out in the summer semester of the 2021/2022 academic year and in chapters 9–11, there were some indirect references to the challenges related to the conflict in Ukraine.

The reflections presented by Aleksandra Gawlikowska-Fyk on energy issues on the global market in Chapter I concern the analysis of trends in global energy demand and supply from the perspective of 2020. The author focuses on the issue of forecasting uncertainty and the effects of the pandemic on the energy sector; she refers in detail to the currently important problems related to electrification and CO_2 emissions.

The issues of climate change and the challenges it poses in the sphere of finance were taken up by Dariusz Michalski in Chapter II. The author emphasises the systemic risk for financial institutions and their functioning related to climate changes, and he attempts to determine the role of finance, financial institutions and financial instruments in the green transition.

---

[1] Presentations of invited experts/substantive guests are available at https://energia.sgh.waw.pl

In Chapter III, Honorata Nyga-Łukaszewska analyses energy security issues in the era of the COVID-19 pandemic. The analysis refers to selected international markets of energy raw materials and the continuity of supply in the pandemic conditions.

The next two chapters refer to the concept of building a low-carbon economy in Europe till 2050. In Chapter IV , Paweł Wróbel presents the model of energy transition in the European Union. He focuses on the actions already taken in the Union to change the economic structure and addresses the issues of the need to integrate the energy sector also in the context of financing the transition.

The issue of integration of the energy sector is thoroughly and multifacetedly presented by Ewa Mataczyńska in Chapter V. She presents the background of the current changes in the energy sector and she proves the significance of joining different sectors due to the changes on the energy market. Then, she examines the main guidelines for the integration of the energy system, including the concept of closed circularity and energy efficiency, direct electrification, renewable energy sources and hydrogen fuels, and the activation of the demand side. The considerations are the basis for showing possible solutions, visible challenges and barriers in the final part of the study.

The next three chapters are devoted to the theme of development possibilities of the Polish economy, with its energy determinants in the aspect of the EU energy and climate policy. In Chapter VI, Katarzyna Stala-Szlugaj attempts to answer the question whether a coal-neutral Poland is possible in the perspective of 2050. She presents in detail the balance of coal in Poland, its consumption forecasts and confronts them with the main directions of the EU energy and climate policy.

The energy transition is not only about the departure from high-emission fuels, but nowadays it is primarily about the opportunity to develop renewable energy sources. Determinants and barriers to the development of green energy are the subject of Dorota Niedziółka's reflections in Chapter VII. Introducing the initial concepts, the author defines the determinants of Poland in terms of the potential availability and possibility of using green energy, confronting it with the possibilities of its use on the Polish electricity market.

The topic of renewable and distributed energy sources in the National Power System is subjected to an in-depth analysis by Józef Paska in Chapter VII. The author introduces the issues related to the definition and methodology as well as the idea of renewable and distributed energy technologies and discusses their importance in the power system, paying particular attention to the economic issues.

The subject matter of the next three chapters refers to the importance of technological progress in the energy sector and the related transitions. They begin with Tomasz Wiśniewski's reflections on the energy transition and its technological determinants from the historical as well as contemporary perspective in Chapter IX.

Next , Hanna Bartosiewicz-Burczy and Filip Schraube analyse the role of technological and regulatory aspects of transition in Chapter X. They draw attention to their importance in increasing the development opportunities of renewable energy sources on electric power markets.

In the last chapter, Krzysztof Zagrajek presents the issue of new energy services in the form of the use of electric vehicles as mobile energy storage facilities. In the first part of his reflections, he analyses the legal framework necessary for the use of electric vehicles to create new energy services, then he presents the concept of a programme of such services.

The texts presented in the study may constitute an interesting material developing the interests and expanding the knowledge of undergraduate, graduate, doctoral and postgraduate students on the contemporary issues of energy management, in particular global trends in energy demand and its coverage, EU energy and climate policy and energy transition. At the same time, it can also become an inspiration for those interested in further expanding their knowledge in the field of sustainable energy management.

Grażyna Wojtkowska-Łodej

Aleksandra Gawlikowska-Fyk
Energy Forum

Chapter I

Trends in Global Energy Demand and Supply

Abstract

The COVID-19 pandemic was a shock to the energy system that had no precedent. It affected the functioning of all fuel and energy markets, although this impact was not always negative. The effects of the pandemic and, as a result, the slowdown in the global pace of economic development disrupted the functioning of markets. Although changes in the global demand and supply were significant, long-term trends remained largely unchanged, as shown by 2021 – the year of post-pandemic rebound. Regulatory policies are and will remain necessary to achieve sustainable changes, such as a significant reduction in greenhouse gas emissions or a reduction in the dependence on fossil energy resources.

Keywords: pandemic, energy market, energy transition, climate neutrality, energy trends

Introduction

The operation of energy markets in 2020 was disrupted by the COVID-19 pandemic. Predictions about the effects of the successive lockdowns of economies around the world proved difficult, but the prevailing view [Steffen, Egli, Pahle, Schmidt, 2020] was that 2020 would affect deviations from the economic and energy trends. The forecasts made in the middle of the crisis are not yet verifiable, especially since 2021 was also exceptional in terms of economic recovery, unstable fuel and energy markets or record high increases in emissions [IEA, 2021].

This chapter summarises the effects of COVID-19 on the global energy sector, based on the annual reports of the International Energy Agency – World Energy Outlook [IEA, 2020; IEA, 2021].

1. GDP and demography – increased energy demand factors

The pandemic had the greatest impact on the change in the demand for fuels and energy and their consumption. The main factors affecting energy demand in the long term are population growth and per capita income. GDP may grow at a rate of about 3.25% till 2040, while in 2050 there will be about 2 billion people more living in the world than today, a total of 9.6 billion, with the population growth accounting for less than 20% of GDP growth. Prosperity will become one of the factors creating energy trends in the coming years. The remaining increase will result from increased productivity. Thanks to it, the global income will have doubled by the middle of the century [IEA, 2020].

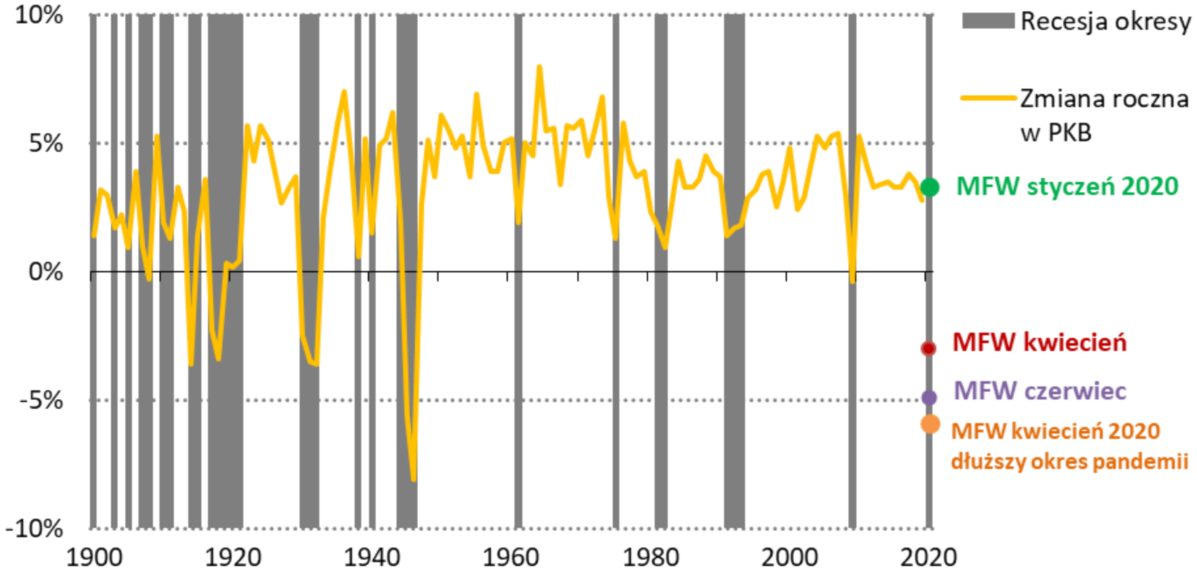
Global energy demand is not evenly distributed. Currently, developing countries (outside the OECD) account for 80% of the growth, of which India and China account for about half. However, after 2030, India will have the largest increase in energy consumption and will overtake China. The Middle Kingdom is already slowing down. It is due not only to the slowdown in economic growth, but also to the shift of the Chinese economy to more sustainable sectors. This shows the end of a phase of rapid economic growth connected with an increase in energy demand. Until now, in China, it has been concentrated primarily on the industrialisation of the country and driven by electrification. A slower growth and lower energy intensity of the country's economy are due to the fact that the growth will be less dependent on heavy industry, and services will play an increasingly important role.

An important characteristic of the increase in primary energy demand is that it grows more slowly than GDP growth. It is estimated [BP, 2020] that when global income doubles I 30 years, energy consumption will only increase by 35%. The average annual change in demand will be around 1.2% (2018–2050), while in previous years (1995–2018) it was 2%.

2. Forecasting uncertainty

Due to the growing global population and the continued rise in energy demand, the demand and supply trends are expected to continue. Nevertheless, the COVID-19 pandemic increased uncertainty about the depth and duration of the recession it caused, and consequently about energy forecasts. The International Energy Agency's flagship global forecasts in the World Energy Outlook reflect an increase in forecasting difficulties in the coming years, e.g. due to uncertainty about the GDP decline (see Figure 1).

Figure 1. Change in the global GDP against the background of global recessions (forecasts during the pandemic)



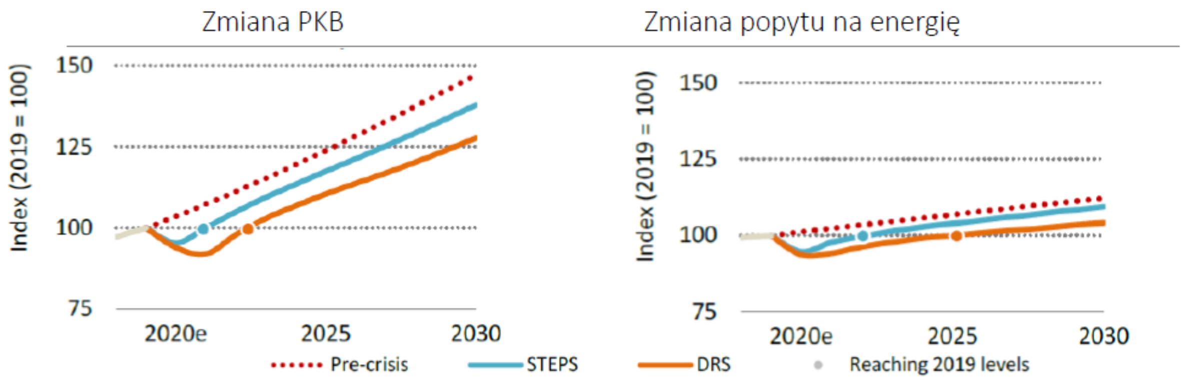
Source: IEA, 2020.

The scenarios proposed by the International Energy Agency were differentiated with regard to the duration of the pandemic, i.e. the impact on the economy and energy markets as well as climate targets. These scenarios were as follows [IEA, 2020]:

- *Stated Policies Scenario* (STEPS) – the scenario with the COVID-19 pandemic to be brought under control in 2021 and the economy to return to normal by that time. The scenario reflects the energy and climate policies already announced.
- *The Delayed Recovery Scenario* (DRS) – the pandemic will not be brought under control as quickly as in the STEPS scenario; cyclical outbreaks of COVID-19 will occur. The economy will return to normal in 2023. Like STEPS, this scenario also reflects the already announced policy intentions in the field of climate and energy.
- *Sustainable Development Scenario* (SDS) – the scenario in which the impact of COVID-19 is the same as in STEPS, and therefore relatively short-lived. An important element of the scenario is the assumption of achieving the goal of the Paris Agreement, i.e. an increase in the average global temperature at a level well below 2^0C. In this scenario, developed economies will become climate neutral by 2050 and the whole world by 2070.
- *Net Zero Emissions by 2050* (NZE2050) – this scenario duplicates the assumptions of the SDS (COVID-19 to be quickly combated, the goal of the Paris Agreement to be achieved), but with a faster pace of achieving climate neutrality – globally by 2050.

The scenarios constructed in this way gave rise to the presentation of various forecasts of the duration of the crisis and its consequences for the global energy demand. It is illustrated in Figure 2 and Table 1.

Figure 2. Forecasts of changes in GDP and energy demand



Source: IEA, 2020.

Table 1. Economic and energy impact of the COVID-19 pandemic

IEA scenario	Impact on the economy	Energy demand
STEPS	GDP returns to pre-crisis levels in 2021	Demand returns to pre-crisis levels in 2023
	In 2030, the global GDP is 7% lower than before the crisis	In 2030, the demand for coal is 8% lower than before the crisis
DRS	GDP returns to pre-crisis levels in 2023	Demand returns to pre-crisis levels in 2025
	In 2030, global GDP is 14% lower than before the crisis	In 2030, the demand for coal is 17% lower than before the crisis

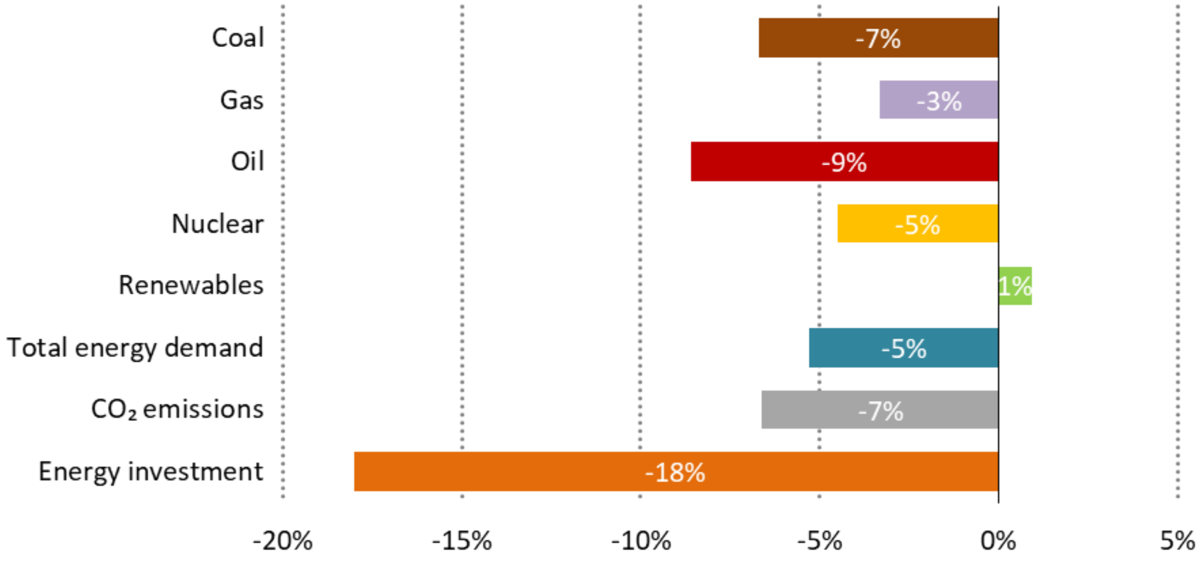
Source: IEA, 2020.

The results of the forecasts show that the effects of the pandemic, which in itself does not have to be long-lasting, on the economy and energy will be strongly felt in the next decade. Even if the world copes quickly with the pandemic, global energy demand will decrease by 8%. In a scenario of prolonged lockdowns, economies could fall by as much as 17%.

3. Impact of the pandemic on the energy sector

Nevertheless, the demand shock did not affect all energy sources evenly. Figure 3 shows that in 2020 there was a decline in demand for all fuels and raw materials except renewables. While the total decline in demand was 5%, renewables recorded a one-percent increase. The oil market (-9%) and coal (-7%) were hardest hit by the recession. It is also worth mentioning that such a change in the primary energy balance, according to the estimates of the International Energy Agency, translated into a significant, as much as, seven percent decrease in CO_2 emissions [IEA, 2020]. Another area negatively affected by the pandemic was energy investment. It was caused by many factors related, e.g. to the disruption of global supply chains, financial problems or physical absence of employees.

Figure 3. Impact of the COVID-19 pandemic on the global energy market (in %)



Source: IEA, 2020.

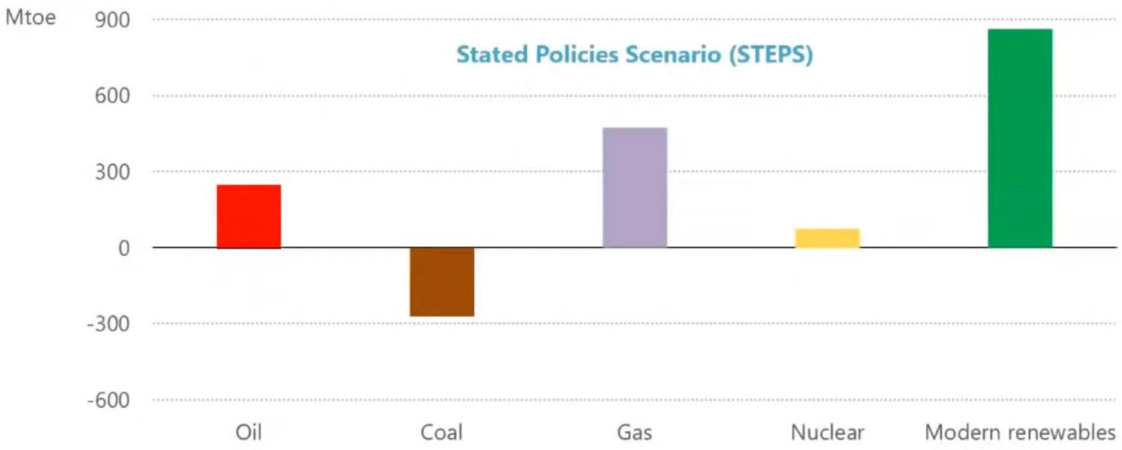
Medium-term trends for energy sources will depend on the duration of the recession. The longer it is, the greater the projected declines in fuel and energy demand (see Figure 4). In the coming years, the importance of renewables will systematically increase, which will gain global markets in comparison with other energy sources. Photovoltaics was the most dynamically developing renewable technology in 2020. Upward trends will also apply to gas, although in 2021, the International Energy Agency slightly lowered its forecasts for gas demand [IEA, 2021]. This shows lasting but slow changes in the global energy structure – the transition towards low-carbon is progressing, and RES and gas will account for as much as 85% of the increase in demand.

The significance of natural gas in the energy transition has not yet been decided. Gas was considered a transitional fuel to move away from more emission-intensive fuels (e.g. coal) towards zero-emission technologies. The substitution for natural gas was supposed to reduce greenhouse gas emissions in the medium term [Gürsan, Gooyert, 2021]. The renewed significance of the security of natural gas supply and the political context caused by Russia's aggression against Ukraine may affect the future importance of natural gas and permanently change demand trends, especially in the European Union. Such changes confirm, e.g. proposals announced in March 2022 by the European Commission to accelerate independence from fossil fuels, including natural gas [European Commission, 2022].

Coal, the most emitting fuel, will slowly reduce its role in the global economy, recording negative growth rates. According to the International Energy Agency, it is the only fuel whose consumption will never return to pre-pandemic levels. Its share in the global demand will decline in the coming years, and around 2040 it will be at a record low – below 20% (10%), the lowest since the industrial revolution [IEA, 2020].

The pandemic intensified the uncertainty of the conditions for the functioning of the oil and gas industries. In 2020, there was a decrease in investment by as much as a third. Therefore, it is unclear when and to what extent they will recover, given the significant overcapacity in oil and gas markets and uncertainty about the outlook for US shale and global demand. Meanwhile, there is a growing pressure in many industrial sectors for taking into account the consequences of energy transitions in their activities and business models and for the explanation about the contribution they can make to emission reductions. The International Energy Agency estimates that although oil will disappear from the market, demand will gradually return to previous levels.

Figure 4. Change in fuel demand in 2019–2030 (in billions of toe)



Source: IEA, 2020.

The pandemic also increased the problem of energy poverty. The lack of access to electricity and the inability to prepare meals affect 1.1 billion and 2.8 billion people in the world, respectively. The problem affects the entire developing world, mainly sub-Saharan Africa and Asia (95% together) [IEA, 2020].

The worst effects of the crisis are felt among the weakest. The pandemic reversed several-year decline in population number in sub-Saharan Africa without access to electricity. Rising poverty levels may have made basic electrical services unattainable for the more than 100 million people around the world who had access to electricity. Without the right policy, the scale of the phenomenon will not fall.

4. Electrification

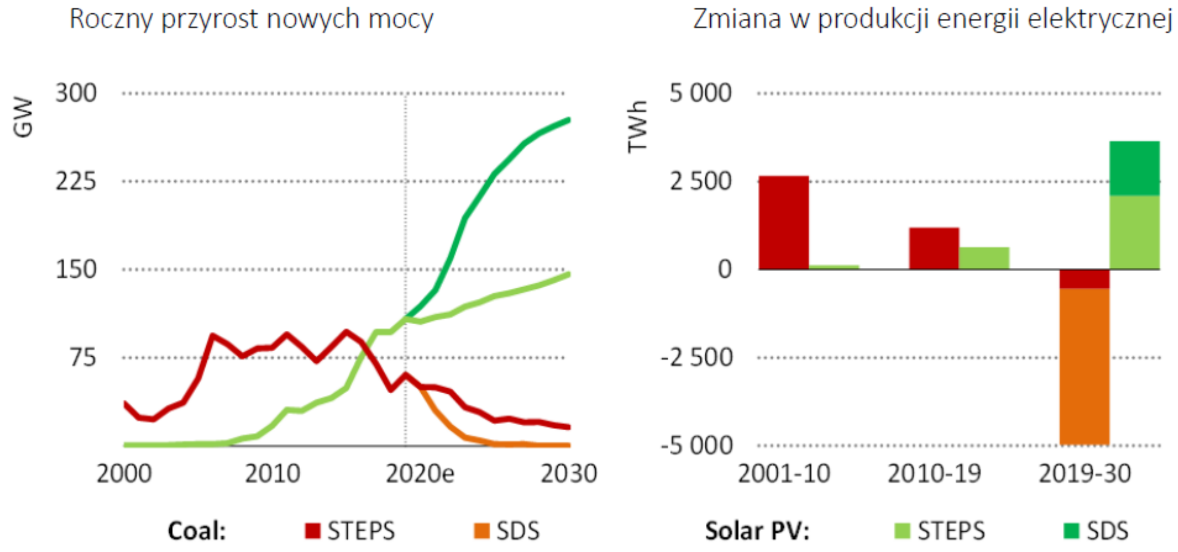
Electrification is an extremely important trend in the global economy. The convenience of using electricity and the fact that the electrification of new sectors (transport, district heating) allows for their decarbonisation will result in an increasingly faster increase in demand for electricity. So far, the growth rate of demand for electricity has grown twice as fast as in the case of other fuels. On the other hand, during the pandemic, the decline was more than twice smaller (-2% vs. -5% of the total decline in demand).

Currently, electric power covers 20% of the final demand for energy. However, the International Energy Agency estimates an increase of up to 23–31% depending on the scenario by 2040 [IEA, 2020].

Renewables play a central role in all the scenarios presented by the International Energy Agency. This is especially true for solar energy. The supporting policies and market technological maturity have enabled a very cheap access to capital on the leading markets. Photovoltaics is now consistently cheaper than new coal or gas-based power plants in most countries, and solar projects offer some of the lowest electricity costs. In the STEPS scenario, renewables will meet 80% of the global electricity demand growth over the next decade. Hydropower remains the largest renewable source, but the main growth area is solar energy, followed by onshore and offshore wind.

Due to climate commitments to global trends in electricity carriers and generation technologies, the adopted regulations are of great importance. Figure 5 illustrates the impact of an ambitious policy to reduce greenhouse gas emissions (SDS scenario) on accelerating the pace of coal transition, but above all, on accelerating the development of photovoltaics even further. In this scenario, electricity production from coal will fall by half in the next decade, and it will increase by 550% in the area of photovoltaic installations.

Figure 5. Changes in the installed capacity and in the solar and coal power production



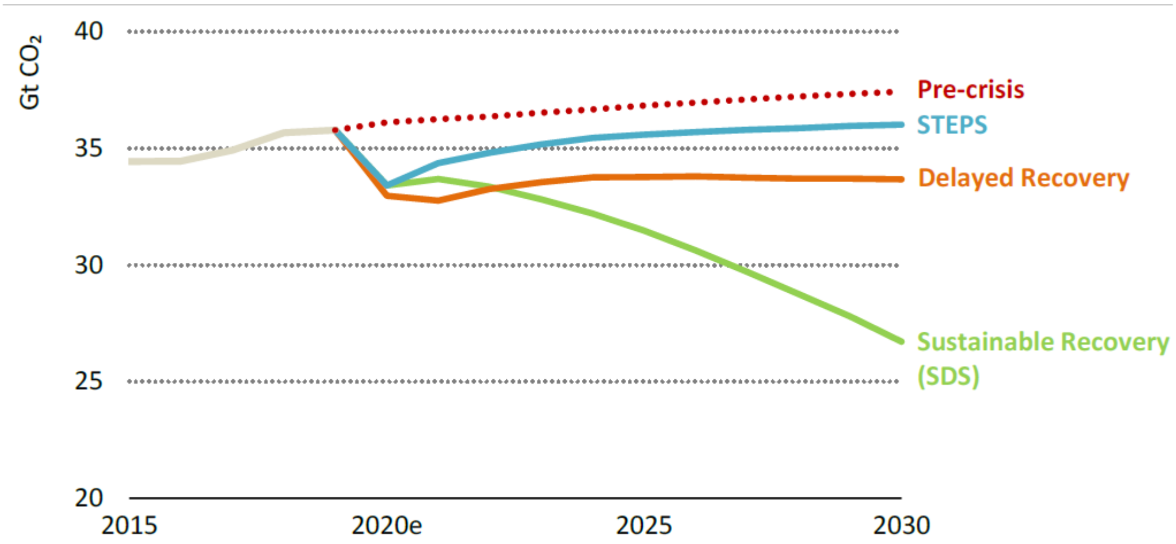
Source: IEA, 2020.

The forecasts of the International Energy Agency also show that a strong growth in renewable energy sources must develop in parallel with large investments in power grids. Without sufficient investment, the grids will prove to be a weak link in the transition of electricity sector, which will affect the reliability and security of electric power supply.

5. CO_2 emissions

The change in the generation mix in the global energy sector (a decrease in the consumption of fossil fuels and an increase in the importance of RES) has resulted in a decrease in CO_2 emissions. It is important, however, according to the International Energy Agency, it is a temporary phenomenon. Before the crisis, there was an upward emissions trend, and it will continue also after the crisis (see Figure 6 – STEPS scenario). This is confirmed by the estimates made by the agency, which predicts that the global post-pandemic recovery will give rise to an increase in emissions of 4% in 2021 [IEA, 2021]. This is the second highest absolute increase in emissions in history and shows that the economic recovery was not sustainable. Radically changing investment in clean energy would be a way to boost economic growth, create jobs and reduce emissions. This approach has not yet been included in the plans proposed so far, with the exception of the European Union, the United Kingdom, Canada, Korea, New Zealand and a few other countries. The European Union and its Green Deal project, which will be financed not only from the 2020–2027 budget but also from a specially dedicated recovery and resilience instrument, promotes green investment by introducing a number of incentives (financial measures, e.g. the Just Transition Mechanism) as well as restrictions (e.g. taxonomy).

Figure 6. Projected CO_2 emissions till 2030



Source: IEA, 2020.

Conclusions

The demand for energy and fuels in the next decade will depend on the development of many factors, but the upward trend will not be reversed. This is shown by the effects of the pandemic, which were relatively short-lived. Already in 2021, economies returned to the path of economic growth, increasing the demand for energy.

However, the pandemic and the subsequent economic recovery intensified uncertainty in the oil and gas industry. Fluctuations in commodity prices, access to capital or the pursuit of energy transition put future investments into question. An additional factor of uncertainty is the geopolitical situation and the effects of Russian aggression in Ukraine. The impact on commodity markets will be inevitable. Despite this, renewable energy sources, especially in the power industry, proved resilient to the crisis. In the coming years, they will develop dynamically (photovoltaics, onshore and offshore wind), accounting for nearly 90% of the new generation capacity. They can be expected to gain in importance as they are seen as domestic sources of supply.

Energy policies will have different impacts on individual fuels and carriers. Medium-term forecasts have so far confirmed positive trends for RES and natural gas, and negative trends for coal. This may change now, as gas is no longer seen as a transitional fuel due to the political risk. However, in the long term, forecasting is difficult, and the importance of individual energy sources will be the result of policies implemented by states.

It should be remembered that the next decade will be important from the point of view of accelerating the energy transition and achieving the climate neutrality goals declared by many countries. The decrease in CO_2 emissions observed in 2020 turned out to be temporary, and the implemented policies do not provide breakthrough changes in terms of emission reductions. A structural change in the energy sector is possible, but it requires political decisions, above all investments in new, clean and efficient assets.

References

BP (2020). *Energy Outlook 2020*, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2020.pdf?utm_source=newsletter&utm_medium=email&utm_campaign=newsletter_axiosgenerate&stream=top (access: 27.12.2020).

Gürsan, C., de Gooyert, V. (2021). The systemic impact of a transition fuel: Does natural gas help or hinder the energy transition? *Renewable and Sustainable Energy Reviews*, 138. DOI: 10.1016/j.rser.2020.110552.

IEA (2021). *World Energy Outlook 2021*, https://www.iea.org/reports/world-energy-outlook-2021 (access: 27.12.2020).

IEA (2020). *World Energy Outlook 2020*, https://www.iea.org/reports/world-energy-outlook-2020 (access: 27.12.2020).

Komisja Europejska (2022). *REPowerEU: Wspólne europejskie działania w kierunku bezpiecznej i zrównoważonej energii po przystępnej cenie*, Komunikat Komisji do Parlamentu Europejskiego, Rady Europejskiej, Rady, Europejskiego Komitetu Ekonomiczno-Społecznego i Komitetu Regionów, Strasburg, dnia 8.3.2022, COM(2022) 108 final.

Steffen, B., Egli, F., Pahle, M., Schmidt, T. (2020). Navigating the Clean Energy Transition in the COVID-19 Crisis, *Joule*, 4(6). DOI: 10.1016/j.joule.2020.04.011.

Dariusz Michalski
The University of Bielsko-Biała

Chapter II

Green Transition Financing Management

Abstract
A sustainable financial system creates, evaluates financial assets and enables transactions to be executed in a way that creates real prosperity to meet long-term needs in favour of an environmentally sustainable economy. Green finance refers to any financial instruments used to implement initiatives and undertakings related to sustainable development, products and environmental policies as part of the promotion of the ecological economic transition in pursuit of the objectives of the green transition. Promoting green finance on a large and economically viable scale helps to ensure that green investments are prioritised over investments that perpetuate patterns of unsustainable growth. The aim of this chapter is to define the role of green finance, present selected instruments and indicate their role in financing the green transformation of economies and enterprises. It is pointed out that green finance encourages long-term analysis of investments affecting environmental objectives and includes all sustainability criteria and that green finance covers different products and financial services. Debt and equity capitals are important financial instruments in green finance. To meet the growing demand for sustainable finance, new financial instruments such as green bonds and greenhouse gas emission market instruments have been created, as well as new financial institutions such as green banks and green funds. Investments in renewable energy, sustainable infrastructure financing and green bonds are the areas of greatest interest in green finance activities.

Until recently, the role of financial institutions, especially in the banking sector, in the green revolution was underestimated. In the modern economy, the banking sector is responsible for the creation of about 85%–97% of money supply, so credit policy should also become an effective tool in the fight against climate change. And central banks, together with governments, can influence decisions on the allocation of not only state funds, but also private resources, using similar tools as during the last financial crisis (monetary policy, income policy, financial market regulation). Green finance provides financing for investments in all financial sectors and asset classes that incorporate environmental, social and management criteria into investment decisions and take climate risks into account in order to support the development of a more sustainable economy.

Keywords: RES, energy transition, climate risk, management, energy market, green finance

1. Systemic risk for financial institutions caused by climate change

Climate risk creates systemic risk for financial institutions resulting from possible losses in investment and credit portfolios. They are currently extremely difficult to capture due to their increasing intensity and frequency of occurrence. At the same time, this risk is a challenge for investors due to its characteristics, as it concerns the financial and market spheres (revenues, business profitability), physical assets (destruction as a result of extreme weather events) as well as regulatory and social spheres. Power companies may serve as an example, they are exposed to extreme weather phenomena, affecting not only the state of fixed assets, but also the volatility of market prices. For example, for banks, climate risk affects their lending – banks can adjust lending to take into account environmental impacts in the risk assessment and cost of capital. It is also important to coordinate the maturities of available financing with the needs of investors. A harmonised definition of green finance is needed, i.e. the emergence of green activities taxonomy, to help investors and financial institutions to allocate capital efficiently and make conscious decisions. The definition of green finance must be clear. A common set of minimum standards for green finance is necessary to ensure transparency in the redirection of capital flows towards green and sustainable investment, as well as to analyse the changing financial market and climate risks. Disclosure standards and rules will help develop green financial assets. Some investments are probably "greener" than others. Hence the need to agree on the definition of what may be considered green or sustainable finance, as more and more financial institutions seek to engage exclusively in fossil-free projects. It is important that financial institutions should require material and service providers to reduce their carbon footprint, which should increase the global focus on this type of activity. This is because corporate sustainability progress typically follows a sequence of problem identification, policy-making, disclosure and standardisation before consistent substantive reporting can be achieved.

Green financing creates innovations on financial markets; new financial instruments appear. The relationship between risk and return analysis for those investing in green finance is challenging. This type of analysis is most advanced in the green bond market due to its scale and relative transparency. Institutional investors need to be able to make precise analyses by allocating increasing amounts of capital to green finance. The "Green Label" informs investors that the collected funds will be used to finance projects that are beneficial for the environment.

The world's largest banks analyse the level of exposure to climate risk of assets which are in their balance sheets. This applies both to corporate financing instruments and to hypothetical loans to households. Thus, a process of quasi-accounting carbon footprint analysis takes place, in which a specific financial institution is involved. According to UN analyses, the lack of new limits on greenhouse gas emissions and accelerating the reduction of global temperature growth may lead to problems with food and water supplies and large population migrations as well as global instability as early as 2040. However, for financial institutions, it creates the risk that the introduction of a low-carbon economy will lead to a fundamental reduction in the value of those customers who produce large amounts of greenhouse gases. Hidden and unreported climate risks can lead to a financial crisis. Hence, reporting on climate risk, which is an element of banks' portfolios of financial instruments, will become increasingly important. Indeed, it can be said that these data will be key factors to achieve success by financial institutions. In November 2020, the Fed (Federal Reserve, USA) for the first time stressed that climate risk is part of systemic risk and can cause instability of the financial system. It is important to understand how climate risk affects the return on investments and how it should be included in the cost of funding in order to avoid unforeseen changes in the value of assets in the portfolios of financial institutions. It is important to include, in the methodology the cost evaluation, the climate risk financing and the consequences of climate change for markets, financial exposures and the relationship between markets and financial institutions. Climate risk is also becoming an opportunity for financial markets. There is an increase in the assets of funds investing in accordance with the criteria of responsibility for the natural environment, society or corporate governance. In general, in real sphere enterprises, the implementation of good practices in the field of corporate social responsibility, especially environmental responsibility and limiting climate change, is an opportunity to attract both investors and customers. Increasingly, climate risk factors are affecting the creation of value for investors.

The world is in the process of defining the framework of its sustainable economy. Service providers, especially those operating in the mutual fund industry, need to develop a support strategy for their clients to meet the demands of the new era of green finance. The world is turning green, from recycling and energy generation to organic food and sustainable fisheries. Hence, financial institutions are beginning to consider the impact of climate change risk (scenario analyses, stress test analyses) on their loan portfolios and investments and optimise their structure by managing the risk value.[1] It is becoming important to analyse the impact of climate change on the portfolio of loans in banks. That is why it is so important to quantify this risk, which should also be reflected in stress tests (currently, for example, banks

---

[1] A risk of environmental regulations is an element of this risk. Regulations related to the development of RES and greenhouse gas emissions serve as an example. The Industrial and Commercial Bank of China already in 2016 indicated that about 68% of fossil fuel-fired and AA-rated power plants are exposed to the risk of rating decline as a result of tightened environmental regulations.

are analysing the impact of an increase in unemployment of 5% or rapid changes in interest rates on their loan portfolios). For example, a question should be asked what will happen to the quality of the loan portfolio if the temperature rises above the limits set at the COP21 conference in Paris, e.g. by 2% or 4%. However, stress testing in the case of climate change risks should help identify not only the risk to the financial institution but also the opportunities to develop its business in the areas that may benefit from responding to the risk of climate change.

PNS is carrying out a stress test of the energy portfolio in the gas and oil industry to identify scenarios for an increase in demand for electric cars in the situation of global warming and to prepare for a change in the portfolio structure, e.g. by increasing involvement in companies possessing electric car charging stations.[2] For more see Marlin [2018]. Moody's pointed out that in the situation of ongoing climate changes, Bank of America, Citigroup, Goldman Sachs or JP Morgan Stanley may suffer losses as a result of problems with settling their liabilities by the gas and oil sector amounting to about USD 9 billion. In June 2018, City had a $51 billion commitment to the energy sector (most of the U.S. banks). However, as part of its diversification of climate change risks, it pledged $57 billion to fund climate change response projects (with the option to increase to $100 billion by 2025), while JP Morgan committed $42 billion in the gas and oil sectors.

The heat and forest fires in California in 2017–2019 led to the bankruptcy of PG&E Corporation, the parent company of energy company Pacific and Gas Corporation, which was accused of causing them as a result of poor operation of the network infrastructure (in August 2019, the company benefited from judicial protection against USD 4.1 billion in damages claims).

Investors must therefore be assured that the financial institution is properly managing the risk of climate change. To this end, they should be provided with a global assessment of the impact of the risk of climate change on the performance of the financial institution, i.e. to measure it, analyse it, implement the necessary procedures for responding to it and supplement the reporting with an assessment of the impact of risk of climate change, defined and managed in this way, on the results of operations on financial markets. Therefore, in addition to regularly measuring the risk of climate change and its impact on the investment portfolios of financial institutions, they should reposition their investment portfolios in order to make them more resilient to those risks. The risk factor is greenhouse gas emissions, which are created by the financial activities of banks.[3]

---

[2] Climate change risk analysis is needed by PNS to design the capital structure over a 10-year horizon.

[3] For example, environmental risk creates high credit risk for many sectors of the economy, and even materialises for the coal industry and coal-based investments (an example is the problems with preparing financing for investments in the Ostrołęka power plant). In August 2018, the *Carbon Tracker* think-tank warned that the investment in the Ostrołęka power plant would be permanently unprofitable, without support in the form of subsidies, e.g. subsidies from the capacity market. Such opinions may also be the reason for problems with obtaining financing on the financial market.

On 18 December 2018, the European Securities and Markets Authority (ESMA) published a consultation paper on technical guidelines integrating climate risk and its factors into MiFID II. The answers to the questions posed in it indicate that it is necessary to supplement MiFID II with additional regulations specifying environmental and social or organisational issues and the risks associated with them [ESMA, 2018][4]. A similar challenge applies to capital requirements – a one-year horizon for their analysis is too short to properly address the climate risk.

The Bank of England (BoE) is the first regulator to provide guidance to banks and insurers that set out requirements for climate risk liability. The financial institution is required to determine which organisational units are suitable for managing this risk. The BoE requires active climate risk management, measurement (including stress-testing) of the resulting exposure, climate risk reporting. This approach will require a holistic analysis of the financial institution's climate risk, not just a specific business line. The next step in this direction is the ESMA guidelines for the MiFID II Directive, in which it requires climate risk analysis in the area of compliance and internal audit as well as top management.

2. Role of finance in the green transition

The financial sector plays a key role in the transition of the economy and society to a green, sustainable future by influencing the allocation of capital in the economy, which means the inclusion of long-term environmental, social and governance criteria (ESG) into global business and investment. It is crucial to be able to track these criteria to make real sustainability improvement at the national and global levels. Financial institutions can support the green transition by developing the so-called green products, expanding their offer with products that protect against the materialisation of climate risk and including this risk in risk management schemes.[5] Non-financial aspects of corporate activities related to the ESG area have already been of interest to some investment funds, and were also criteria for assessing projects financed from certain public funds or international institutions, e.g. the European Bank for Reconstruction and Development (EBRD) [Krukowska, 2021]. Financial institutions need to watch market leaders and set ambitious strategies to ensure that they are ahead of the competition. Private investors will transfer their assets to those entities which will ensure not only an adequate return on capital, but also an improvement in the condition of the planet, as most of them now identify the mitigation of climate change as the major carrier of value. Not only states and local governments around the world, but also private investors are working in this direction, changing public procurement and investment plans to account for ecological

---

[4] Or rather, risk factors for sustainable and permanent growth.

[5] European banks pledge more than USD 1.5 trillion for this purpose by 2030, and the EIB has become the European climate bank.

criteria. On the one hand, it is a continuation of efforts in favour of sustainable development and corporate social responsibility (CSR) of the past. However, ESG is broader and more important. Where CSR and sustainability were pushed too often (though not always) from a marketing perspective, ESG has the potential to become a significant measure of an organisational integrity in realising its values. In addition, enterprises need to restructure their approach to corporate elements and risk management, including compliance risk, to include and execute ESG monitoring and reporting. It should be noted that ESG is not just about environmental values and climate change. Managing the rest of the areas is equally important.

A modern organisation is a network of relationships with entities in its environment: sellers, suppliers, outsourcers, service providers, contractors, consultants, temporary employees, intermediaries, agents, partners and others. A true ESG implementation requires monitoring and managing shared values and integrity throughout the expanded area of corporate operation.

ESG factors increasingly affect the activities and financial profiles of entrepreneurs, which is why they are systematically included in the analyses made by credit rating agencies, which have begun to assess ESG factors in company ratings. Companies must be prepared to take risks at ESG factors in the medium and long term and are required to adequately manage short and medium-term capital expenditures and operating costs which may affect the environmental and social aspects.

E – environment concerns the value and commitment of the company to environmental management. It includes reporting and monitoring of organisation environmental initiatives on climate change, waste management, pollution, resource use and depletion, greenhouse gases, etc.
S – community includes relations of employees and customers, contractors and customers, human rights (e.g. counteracting slavery), diversity and integration, counteracting harassment and discrimination, privacy of individuals (employees and others), working conditions and working standards (e.g. child labour, forced labour, health and safety), and how the company participates in and supports the society and communities in which it operates.
G – corporate governance refers to the culture and behaviour of the organisation in the context of adaptation to its values and commitment. It includes financial and tax strategies, information on irregularities and problems, resilience to environmental shocks, counteracting bribery and corruption, security, diversity and structure of management as well as overall transparency and accountability.

The impact of ESG factors is directly visible in the acquisitions made by the best-known credit rating agencies, which were aimed at complementing and increasing the importance of the environmental and social impact on the methodology of ratings prepared by them. Standard & Poor’s acquired Trucost, a source of carbon and environmental data and risk analysis, and ESG rating company RobecoSAM. Moody’s acquired the world leader in ESG assessments Vigeo Eiris, provider of information on economic risks caused by climate change Four Twenty Seven and Chinese provider of ESG data and analysis SynTao Green Finance. As of the end of

2020, the MSCI Index determines the ESG rating for 7,500 companies listed on the MSCI All Country World Index. The European Securities and Markets Authority (ESMA) also indicates in its regulations that credit rating agencies in their communications must refer to the issue of ESG, indicating whether ESG factors were the main reason for making a specific rating decision [ESMA, 2021]. Concrete examples of rating activities taking into account ESG factors include downgrading the credit rating and limiting the flexibility of the OEM automotive company due to legal unreliability in terms of CO_2 emissions, and the inclusion on CreditWatch of the major oil companies of Europe, North America and China in relation to the planned energy transitions.

The financial market is also reacting to the requirement of compliance with ESG standards. For example, sustainability-oriented index funds are developing, dynamically increasing the value of their assets. At the end of the second quarter of 2020, there were 534 funds of this type in operation managing USD 250 billion. It is estimated that about 15% of assets under the global management are sustainable development funds [Krukowska, 2021].

On the capital market, there are listed companies which differ in the amount of greenhouse gas emissions. They also have a different potential to support the energy transition. Investors entrust capital to them – actively choosing listed companies or passively investing in equity funds. Investment fund managers develop products which are related to entrusting capital to companies actively participating in the energy transition and support the fight against climate change. An example is Swedish fund AP4, which reduces its involvement in coal-consuming companies (decarbonises the investment portfolio). U.S. pension fund CalSTRS invests more than 3% of its portfolio in low-carbon ventures, including renewables, Australia's Local Government Super Scheme up to 8% of its assets in decarbonised ventures, and the UK's Environment Agency Pension Found aims to achieve a 25% portfolio commitment to companies ensuring a positive climate effect. Stock market managers also create indices that are used to invest in companies with low greenhouse gas emissions as well as to weight companies in indices from the point of view of decarbonising the economy.

The support for the energy transition of economies by the financial sector is particularly important in developing countries. It is important to provide aid to these countries in order to finance the energy transition, i.e. to develop the necessary infrastructure and change the behaviour of societies in this area.[6] Green bonds and loans related to sustainable development are designed to direct financing towards new sustainable projects and investments that will help companies achieve measurable sustainability results. Leading capital owners and asset managers indicate a clear preference for low-carbon projects. In addition, any form of project financing traditional green bonds gains credibility in the market only if the issuer has demonstrated that the project commitments support a coherent energy transition plan and represent a sustainable financial framework.

---

[6] Some activities of insurance institutions may serve as an example. Allianz offered insurance for crops (Brazil) and property (Indonesia, Egypt, India, Cameroon, Senegal, Colombia) against adverse weather events, while supporting the construction of infrastructure to protect against climate risk.

Indonesia’s state-owned energy company PT Perusahaan Listrik Negara (PLN) announced in early 2021 that it had finalised a $500 million sustainability loan from a consortium of the world’s leading banks, including Citibank, DBS, JP Morgan, Standard Chartered and SMBC. The loan was secured by guarantees from the World Bank Group (MIGA), which gave the lenders a guarantee to cover the risk if PLN was unable to meet its obligations. This loan is an element of building the credibility of PLN on the green and sustainable financial market in order to provide financing for the company’s transformation. The loan will be used to finance the planned RES projects. However, there are doubts as to whether these investments meet the ESG requirements.

A significant area of involvement of financial institutions in reducing climate risk is cooperation with enterprises to which they entrust their capital. An important issue from the point of view of the green transition is to answer the question whether financial institutions should sell shares in companies that do not respond to the need to fight climate change, or rather exercise their ownership rights by forcing a change in the corporate behaviour. It can be assumed that both approaches are important and effective, as they force capitalists to change their approach to climate change, creating new standards for industry. One of such actions of financial institutions is to stop financing projects related to coal combustion. Financial institutions also work with public administration decision-makers to ensure the coherence and effectiveness of regulatory actions taken in the fight against climate change. This is due to the fact that the tools implemented by the public sector usually affect the situation on the financial markets.[7] At the beginning of 2021, the President of the European Investment Bank indicated that the financing of projects related to fossil fuels (including gases) should be discontinued. The EIB also called on the World Bank to stop financing gas projects, similarly to coal and oil projects. Pressure exerted by governments of developed countries and international organisations limits the financing of projects related to fossil fuels, which are being replaced by RES. In addition, many countries in Asia, including Bangladesh, Pakistan and Indonesia, are already experiencing overcapacity in coal-fired power plants, which means that the available supply exceeds demand and power plants are operating below optimal utilisation rates. Hence, for example, Pakistan announced in December 2020 that it would stop the construction of coal-fired power plants.

Potentially, climate change affects the value of assets not only in the energy sector. For example, the valuation of a hotel, the value of which should be influenced not only by the factors observed today, but also by future operating conditions, which may increase its operating costs, change the attractiveness of the location and increase taxes. These effects may be the result of the materialisation of the risk of climate change. Moreover, the value of a hotel can be influenced by various risks and opportunities that arise in the financial market. But the problem of climate change is not just about hotels, as 80% of the world’s industry is vulnerable to climate change. Rain or lack thereof or unfavorable temperatures and wind affect tourism, crops, mining, breeding, energy, etc. So do hurricanes and rapid weather.

UBS identified a 14.5% risk of U.S. power generation reduction as a result of gradual climate change [Marlin, 2018]. In 2020, according to Munich Re, natural disasters (droughts, storms, hurricanes, fires and floods) caused

---

[7] Examples include market assessment of the effects of the introduction of selected tools, consultations on the levels of expected greenhouse gas reductions or recommendations in the field of climate risk reporting.

losses of about USD 210 billion, of which, according to various estimates, about USD 76–82 billion were insured (a year earlier these values amounted to USD 166 billion and USD 57 billion, respectively). The increase in reinsurance costs creates the potential for an increase in the prices of insurance policies.

Therefore, the issue of climate change affects the behaviour of investors, as it creates risks and opportunities. Investors conduct impact analyses on the profitability of their fossil fuel decisions and greenhouse gas emissions, expecting to reduce the impact of climate change risk on the return on their investment. This creates exposure to the risk of climate change for investment decisions, a thorough analysis of which may allow at the same time to identify opportunities.

Pro-ecological investors, managing over USD 32 billion, established Climate Action 100+ in 2017. This organisation points out that climate change is a systemic risk. The answer is for financial institutions to adopt environmental policies that define internal procedures for operating companies using fossil fuels. In this way, the risk of climate change also becomes an element of the global risk management in financial institutions.[8]

Opportunities for the development of financial institutions are created by new products, the development of which is supported by innovative leasing or ESG loans, financing RES and energy efficiency. The pressure of investors makes financial institutions develop products aimed at supporting initiatives to prevent climate change, look for opportunities in this area and focus managers' attention on new challenges. Thus, activities related to combating climate change create a new business area for financial institutions and new instruments for building customer loyalty. For example, banks can enter the RES market with financing investment projects or issuing financial instruments related to RES.

3. Impact of climate change risk on the performance of financial institutions

Financial institutions are exposed to the risks of climate change, which of course should become an integral part of their risk management process. Climate change affects financial institutions both by affecting their financial situation as a result of natural disasters and by affecting the situation in the economy, where financial markets are a significant element. Another important element affecting financial institutions is the transformation of the economy towards a climate-neutral economy, which affects the prices of assets which are listed on financial markets and the financial situation of individual companies. Therefore, financial institutions must develop effective methods of climate risk management to ensure the stability of their financial situation. Insurance companies may serve as an example. They have to adapt their procedures to the increasing risk of natural disasters, or the increasingly frequent small

---

[8] Climate Action 100+ brings together over 300 financial investors.

but costly weather events for their clients. A proper estimation of the climate risk premium is also important for the management of transition period risks. Hence, already in 2016, the European Systemic Risk Board (ESRB) initiated actions to develop a framework in the financial system for climate change management, recommending the launch of stress tests for climate risk in the European financial system. Similarly, the European Commission points out that it is important to consider the risk of climate change in the management of banks, assuming, for example, that green assets are less risky from a climate point of view than assets based on fossil fuels. Regulators also expect to increase the climate transparency of financial institutions. The integration of the climate risk approach of financial institutions should be carried out in accordance with its exposure (also on a sectoral basis). Insurers are exposed in their operations similarly to banks or investment funds, which enables the use of similar methods of climate risk analysis and management. Therefore, investors expect to carry out stress tests of the impact of climate risk on the economic performance of financial institutions, which must also be prepared for changes in customer behaviour and investment profitability, caused not only by global policies to counteract climate change, but also by local weather changes (mainly catastrophic). As a consequence, it important to change the approach to investing, the effectiveness of which depends on new risk factors, such as volatility of climate change regulations, dynamics of property values, credibility of business models, reputation risk or weather risk.

The European Investment Bank announced a reduction in the financing of fossil fuel projects also in the field of gas projects in July 2019. It is due to the announcement of the introduction of an emission standard of a maximum of 100 kg CO_2/MWh (in July 2019 it was 450 kg CO_2/MWh). The European Investment Bank is the most important lender to the electricity sector. Such a standard will mean that the EIB will only finance RES, i.e. the EIB in such a situation becomes a European climate bank.

4. Selected activities of financial institutions related to climate change

More than 45 global financial institutions in 2019 were already operating under the Science Based Targets Initiative, which aims to voluntarily reduce greenhouse gas emissions. Other activities of financial institutions are presented below.[9] Since 2013, more than 100 global

---

[9] *Science Based Target Initiative* – the result of a partnership between the World Resources Institute (WRI), the World Wildlife Fund (WWF), CDP (formerly known as the Carbon Disclosure Project) and the United Nations Global Compact supports its affiliated organisations (over 370) in preventing the negative effects of climate change by determining the level of necessary reductions in carbon dioxide emissions. See more in: Boston Common Assets Management [2005].

financial institutions have implemented policies to reduce their involvement in coal-related projects. The process began in 2013. The World Bank[10][2013], and in the following years continued Axa and Allianz (2015) as the first insurers to plan to reduce the insurance of investments and carbon-related assets. In 2015, 35 export credit institutions also set out rules limiting credit for coal-related activities. In the same year, the Asian Infrastructure Investment Bank also announced a reduction in its involvement in the coal business and the development of activities in the green technology sector. However, the most important action was the announced withdrawal of Norway's state investment fund from financing the industry involved in coal combustion. In May 2018, Dai-ichi Life Insurance Company of Japan implemented a new policy that excluded insuring industries involved in burning coal, and in September 2018, Standard Chartered PLC bank in London announced the end of lending to new coal-fired power plants.

In 2018, the ClientEarth Lawyers for the Earth Foundation, which is a shareholder of Enea, filed a lawsuit against the construction of unit C at the Ostrołęcka power plant – the value of the investment is about PLN 6 billion. This investment is controversial because, for example, Carbon Tracker analysts indicate that it will never pay off, and may even bring a loss of 1.7 billion euros. The closure of its financing is also a problem because banks and financial institutions are not willing to finance the coal project in the energy sector. This project is also exposed to the risk of rising prices of greenhouse gas emission rights, competition from low-cost RES technologies and the regulatory risk of European Union regulations.

At the beginning of 2019, more than 30 global banks announced withdrawal from financing coal mines and coal-fired power plants. The European Investment Bank announced a reduction in financing fossil fuel projects also in the field of gas projects in July 2019. This is due to the announcement of the introduction of an emission standard of a maximum of 100 kg CO_2 / MWh (in July 2019 it was 450 kg CO_2 / MWh). The European Investment Bank is the most important lender to the electricity sector. Such a standard will mean that the EIB will only finance RES, i.e. the EIB in such a situation becomes a European climate bank. It should be stated already today that in the near future the assets involved in coal combustion will have great problems with obtaining not only financing, but also insurance. Coking coal projects are an exception.[11] Financial institutions see green technologies as an alternative investment direction that is a hedge against climate risk, but in India, Mexico, Australia and the USA, for example, it is a competitive source of electricity.

---

[10] In 2018, the World Bank decided to stop financing the coal-fired Power Plant in Kosovo (500 MW), which was the last coal project in its portfolio.

[11] The construction of the Ostrołęka Power Plant or projects implemented in India, which recorded problems with obtaining financing already in 2019 may serve as examples.

As part of the response to climate risk, financial institutions undertake the following actions: investing entrusted capital in projects with low greenhouse gas emissions and energy efficiency; support for RES projects, especially through private equity projects and lending to them; support for the development of RES and energy efficiency in developing countries; the development of the green bond market and the provision of capital for the energy transition of the economy; financing activities related to improving the energy efficiency of buildings and neutralising their impact on the natural environment;[12] limiting the involvement in financing coal-burning enterprises; developing reporting by companies and financial institutions on their climate impact and reducing greenhouse gas emissions; involving policymakers and politicians in initiatives to reduce greenhouse gas emissions. It is important to ensure a change in the direction of capital allocation to low-carbon projects. The results of financial institutions' activities in the area of green finance are presented in the table below.

Table 1. Examples of activities financial institutions in the area of climate change

Activities of the financial sector	Results of activities					
	Use of capital	Emission reduction	Improvement of funding transparency	Change of the corporate behaviour	Improvement of climate policies	Knowledge development
Investments in low-carbon projects	▨	▨	▨			▨
Investments in reduction of CO_2 emissions	▨	▨	▨			▨
Financing the energy transition	▨	▨	▨			▨
Ensuring climate transparency		▨	▨	▨		▨
Cooperation with companies			▨	▨		▨
Cooperation with decision-makers					▨	▨

Source: Author's own material.

In 2019, more than 100 banks around the world joined the UN Responsible Banking initiative, which is also related to climate responsibility. Among the banks operating in Poland, Santander, BNP Paribas, ING Bank Śląski and mBank joined the UN initiative.

---

[12] Buildings, in addition to their significant value, are also significant creators of greenhouse gas emissions. The improvement of their energy efficiency means not only a reduction in the costs of their operation, but also a significantly lower burden on the natural environment.

Below are presented selected activities of financial institutions in support of the fight against climate change.

- BBVA prepared eco-rating, a tool that assesses the impact of climate change risk on the credit risk of enterprises. The accessed factors include location, pollutant emissions, environmental impact and regulatory risk.
- Chinese banks signed an agreement that aims to intensify support for pro-environmental initiatives.
- In the process of reviewing the loan portfolio, TD Bank analyses clients' exposure to the risk of climate change. Approximately 87% of loans granted relate to low-carbon projects.
- Itau worked out a methodology for assessing environmental factors affecting the financial situation of enterprises. In addition, the long-term impact of climate change risks on the sectors most exposed to them: energy, water, gas, oil.
- UBS set up a committee to identify and implement annual targets for the bank's climate change response strategy.
- Westpac set targets for investment in low-greenhouse gas emitting sectors.
- Australia and New Zealand Bank aiming to position itself as the most important financial institution in terms of investment in renewable energy sources in Australia, supports the development of wind and solar power plants and geothermal energy. The Bank aims to increase lending to RES and gas-fired power plants compared to 2011 by 15%–20% by 2020.
- Clean Energy Finance Corporation (CEFC), Australia's state-owned investment bank, supported renewables and energy-efficient projects with more than A$19 billion until 2018.
- Bank of America committed to funding initiatives in environmentally friendly technologies and energy efficiency amounting to $125 billion till 2025 (as of 2007) and $300 billion till 2030 into a low-carbon economy through the Environmental Business Initiative. In this way, Bank of America made a commitment of USD 445 billion in green finance since 2007.
- Citigroup continues to fund energy efficiency and distributed generation of $104 billion. When managing the risk of climate change, the bank conducts regular stress tests of exposure to this risk, especially when analysing exposure to the energy sector. Other banks made a similar commitment: Wells Fargo $200 billion till 2030, JPM Chase $200 billion till 2025, Goldman Sachs $150 billion till 2025, HSBC $100 billion till 2025, BBVA $100 billion till 2025 and Credit Agricole €100 billion till 2025.
- JP Morgan stopped financing coal-fired power plants in some countries in March 2016 after analysing the impact of environmental regulations on its energy investment portfolio. JP Morgan set a $200 billion target to fund clean energy projects by 2025 (it already had a commitment of $60.6 billion in 2018), and its commitment to coal projects was reduced by nearly 85% [Buckley, 2019, p. 24]. After pressure from shareholders and environmentalists, JPM announced a move away from financing fossil fuel businesses (the bank is the largest lender to the fossil fuel industry) and ending financing customers who do not meet the climate requirements of the Paris Agreement, reducing its emissions by 2030 and encouraging its customers in the energy, mining and automotive sectors to do so as well. The Bank has also established a special advisory unit whose task is to search for projects in the area of green transition.
- SEB has been developing the green bond market since 2008, offering this type of financing since 2015 through a special fund for both retail and corporate clients.
- Deutsche Bank analyses all transactions from the point of view of reputational risk, which is increasingly becoming an element of climate change risk. In January 2018, Deutsche Bank and Rabobank determined their policies to reduce their exposure to coal-fired power plants, similarly to ABN Amro, which has already been implementing such a policy since May 2017.
- Bank of Nova Scotia clearly indicates that it has combined its lending policy with elements of climate policy.
- Intesa Sanpaolo and PNF Financial apply preferential conditions for financing pro-environmental projects.
- In 2015, InG Group and DNB already held in their loan portfolios 39% and 36% of the share of project financing in RES, respectively. InG is one of the European banks that plan to contribute to keeping the global temperature increase below 2ºC. Hence, since 2016, it has introduced a policy of exiting coal investments, which was tightened in 2017, when the exit date from coal investments was set for 2025. environment, either directly on the basis of project financing or by issuing green financial instruments.In 2015, InG Group and DNB already held in their loan portfolios 39% and 36% of the share of project financing in RES, respectively. InG is one of the European banks that plan to contribute to keeping the global temperature increase below 2ºC. Hence, since 2016, it has introduced a policy of exiting coal investments, which was tightened in 2017, when the exit date from coal investments was

set for 2025. ING BSK in Poland, after the end of financing of coal energy, is increasingly developing its offer for financing environmentally friendly technologies, either directly on the basis of project financing, or by issuing green financial instruments.

- In January 2019, Barclays Bank tightened its policy of financing investment projects, including coal-fired power plants.
- Storebrand, a Norwegian pension fund, withdrew from coal-related investments (it sold shares, e.g. of PGE SA).
- In 2018, Swiss Re ceased to insure the risk of companies with more than 30% of coal in their operations. It resulted from the climate change policy which became effective in 2017. Similar steps had previously been taken by Allianz, AXA, SCOR, Zurich Insurance and Lloyd's, Aviva, CNP Insurance, Aegon, Zurich, Hannover Re, SCOR, Macif, AG2R La Mondiale, Groupama France, Generali, Varma, VIG of Austria. Swiss Re is developing its business activity in the area of RES insurance, especially photovoltaic and wind power plants, also offering support to manufacturers of their equipment. Swiss Re plans to eliminate thermal coal from mandatory reinsurance in OECD countries by 2030. This is part of a policy to support the transition to a zero-carbon economy. In addition, Swiss Re aims to eliminate coal-based assets from its portfolio, while increasing investments in renewables and green or sustainable bonds. Munich Re decided to reduce its involvement in the coal sector by ceasing to invest in financial instruments of companies that generate more than 30% of revenues in coal-based sectors. The decision was made under pressure from investors. AXA plans to exit its €500 million coal asset investment and invest €3 billion in green investments by 2020. This is also a consequence of the compensation that has been paid by the insurer. AXA has therefore ceased to cooperate with RWE as a customer.[13] Such a decision taken in the context of the crisis caused by the coronavirus pandemic in 2020 indicates that for some financial institutions, climate change moved from a discussion point to a key factor in everyday business decisions. The actions taken by AXA and Allianz attracts investors' attention to companies that emit significant amounts of greenhouse gases or plan to build new coal-fired power plants, which creates a high climate risk for them and is reflected in the financial results of insurers.[14] Similar actions are also being carried out by the largest Spanish insurance company MAPFRE, which announced in March 2021 that it would phase out the provision of services to companies in the coal sector by 2030. A similar decision was made by AIA, an insurance company from Hong Kong, which announced that by 2028 it would exit investments in the coal sector (out of about USD 32 billion of investments in the AIA management board, USD 6 billion are assets related to coal energy). In 2020, AIA pledged to withdraw from shares in companies that generate more than 30% from coal mining or combustion by the end of 2021.
- Singapore-based DBS Bank will phase out financing its coal business by 2039, making it the first bank in Singapore to discontinue financing in this area. DBS announced in April 2021 that it would cease to acquire new customers with immediate effect, which derive more than a quarter of their revenues from steam coal. From January 2026, DBS will also stop financing customers who derive more than half of their revenues from steam coal. The bank announced that over time both thresholds will be lowered. It will also disclose its exposure to steam coal in its annual sustainability report to ensure the transparency of progress made. According to DBS's 2020 sustainability report, its commitment to steam coal mining and coal-fired power plants at the end of 2019 was $1.17 billion and $1.63 billion, respectively, representing 0.24% and 0.33% of its total exposure to its institutional banking group. At the same time, its exposure to renewable energy projects increased in 2020 to $4.2 billion ($2.85 billion in 2019).
- Vitol, an electricity and gas trading company, and Low Carbon have created the VLC Renewables fund, which aims to finance the development of renewable energy sources in Europe, with a particular focus on the construction of wind farms. The initial capital of the fund is 250 million euros. Previously, the two companies had invested around £250 million in distributed generation and storage in the UK.
- In 2017, the Asian Infrastructure Investment Bank identified green references for investment projects which excluded financing coal projects. That year, the New Development Bank also redefined its preferences in the field of green technologies, supporting since then mainly non-coal infrastructure projects. In 2018, the Asian Development Bank similarly ruled out financing investments in coal-fired power plants.

---

[13] It exemplifies a situation where a company believes that a financial institution has too high exposures on the energy market related to coal combustion and too slowly reduces its carbon footprint.

[14] Glencore, KEPCO (Korea), Chinese and Indian companies (Adani Group, NTPC Ltd.) are examples.

- China Investment Corporation (CIC) invested $710 million in green energy supplier GCL-Poly Energy Holding already in 2009 to develop photovoltaics (both solar panel production and solar power plants).
- In 2016, Brazil’s BNDES announced it would stop supporting coal-fired and oil-fired power plants and actively increased its involvement in renewables.
- The Rockefeller Foundation, with $5 billion in assets, has become the largest foundation in the U.S. to support the withdrawal of fossil fuel assets, and will not make any new investments in the area from its decision. This is extremely significant because this foundation was established thanks to capital from the oil sector.
- Lloyd’s is reducing its commitment to coal and oil sands by reversing its traditional approach to climate change strategies. Lloyds has come under pressure from environmentalists as its members have insured controversial projects such as Adani Enterprises’ Carmichael thermal coal mine in Australia and Canadian Trans Mountain oil pipeline. Lloyd’s Corporation and its members will complete new investments in coal-fired power plants, coal mines, oil sands and new Arctic energy exploration activities from January 1, 2022. This will lead to a gradual withdrawal of corporations from existing investments in enterprises that generate at least 30% of their revenues from these sectors by the end of 2025.
- Macquarie Group Ltd., or to be mor precise its Green Investment Group Renewable Energy Fund 2,[15] prepared a €1.6 billion renewable energy fund. The capital was raised as a result of a commitment to entrust funds by 32 pension funds and insurers mainly from the UK and Germany, as well as some state wealth funds.
- The Japanese Bank for International Cooperation (JBIC) has announced that it will stop financing coal energy abroad. JBIC’s announcement followed similar policy changes of Japanese commercial banks, including Sumitomo Mitsui and Mizuho. Mitsubishi Corporation withdrew from a major coal project in southern Vietnam in February 2021 and pledged not to engage in any further coal projects abroad. Similarly, South Korea will halt state-backed financing of coal-fired power plants abroad from 2021 and plans to strengthen its commitment to reduce emissions under the Paris Agreement.
- The Bank of the Philippine Islands (BPI) announced a halving of financing coal-fired power plants over a five-year period from 2021.
- The state of Colorado passed a bill in 2021 that forces the Public Employees Retirement Association (PERA) to follow the example of other large investors who have withdrawn money from fossil fuel-oriented companies. For example, BlackRock, the world’s largest fund with approximately $9 trillion in assets, reported in January 2021 that New York City pension funds would be better protected from climate risk and impairment if the city divested itself of investments in oil and gas assets.

Renewables and green transition have been identified as a large area of the global economic growth. Everyone, from niche tech companies to major energy companies, is stepping into this area as countries around the world commit to achieving a net-zero carbon footprint. At the same time, more than 50 major global financial institutions have announced to exit investments in oil and natural gas projects by the end of 2022; and 23 of them have already implemented these announcements.

5. Selected elements of green finance

Green finance, combined with the requirement to improve the state of the natural environment, is becoming the basic instrument to adjust the corporate operation to the

---

[15] MGREF2 is a twenty-five-year closed-end fund that will invest in wind and solar projects in Western Europe, the USA, Canada, Mexico, Japan, Taiwan, Australia and New Zealand.

requirements of the green transition. The list of financial instruments related to sustainable development attracting the attention of investors around the world is growing.

An instrument which is becoming increasingly important for the development of RES is commercial contracts for the purchase of electricity from RES, i.e. PPAs (Power Purchase Agreements), which include long-term electricity supply, becoming an alternative to government support, providing consumers with electricity at competitive prices, and enabling investors to finance investments. Thus, PPAs allow for the purchase of electricity and green certificates from renewable energy projects at an agreed price. In addition to securing the supply of electricity from renewable sources, PPAs also serve as a way to secure electricity costs while also providing renewable energy projects with revenue certainty, which helps to obtain financing. There is a risk that in the long term an increase in the share of wind or solar energy in the total supply will reduce its price on the wholesale market because the variable cost of production in RES is zero. Such a situation may worsen the return on investment in RES, which is taken into account by financial institutions in the assessment of RES projects: how many new renewable projects will be ready and launched before their investment project is put into operation and what can be expected in the coming years in terms of, for example, electricity storage. The conclusion of the PPA allows investors and institutions financing RES to protect themselves against this risk and ensure the expected value of return on investment (e.g. measured by NPV) and meet the investor’s obligations to financial institutions.

Other instruments supporting the development of climate-friendly ventures are green bonds, which are becoming the instruments, besides PPAs, financing the fight against climate change. They are used to provide capital for projects which have a positive impact on the environment. Part of the issue of green bonds is used by governments or companies to support investments in RES. Local governments also issue such bonds. However, their issuance is associated with higher costs than other types of bonds, as it requires the certification of financed projects as green. Anyway, the green bond market is still immature, representing less than 1% of the global bond market [Bloomberg, 2019]. Already in 2008, Swedish bank SEB together with the World Bank issued green bonds to support climate change projects. In the US, CalSTRS, AP2, AP3, UNJSPF and California State Treasurer funds support the issuance of green bonds and the creation of a market for them. Green bonds are also issued in Peru (IFC issuer), Germany (KfW bank) and Australia (World Bank).

Green bonds in 2018 were rivaled by Treasury bonds, whose profitability rose, as well as the appreciation of the US dollar and alternative instruments from green private equity markets. Poland was the first country to issue green bonds in 2016, renewing the issue in 2018 – the total value of the issue is EUR 1.75 billion. Ireland is another example, with the issuance of twelve-year bonds worth €3 billion with a demand of €12 billion in 2018.

The issuance of green bonds usually increases the interest of long-term investors in the company. An impulse for the development of the green bond market may come from the actions of the Chinese government, which is striving to develop RES. However, public finances can provide funding for about 15% of the $400–800 billion needed to fund green investments. Hence, after the Paris Agreement, the Chinese government published national standards for green bonds, which should provide the missing funds. Other countries that focus on the development of the green bond market are India and Brazil. Different types of issued bonds should be indicated: green bonds, climate bonds, sustainability bonds; social bonds, ESG bonds; blue bonds (related to the oceans), etc. There are also bonds financing the reduction of plastic waste, which are to finance projects related to the efforts made by companies to reduce the amount of packaging waste. For example, sustainability bonds are used to finance projects that bring clear environmental and social benefits and are aimed at achieving positive economic results for a specific target group with a neutral or positive environmental impact, while green bonds are used to finance projects and activities that are beneficial for the environment. Such an activity may be exemplified by the issue of green bonds by the city of Łódź, which plans to raise PLN 50 million from the issue, for example in order to construct retention tanks at the Group Sewage Treatment Plant.[16] In the transition period of the green transformation, transition bonds appear, the purpose of which is to finance the activities of entities from less green sectors of the economy, and which, when entering the sustainable development market, are often the ones that can make the most difference in the fight against climate change, changing their business model to a more sustainable one, although the path to sustainable development may be less direct. Thus, transition bond goals often similar to those of green bonds may not always be achieved.

In February 2020, Verizon's green bonds attracted orders from more than 300 investors, amounting to eight times more than $1 billion, which the company had planned to raise. "In 25 minutes, orders already exceeded $1 billion," said James Gowen, the company's vice president and chief sustainability officer. By that afternoon, more than 300 investors had ordered more than $8 billion in debt. In 2020 Visa, issued $500 million worth of green bonds to be used to fund energy efficiency improvements, greater use of renewables, commuting programmes for workers, water-saving projects, and initiatives to support the United Nations Sustainable Development Goals. In 2020, Alphabet, the parent company of the Google capital group, also issued $5.75 billion worth of green bonds. The

---

[16] The first Polish city to issue green bonds was Grudziądz, which, in this way, raised PLN 63 million for water and sewage investments in 2020.

purpose of the issue was to finance tasks in the field of energy efficiency, clean energy, green buildings, clean transport or circular economy.

Another instrument of green finance is ESG-linked (Environmental, Social and Governance) loan agreements, the cost of which is partly determined as a result of the assessment of the borrower's commitment to sustainable development and responsible business, the number of which began to grow in 2019 (in 2019, there was an increase in this type of lending by 168%, with the global value of USD 122 billion) [Bloomberg NEF, 2020]. ESG-linked financing makes the borrower set ambitious and meaningful sustainability performance targets and report regularly, at least once a year, on the progress made, confirmed by independent verification. Targets may be set for greenhouse gas reductions, energy efficiency improvements or the achievement of an external sustainability rating. Funds from sustainability loans can be used for general business purposes, however, their interest rate is partly tied to the borrower's sustainability performance. The interest rate on the loan is lowered if the borrower achieves his goals, however, it can increase if the goals are not achieved. About 80% of sustainability loans were granted in Europe by the end of 2019. The development of various green finance instruments is to be expected as they respond to a combination of climate risk problems and societal expectations of climate improvement. Green loans should be indicated as another example such instruments. They have the characteristics of standard loans, only distinguished by the objective of green projects and the requirement of transparency in the selection of sustainable projects and the allocation of funds. Sustainability loans allow companies to raise financing to a wider extent than green loans or green bonds, give access to finance even to small entities, while expanding the set of projects supporting the green transition. The structure of sustainable development loans allows, the provision of the contract permitting, to periodically use and repay them if necessary. This feature means that they are best suited for flexible use to achieve overall corporate goals that are not necessarily known at the time of initial loan negotiation. In this way, the sustainable credit agreement becomes a flexible instrument for achieving the corporate climate goals, while the implementation of the Sustainable Development Goals provides the financial benefit of reducing the cost of credit.[17] Entities investing in their own sustainable development are adjusting to the global trend to disclose information related to their climate impact, which is also reflected in the assessment that the confirmation of a high ESG standard directly translates into a reduction in the credit

---

[17] In February 2020, investment firm Neuberger Berman became the first financial services firm in North America to announce a $175 million corporate revolving credit facility related to sustainability. The loan will be reviewed annually with ESG criteria in accordance with the UN Principles of Responsible Investment.

risk of such a company. Green credits are used if the desired use of the proceeds of the loan, although favorable for the environment, will not improve the general profile of the corporate sustainable development.

Sustainable development loans worth €600 million in 2020 were prepared and made available to companies by Investec Bank plc, the coordinator of the consortium of lenders. The cost of funding was directly linked to the ESG factors in the areas like environment, gender diversity and governance and will be reduced as long as the SDGs are met and confirmed by an authorised body.

In 2020, Royal Bank of Scotland prepared ESG-linked loans for EQT Private Equity with a group of entities, the maximum value of which was set at EUR 5 billion.

In 2020, a consortium of 18 banks (e.g. JPMorgan Chase, Bank of America, Barclays and Citibank) prepared a $3 billion sustainability credit line for Johnson Controls, the cost of which is linked to sustainability goals in the areas of employee safety and greenhouse gas emission reduction of Johnson Controls' customer projects and from the company's own operations.

In 2020, JetBlue Airways announced a sustainability loan agreement with French banking group BNP Paribas, amending its existing $550 million credit line. The interest rate is linked to the airline's ESG score. The assessment of ESG indicators will be carried out once a year by Vigeo Eiris (a company in the Moody's group) – an independent, international rating agency specialising in the field of ESG.

In Poland, Santander Bank Polska concluded the first sustainable development loan agreement with Energa already in 2019. The provisions of the agreement prohibit the allocation of funds from the loan for any capital expenditures in the field of coal energy. The verification of ESG indicators will be carried out by Vigeo Eris. The agreement is valid until 2024 and can be extended until 2026.

Conclusions

Green transition creates risks which can become an opportunity for financial institutions. The risk arises in an area that has been subjected to regulatory and market pressure, forcing changes in market strategy or energy generation techniques. Opportunities are a consequence of regulation as well as pressure from the markets, including investor expectations. These include clean technologies, especially the area of energy efficiency, technologies reducing greenhouse gas emissions or the development of renewable energy sources and the digital revolution on the energy market. Thus, whether a risk factor is an opportunity or a potential risk depends mainly on the strategy adopted by the company. However, it should be stated today that the current situation is creating a revolution for financial markets. The changes make the existing models of financing the energy sector and industry involved in the combustion of fossil fuels obsolete, especially in the light of the maturation of production technologies in RES and energy storage. The price of greenhouse gas emission rights at the level of €55 confirms the scenario of decarbonisation of economies through market impulses. It is also a confirmation of the need to develop green finance. The global development of RES means that currently in many markets the cost of production in large, industrial photovoltaic farms is lower than production in conventional and nuclear power plants, production costs in domestic photovoltaic installations often become competitive in relation to the purchase of energy from the power industry. Green finance is the basis for low-carbon economic growth on a global scale.

References

Bloomberg (2019). *Bonds to Save the Planet* (access: 29.04.2019).

BloombergNEF (2020). *Sustainable Debt Sees Record Issuance At $465Bn in 2019, Up 78% From 2018*, https://about.bnef.com/blog/sustainable-debt-sees-record-issuance-at-465bn-in-2019-up-78-from-2018/ (access: 27.12.2020).

Boston Common Assets Management (2005). *Are banks prepared for climate change? Impact Report 2005.*

Buckley, T. (2019). *Over 100 global financial institution are exiting coal, with more to come*. Cleveland: Institute for Energy Economics and Financial Analysis.

ESMA (2018). *Final report. ESMA's technical advice to the European Commission on integrating sustainability risk and factors in MiFID II*, ESMA35-43-1737.

ESMA (2021).*Guidance on disclosure requirements applicable to credit ratings*.

Krukowska, M. (2021). *Oceny ESG wymagają ujednolicenia (ESG assessments need to be standardised)*, https://www.obserwatorfinansowy.pl/bez-kategorii/rotator/oceny-esg-wymagaja-ujednolicenia-2/ (access: 1.05.2021).

Marlin, S. (2018). *Stress tests expose climate risk in loan books*, risk.net (access: 13.09.2018).

World Bank (2013). *Toward a sustainable energy future for all : directions for the World Bank Group's energy sector.*

Honorata Nyga-Łukaszewska
Warsaw School of Economics

Chapter III

International Energy Markets and the Continuity of Energy Supply in the Era of the COVID-19 Pandemic

Abstract
Energy is an essential part of any economy. The continuity of energy supply is one of the most important economic challenges, also in the pandemic era. The chapter analyses the impact of the pandemic on global energy markets, with particular emphasis on the continuity of energy supply. The phenomenon is illustrated by the example of the hydrocarbon market, describing the situation of countries exporting and importing natural resources. The chapter uses commonly recognised sectoral studies, especially publications of the International Energy Agency.

Keywords: energy security, pandemic, demand shock

Introduction

Energy is an essential part of any economy. Regardless of the level of economic development or the structure of energy supply, the issue of continuous access to energy determines the durability of production. The importance of energy in the economy makes it an important element of the economic policy of many countries. The issues of the structure of electricity generation, sources of supply of primary fuels, infrastructure investments, energy intensity of economies are one of the most important elements of energy policy. It does not mean, however, that energy policy is a separate, individualised being, completely detached from climate policy. Nowadays, we are dealing with energy and climate policy rather than just energy or climate policy. Therefore, the structure of energy generation is most often accompanied by concerns about the use of solid fossil fuels generating relatively the highest greenhouse gas emissions. The same applies to the structure of the supply of primary fuels. On the other hand, in the area of infrastructure investments, great emphasis is most often placed on the choice of environmentally and climate-friendly technologies. What appears to be the least controversial from this point of view is the so-called fifth fuel, i.e. energy efficiency, which in fact is an inverted concept of energy intensity, according to which the aim is currently to reduce the consumption of energy used per unit of production or GDP. In other words, reducing energy intensity means increasing energy efficiency. Such strong links between energy and climate policy affect every element of economic policy, including energy security.

Nowadays, the continuity of energy supply, referred to as energy security, is a concept that takes into account both energy and climate aspects. And it would probably be difficult today to imagine this idea without climate protection issues. The International Energy Agency, which sets trends in the way of looking at energy security, emphasises that it consists of several elements. The first is the continuity of energy supply, the second is an acceptable price and the third is the reduction of the negative impact of energy industry on the natural environment. Currently, these are three inextricably linked elements, but it has not always been like this.

Energy security is an evolving concept. When it appeared for the first time in the political and economic discourse, the issue of continuity of energy supply was really paramount. In the 1970s, when this issue emerged, political conflicts disrupted oil supplies to many countries. The limited supply made pressure on the rise in global oil prices. The same fears returned at the beginning of the twenty-first century, which saw problems with the continuity of natural gas supplies in Europe. There were concerns not only about the supply of this raw material, but also about its prices in the future.

Currently, in the discussion in international fora, the issues of changing or reducing the impact of the energy industry on the natural environment are more often raised. Although at first glance the issue of energy security is not directly related to climate protection, a more thorough analysis seems to contradict this. The relations are particularly conspicuous in the case of those countries which, on the one hand, perceive energy security mainly in terms of energy self-sufficiency, and on the other hand, use to a large extent the indigenous base of solid fossil fuels for energy production. It seems that this approach significantly simplifies energy security and reduces the relationship with climate protection only to the emissivity of fuels. Research to date shows [Turton, Barreto, 2006] that this relationship can also be considered in more detail, and to be more precise, in terms of the technologies used.

The aim of this chapter is to show the contemporary dimension of energy security in the era of the COVID-19 pandemic. To prepare the text, the author used commonly available materials of recognised sectoral institutions and organisations, e.g. the International Energy Agency.

1. Energy security in the 21st century

Energy security has been present in the political and economic discourse since the 1970s and is associated with the so-called petroleum crises. In the scientific discourse, on the other hand, energy security appears in the late 1970s and intensifies in the 80s. In this area, science followed socio-economic events, trying to describe the phenomena taking place. Thus, we can clearly see a kind of delay in research work in relation to the phenomena occurring in the world. This is due to several reasons. Firstly, at that time, interruptions in the continuity of fuel supplies were a new phenomenon. Secondly, it concerned the market of oil monoculturally used in transport, for which there were few substitutes at that time. Thirdly, empirical studies show a delay due to the need to collect data. The extent of the delay is related to the characteristics of the data (data type, e.g. GDP, inflation, level of imports of raw materials) and their frequency (e.g. daily, monthly, quarterly, annually), but also to the effectiveness of statistical institutions and data sharing policy.

Since the emergence of energy security in the scientific discourse, the discussion has mainly focused on the hydrocarbon market. This is a natural consequence of uneven distribution of these fuels in the world, their intensive use and in many economies and the resulting need for fuel imports. The new century, especially the beginning of it, was associated with interruptions in the continuity of natural gas supplies, but the first decade was largely dominated by the issues related to the extraction of unconventional hydrocarbons, including shale gas. Shale gas extraction in the US gave rise to hopes to achieve energy independence also in the countries that had so far imported natural gas. Changes in the position of the US in the international natural gas market from importer to exporter of hydrocarbons only made these trends stronger.

2. Impact of the COVID-19 pandemic of the selected fuel markets

The impact of COVID-19 on global energy markets is multidimensional. In the era of the pandemic, there is a global demand shock on the energy markets, caused by reduced energy demand and at the same time a supply shock on the oil market.

The global lockdown reduced the need to move and use means of transport for both long and shorter distances. The global demand for crude oil declined in April 2020, compared to January 2020 about a quarter [Sönnichsen, 2021a]. The largest consumer of crude oil in the world, i.e. aviation, significantly reduced its activity. On 19 April 2020, 24,027 commercial flights were registered, which is about three quarters less compared to mid-March 2020 (about 100,000 flights) [Flightradar24, 2021].

As Bassam Fattouh, Andreas Economou [2020] point out, the decline in demand for oil due to the spread of COVID-19 and the termination of the OPEC+ agreement caused a price pressure on the oil market. Brent and WTI prices fell by more than 50% in two weeks in March 2020. The price of Brent crude oil fell to $24.9 a barrel on 18 March 2020 from USD 51.9 per barrel on 2 March 2020, while at the same time the price of WTI fell to $20.4 per barrel from $46.8 per barrel. Fattouh and Economou [2020] claim that the oil market moved from a backwardation[1] phase (deportation) to a deep contango phase.[2] At the same time, the authors predicted that the imbalance between supply and demand would further [3]aggravate contango as inventories increased and the so-called floating storage facilities were used more frequently.[4]

Unlike the oil market, the natural gas market was not hit as hard by the COVID-19 pandemic. As indicated by the International Energy Agency [IEA, 2021], in 2020, the global natural gas consumption decreased by 2% compared to 2019. This is a value equal to about 75 m m^3 of natural gas. The largest decrease in natural gas consumption was recorded in the first half of 2020 (-4% over the same period in 2019), which was mainly due to the mild winter and the pandemic situation.

On the market of this fuel, liquefied natural gas (LNG) gained significance consisting in periodic balancing supply and demand, as well as ensuring energy security. Although COVID-19 contributes to the historical demand shock in energy markets, the market saturated with supply and contracts has been a major force since 2019, to reduce corporate activity.

The effects of COVID-19 on the gas market were also visible in the disruption of the supply chain. The global lockdown negatively affected global supply chains. According to the International Energy Agency [IEA, 2020a], 22 of the 28 global floating production, storage and landing vessels which were built in the first quarter of 2020 were built in shipyards in China, South Korea and Singapore. Moreover, the main center of the production of specialised

---

[1] Backwardation – a term related to the functioning of financial markets, often interchangeably called deportation. It describes a situation in which futures contracts have lower prices than current spot prices. It leads to a sale of raw material stocks, because their longer storage becomes unprofitable. This is the inverse phenomenon of *contango*.

[2] Contango – a term related to the functioning of financial markets. It describes a situation where futures contracts have higher prices than current spot prices. This leads to a situation in which it pays to keep stocks of raw material. Contango is the opposite of backwardation.

[3] Evaluation using the VAR structural model. The imbalance between demand and supply is estimated at 5.7 million barrels per day in 2020 and 3.3 million barrels per day in 2021 [Fattouh and Economou, 2020].

[4] During the contango period, oil storage also takes place on ships transporting oil to destinations, then it is said about the so-called floating storage facilities.

engineering equipment for the oil and gas industry is the region of Lombardy in Italy, which was one of the first areas of Europe where mobility restrictions were applied.

According to Barbosa et al. [2020], the oil and gas industry in the era of pandemic can increasingly feel the effects of the constantly deteriorating condition of companies. The overall situation of the industry is well presented by the annual rates of return on capital employed, which are presented in Table 1. It shows that between 1990 and 2005, the oil and gas industry in general generated higher rates of return for shareholders (13%) than in the years 2005–2019 (2%). The situation was similar in the case of selected segments of the oil and natural gas market. In the exploration and production segment, annual rates of return in the period 1990–2005 reached 12%, while in the years 2005–2019 the upstream segment did not generate any returns for shareholders at all.

Table 1. Annual returns for shareholders in the oil and gas industry between 1990 and 2019 (in %)

	Annual rates of return in the years 1990–2005	**Annual rates of return in the years 2005–2019**
Exploration and extraction	12	0
Oil and gas industry total	13	2

Source: Author’s own elaboration based on Barbosa et al., 2020.

On the coal market, during the pandemic, there was a decline in consumption. As indicated by the International Energy Agency [Alvarez, 2021], global coal consumption fell by 4% in 2020, which is the largest decline since World War II. This decline was mainly concentrated in the first months of 2021. In the first quarter of 2020, the global coal demand fell by 11% (year-on-year) due to the mild weather, competitive gas prices and pandemic restrictions in China. By the end of 2020, demand had risen above the levels observed during the pandemic and was driven mainly by Asian countries. The steel industry, especially the steel manufacturing sector, which is the second largest consumer of coal in the world (following electric energy) (with 15% of global consumption), reduced production mainly in March and April 2020, in China, which accounts for more than half of the global steel production, production only temporarily slowed down in March 2020. In Asian countries, economies quickly returned to pre-pandemic production levels, additionally December 2020 turned out to be extremely cold, which increased the demand for coal. In this way, the consumption of coal in the fourth quarter of 2020 was 3.5% higher than in the same period in 2019, contributing to the global recovery of CO_2 emission.

The International Energy Agency [IEA, 2020b] estimates that in April 2020 the U.S. compared to 2019, due to the global travelling restrictions, greenhouse gas emissions decreased, which significantly affected the air quality in cities. The main reason was the reduction in traffic (from 50% to 75% and up to 95% during peak hours in large cities), which is responsible for nitrogen dioxide emissions (NO_2) in towns. For example, the average concentration in Milan was about 17% lower in the two weeks after the start of the lockdown than in the two weeks preceding it. In New Delhi, a reduction in peak hour traffic in the first weeks of lockdown led to a 66% drop in NO_2 emissions in April 2020 compared to 2019.

Of the energy sources analysed, only renewable energy sources did not succumb to the negative effects of the pandemic. According to Sönnichsen [2021b], in 2020, compared to 2019 although the production of electricity from coal and nuclear energy decreased by about 4%, from natural gas by about 1%, the production of electricity from renewable sources increased in the same period by about 18%. Wind and solar power generation increased in all but two of the G20 countries, while coal power only increased in China. In 2020 93,000 megawatts of wind capacity were installed worldwide. Capital expenditures on renewable energy projects around the world are estimated to be in 2021 240 billion dollars.

3. Impact of the COVID-19 pandemic on the energy security

The impact of the COVID-19 pandemic on energy security is visible on at least two levels. The first is the micro level, i.e. the level of enterprises, and the other one is the macro level, i.e. the level of countries / national economies.

The European Commission [European Commission, 2020], in June 2020, presented a set of 20 good practices that the energy industry could/can use to ensure energy security. The recommendations are the result of the agreements of EU energy ministers in April 2020. They include:

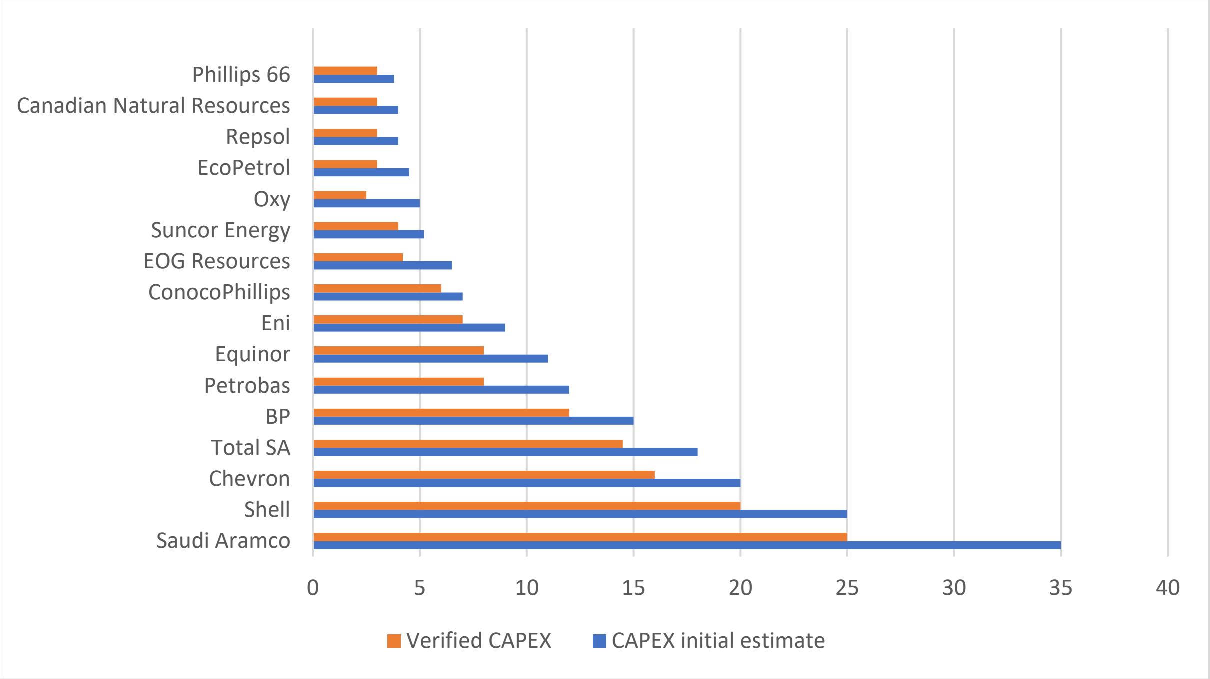
1) protection of the group of the so-called vulnerable customers by monitoring the situation of low-income households, enacting or extending moratoriums on disconnection of energy services for households and small enterprises in arrears, as well as credit extensions or deferral of bill payments in the situations described above;
2) free movement of personnel, whose presence is crucial from the point of view of the stability of energy systems (e.g. the operation of offshore wind farms), but also free movement of goods, components, natural resources critical from the point of view of the entire supply chain in the energy industry;

3) creating emergency plans, exchanging information and constant communication;

4) implementation of remote work in the field of non-shift and non-basic activities, changes in the schedule of maintenance work of less critical importance, implementation of sanitary protocols, equipping employees with hygienic and sanitary agents and implementation of training in hygienic protocols.

The impact of pandemic on the operation of enterprises was not limited to changing the organisation of work. Investments of energy companies were also significantly reduced, so was the spending on investment purposes. As indicated in Figure 1, all major companies in the oil and gas industry reduced their spending on investment purposes as a result of the COVID-19 pandemic in 2020 (the so-called verified CAPEX). The biggest savings in this area were made by Saudi Aramco, Shell and Chevron. A reduction in investment may have a negative impact on energy supply in the future.

Figure 1. Change in capital expenditures of major oil and gas companies in 2020 as a result of the COVID-19 pandemic (in USD billions)



Source: Author’s own elaboration based on the data: Sönnichsen, 2021c.

From the point of view of countries participating in the international energy trade, the COVID-19 pandemic became a catalyst for changes of various nature. This applies to both energy exporters and importers. It seems that in the case of countries producing energy and at the same time being significant exporters of energy, the pandemic strongly demonstrated dependence on income derived from exports and the stability of international energy markets. As forecast by the Organisation for Economic Co-operation and Development [OECD, 2020], the group of energy exporters most affected by the pandemic are the countries of sub-Saharan Africa. This is due to a strong dominance of oil exports in the country's total exports. In the case of African countries such as Algeria, Libya and East Timor, the share of oil exports in total exports reaches 60% [UNCTAD, 2019]. Between 2011 and 2013, the proceeds from oil sales by the ten largest sub-Saharan African oil-exporting countries accounted for more than 50% of their total budget revenues and more than 75% of their export revenues [Gillies, Guéniat, Kummer, 2014]. To a slightly lesser extent, the effects of the pandemic will be felt by oil exporting countries, such as Saudi Arabia, or even (despite the high dependence of the budget on export revenues) Iraq. These are countries that can produce oil even at a price lower than $30 a barrel, while for Venezuela, Nigeria and even Russia, the break-even point is around $50 per barrel of oil [OECD, 2020]. As indicated by the Organisation for Economic Co-operation and Development [OECD, 2020], the situation of African oil-exporting countries will also deteriorate further due to the fact that these countries were heavily indebted (even at the high level of oil prices) before the pandemic and experienced an outflow of foreign investment capital. To sum up, in commodity-exporting countries, the pandemic exposed the sensitivity of economies to demand shocks in energy markets.

Countries importing energy were in a slightly better situation during the pandemic. Travelling restrictions or closure of industrial plants caused a decline in the consumption of, for example, electricity. The reduced needs of economies limited imports, which had a positive impact on the trade balances of many countries importing raw materials. At the same time, the pandemic in these countries became a catalyst for the energy transition towards a green and decarbonised economy. Post-pandemic recovery programmes, such as the *Green Deal* in the European Union, assume not only the reduction of greenhouse gas emissions and the fight against climate change, but also the implementation of new, clean technologies as well as the modernisation of industry towards the principles of sustainable development.

Conclusions

The continuity of energy supply is undoubtedly one of the most important economic challenges, also in the era of the pandemic. The effects of COVID-19 on energy markets are almost comparable to the effects of the oil crises of the 1970s or 80s. In the case of the pandemic, it is not the importers, but the exporters who were most affected by the coronavirus.

Currently, this can be seen in the reduction of investment actions or budget revenues from exports. The situation of hydrocarbon exporters was already difficult before the outbreak of the pandemic. Probably in the long term, as a result of changes in the economies of countries importing raw materials, there will be permanent and profound changes in the structure of energy consumption. This will further aggravate the situation of countries exporting raw materials.

It should also be noted that the energy policy is in parallel with climate policy, and the standards of climate and environmental protection implemented in the world since the so-called Paris Agreement have been significantly dependent on the financial component. This means that financial markets already before the COVID-19 pandemic rewarded those projects that were in line with the principles of sustainable development. It is the strength of the Paris Agreement compared to the Kyoto Protocol, which, regardless of the pandemic, will reinforce the trend towards decarbonisation of economies and phasing out of fossil fuels.

Paradoxically, the pandemic (so far) has not had a significant negative impact on energy importers. The implemented hygienic and sanitary safety protocols counteracted situations of suspension of production or energy supply. The pandemic may be extremely important for this group of countries on the way to independence from imported fossil fuels and fluctuations in their prices.

Due to volume limitations, as well as the fact that the final version of the text was created in June 2021, it was impossible to capture a complete picture of the impact of the COVID-19 pandemic on energy security. Then, it is reasonable to continue the analyses of this problem in the long term, in a detailed approach to selected fuel markets as well as using quantitative research, such as for example Nyga-Łukaszewska and Aruga [2020].

References

Alvarez C. (2021). *Global coal demand surpassed pre-Covid levels in late 2020, underlining the world's emissions challenge*. IEA: Paris, https://www.iea.org/commentaries/global-coal-demand-surpassed-pre-covid-levels-in-late-2020-underlining-the-world-s-emissions-challenge (access: 16.06.2021).

Barbosa, F., Bresciani, G., Graham, P., Nyquist, S., Yanosek, K. (2020). *Oil and gas after COVID-19: The day of reckoning or a new age of opportunity?* https://www.mckinsey.com/industries/oil-and-gas/our-insights/oil-and-gas-after-covid-19-the-day-of-reckoning-or-a-new-age-of-opportunity (access: 16.06.2021).

European Commission (2020). *Commission Staff Working Document Energy Security: Good Practices to Address Pandemic Risks*, https://ec.europa.eu/energy/sites/ener/files/1_en_document_travail_service_part1_v3.pdf (access: 16.06.2021).

Fattouh, B., Economou, A. (2020). *Oil Supply Shock in the time of the Coronavirus*. OIES: Oxford, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/03/Oil-Supply-Shock-in-the-time-of-the-Coronavirus.pdf (access: 16.06.2021).

Fligthradar24 (2021). *Flight tracking statistics*, https://www.flightradar24.com/data/statistics (access: 15.06.2021).

Gillies, A., Guéniat, M., Kummer, L. (2014). *Big Spenders: Swiss Trading Companies, African Oil and the Risks of Opacity*, https://resourcegovernance.org/analysis-tools/publications/big-spenders-swiss-trading-companies-african-oil-and-risks-opacity (access: 17.06.2021).

IEA (2020a). *World Energy Investment Report 2020*, https://www.iea.org/reports/world-energy-investment-2020 (access: 30.06.2020).

IEA (2020b). *Covid-19 and energy: setting the scene*, https://www.iea.org/reports/sustainable-recovery/covid-19-and-energy-setting-the-scene (access: 20.04.2021).

IEA (2021). *Global Energy Review 2021*, https://iea.blob.core.windows.net/assets/d0031107-401d-4a2f-a48b-9eed19457335/GlobalEnergyReview2021.pdf (access: 16.06.2021).

Nyga-Łukaszewska, H., Aruga, K. (2020). Energy Prices and COVID-Immunity: The Case of Crude Oil and Natural Gas Prices in the US and Japan, *Energies*, 23, 6300. DOI: 10.3390/en13236300.

OECD (2020). *The impact of coronavirus (COVID-19) and the global oil price shock on the fiscal position of oil-exporting developing countries*, https://www.oecd.org/coronavirus/policy-responses/the-impact-of-coronavirus-covid-19-and-the-global-oil-price-shock-on-the-fiscal-position-of-oil-exporting-developing-countries-8bafbd95/ (access: 17.06.2021).

UNCTAD (2019). *State of Commodity Dependence 2019*, https://unctad.org/en/PublicationsLibrary/ditccom2019d1_en.pdf (access: 17.06.2021).

Sönnichsen, N. (2021b). *Global daily oil demand by region due to COVID-19*, https://www.statista.com/statistics/561888/global-daily-oil-demand-by-region-due-to-covid-19/ (access: 14.06.2021).

Sönnichsen, N. (2021b). *Coronavirus: impact on the global energy industry – Statistics & Facts*, https://www.statista.com/topics/6254/coronavirus-covid-19-impact-on-the-energy-industry/ (access: 16.06.2021).

Sönnichsen, N. (2021c). *Global oil and gas producers' capex reduction due to coronavirus impact 2020*, https://www.statista.com/statistics/1109778/oil-companies-capex-decrease-due-to-covid-19/ (access: 20.10.2020).

Paweł Wróbel
Gate Brussels (founder)

Chapter IV

Model of Energy Transition in the European Union

Abstract
The implementation of the European Green Deal means putting climate policy at the heart of the European Union activities. Meeting the major target, i.e. the achievement of climate neutrality by 2050, leads to the acceleration of decarbonisation policies. The changes will affect the entire EU economy, including energy, district heating, transport sectors, industry and agriculture. The overall legal framework, including the rules of financing investments which are to lead to the implementation of the European Green Deal, sets out the EU model of energy transition.

Keywords: energy transition, European Green Deal, integration of energy sectors

Introduction

The adoption of the European Green Deal means placing climate policy at the heart of the European Union activities. Meeting the major target, i.e. the achievement of climate neutrality by 2050 , leads to the acceleration of decarbonisation policies. The changes will affect the entire EU economy, including energy, district heating, transport sectors, industry and agriculture. A faster CO_2 emission reduction is needed. That is why, in September 2020, the European Commission adopted a proposal to increase the existing target of a 40% reduction to at least 55% by 2030. According to the so-called impact assessment of the proposal, it will entail the need to adequately increase energy efficiency targets and the share of renewable energy sources. The revision of the legal framework was presented by the European Commission within the Fit for 55 package in July and December 2021. Hence, in both cases, the Commission adopted a proposal to increase the EU targets until 2030: in the case of RES from 32% to 40%, and in the case of energy efficiency from 32.5% to 39% in relation to primary energy consumption and 36% in relation to final energy consumption [European Commission, 2021b].

1. Integration of the energy system

Achieving such ambitious plans in just ten coming years will be possible if the areas where it is feasible in a cost-effective way are accurately identified. The European Commission responded on 8 July 2020 to these challenges adopting the EU Energy System Integration Strategy, also known as the Sector Coupling Strategy [European Commission, 2020a]. It presents the target model of energy transition in the member states which will dominate the EU legislation and development of financing mechanisms. It brings together the sectors with the greatest potential for energy savings and emission reduction, i.e. electric power, district and individual heating, and transport, which together account for three quarters of all EU CO_2 emissions. Firstly, the strategy aims to accelerate the development of renewable sources, whose share in electricity production is expected to double in the next 10 years reaching the level of 55–60%, and 84% in 2050 [European Commission, 2020a]. Secondly, the strategy focuses on the electrification of district and individual heating, as well as on the electrification of transport (primarily road transport). Both these sectors are to stop relying on the combustion of fossil fuels and switch to the use of energy from RES. Thirdly, the system integration by reducing energy losses is intended to implement the principle of “energy efficiency first” and benefit consumers. The facilitation of reuse of waste heat from industrial plants and data processing centers may serve as a practical example. For sectors whose electrification will be hampered, the European Commission proposed measures to introduce cleaner fuels, mainly biofuels, biogas and the so-called clean hydrogen.

The Commission justifies the need for swift action pointing to the fact that the economic life cycle of investments in energy infrastructure is usually between 20 and 60 years. Thus, achieving climate neutrality in 2050 requires some action over the next five to ten years [European Commission, 2020b].

2. What is the role of hydrogen technologies?

In the strategy for the development of hydrogen technologies adopted on 8 July 2020, the European Commission indicates that they will be used primarily in industrial sectors, e.g. steel production or heavy transport [European Commission, 2020b]. According to the activities planned in the strategy, “hydrogen must become an integral part of the integrated energy system. The strategic goal will be to install renewable electrolysers with a capacity of at least 40 gigawatts by 2030 and to produce up to 10 million tonnes of renewable hydrogen in the European Union. The use of hydrogen will be gradually extended to new sectors such as steel production, in trucking, rail freight and some maritime transport. Hydrogen will continue to be produced mainly in the vicinity of the user or renewable energy sources, in local ecosystems" [European Commission, 2020b].

In the case of transport, the most promising area is heavy road transport in the European Union, in urban buses, commercial fleets, special purpose vehicles and long-haul trucks as well as in certain parts of the rail network. In addition, hydrogen can be a fuel for inland waterway and short sea shipping. In the long term, it may be used in the aviation and maritime sectors.

3. Costs and benefits of sector integration

The benefit and cost criterion decided that the time has come to implement the concept of electrification, which has been analysed in Brussels for years. On the climate benefit side, there is a possibility of reducing emissions in several sectors at the same time. The European Commission points to the particularly high potential of the building sector, i.e. the potential to save electricity and heat consumed as well as to reduce emissions. However, economic factors decided to accelerate the adoption of the concept of electrification on the basis of the growing share of RES as a target of transformation. The decline in the cost of investment in energy from renewable sources has continued on for years. And the continuation of this trend is beyond doubt.

Even today, the costs of electricity production from RES are lower than in the case of using fossil fuels. This translates into the competitiveness of economies of member states depending on their energy mix. The situation is similar in the case of storage technology, which will play an increasingly important role as the share of RES in energy production goes on rising [BloombergNEF, 2019].

Meeting electricity supply is to be ensured by solar and wind energy production technologies, both onshore and offshore. As the strategy indicates, especially large increases refer to offshore wind energy. The EU potential is defined at the level of 300 to 450 GW by 2050 (compared to the currently installed 12 GW in the entire Union, and 20 GW including the UK) [European Commission, 2020e]. At the same time, the European Commission points out that other technologies, such as hydrogen, as well as capturing CO_2 (CCS, CCU) from fossil fuels, are considered complementary where effective electrification will not be possible. This applies in particular to certain industrial processes, maritime transport, rail transport and heavy road transport.

The main barriers to sector coupling implementation that the strategy identifies include the need for a more extensive and smart network infrastructure at national and cross-border levels, administrative barriers and a lengthy authorisation process or the provision of adequate funding at public and private levels. Switching to electricity on such a large scale will pose challenges in the management of the power system. The role of regional and cross-border coordination between member states will therefore increase. This was addressed in the reforms introduced by the 2018 Clean Energy Package, e.g by establishing the so-called Regional Coordination Centres.

The European Commission stresses that the implementation of the integration of the energy sector is to enable the transition to be carried out for the benefit of consumers so that their energy bills are lower. It points out that one of the biggest challenges will be to prevent large increases in energy prices in countries that will move away from fossil fuels at a too slow pace. Especially since fossil fuels, such as coal or natural gas, are associated with the increasing cost of CO_2 emission allowances. In many countries, including Poland, it is a dominant factor creating energy prices for customers. Analysts point out that by 2030 we should expect a continuation of the increase in prices per ton of CO_2 emissions even above 100 euros. Forecasts show the continuation of this trend also as a result of the need to reduce CO_2 emissions faster by 2030. Allowances are not only becoming more and more expensive, but they will be mandatory for an increasing number of entities. According to the European Commission proposal, which is part of the Fit for 55 package, from 2026 all the district heating as well as transport in the Union, are to be subject to the obligation to the purchase of greenhouse gas emission allowances, in parallel with the EU ETS [European Commission, 2021a]. This will cause natural gas to share the fate of coal, making investments in this raw material unprofitable.

In order to protect vulnerable customers and combat energy poverty, member states may be given the possibility to use revenues from CO_2 emission allowances, including those intended eventually to contribute to the Union budget. Such a mechanism would temporarily mitigate the effects of moving away from fossil fuels too slowly. In addition, the European Commission proposed the establishment of a new Social Climate Fund to provide funding to support investments in energy efficiency, new heating and cooling systems and clean transport. The groups to be supported will be those at risk of significant costs of energy transition, i.e. households, micro-enterprises and road transport users. Poland is to be the largest beneficiary of the fund [European Commission, 2021c].

4. “Renovation wave” – a new model of modernisation of buildings

The implementation of the EU strategy requires activities in the areas identified as those with the greatest potential. The building sector belongs to the most important areas. That is why a separate strategy of activities is dedicated to it, the so-called renovation wave. It was adopted by the European Commission on 14 October 2020 [European Commission, 2020d]. Its task is to include the modernisation of the building sector in the mainstream of legislative and financial activities in order to implement the Energy Sector Integration. Undoubtedly, the implementation of EU plans will depend on revolutionary changes in this sector. Interestingly, so far it has been on the sidelines of the interest of EU policies. However, the prepared change should not be surprising. Since announcing the European Green Deal, the European Commission has indicated that the time has come to “green” the one of the most carbon-intensive and energy-intensive sectors. All buildings (public, residential and commercial), whose number amounts to around 260 million in the Union, consume more than 40% of final energy, most of which is heating and cooling, accounting for 36% of all EU CO_2 emissions. Therefore, buildings represent an area of great challenges and opportunities in the context of meeting the 2030 climate targets [European Court of Auditors, 2020].

Within the renovation wave, a legal framework and financing mechanisms have been proposed to double the annual rate of currently renovated buildings. The renovation is expected to cover 35 million buildings over the next 10 years. This means decarbonising the heating and cooling sector they use. This target is already included in the EU Energy Efficiency of Buildings Directive (EPBD) of 2018. Its implementation as part of the electrification of the heating and cooling sector is to enable the transition from fossil fuels and the switch primarily to heat pump technology. According to the European Commission forecasts included in the Energy Sector Integration Strategy regarding the increase in electricity consumption for the production of heat and cold, heat pump technology will dominate this area of energy. In residential buildings, their share should reach 40% in 2030, and 50–70% in 2050. In commercial buildings, it will be 65% in 2030 and 80% in 2050, respectively [European Commission, 2020a].

One of the tasks of the “renovation wave” will be to increase the share of RES in the heat and cold sector. After the revision of targets, the share of renewable sources in heating should reach 40% in 2030. Among the new proposals was the introduction of a non-binding target of achieving at the Union level at least 49% of RES in the building sector by 2030. The aim is to accelerate the decarbonisation of buildings. This will lead to a change in the energy mix in district and individual heating. As the European Commission stresses, the effective renovation of buildings should also include the use of digital technologies to optimise energy consumption. Digitalisation will be particularly effective when combined with renewable technologies.

5. Transition financing

This direction of the energy transition is supported not only in regulations, but also reflected in EU financial instruments and funds supporting investment and reforms in the member states. Financing of the new building renovation model is expected to start as soon as possible. That is why the EU Recovery and Resilience Facility, which aims to put the economy back on the path of economic growth after the coronavirus pandemic, has a crucial role to play. Within these funds, Poland should receive over EUR 23 billion in grants. As much as 70% of this funding is to be launched in 2021–2022. The modernisation of buildings is identified as one of the seven main areas in the guidelines on how to prepare the National Recovery Plans that the Commission developed for member states. In addition, at least 37% of these funds must be allocated by every country to reforms and investments in support of the Implementation of the European Green Deal. According to the declaration of the Polish government, Poland wants to allocate as much as 8 billion euros from this instrument to support the "Clean Air" programme. Therefore, it will be important to combat smog and at the same time implement the EU climate and energy targets. It means the need to finance a new model of modernisation, i.e. one that includes support for RES, e.g. photovoltaics, moving away from fossil fuels towards clean technologies such as heat pumps, developing electric car charging infrastructure in buildings, home energy storage, as well as digital devices that allow effective management of energy consumption.

The "renovation wave" will have equally important support from the EU budget in the years 2021–2027. In Poland, its implementation will be to a large extent co-financed by the cohesion policy, of which we will remain the largest beneficiary in the entire Union, receiving about EUR 55–60 billion from the European Regional Development Fund and the Cohesion Fund. As much as a third of the funding received will have to support the implementation of climate goals.

The need to implement the energy transition model in accordance with the Energy Sector Integration Strategy is directly indicated by the European Commission in its assessment, e.g. of the Polish National Energy and Climate Plan (NECP) 2021–2030. Such recommendations for the Polish government were published on 14 October 2020 [European Commission, 2020c].

Conclusions

The European Commission is not only determined to achieve the objectives of the “renovation wave”, but it also has a coherent approach accounting for a wide range of regulations and funding mechanisms. They include EU funds as well as the way of operation of the private and public financial sectors, which determine the movement of capital for investment. A very big change awaits us resulting from the introduction of taxonomy. It is a system of uniform classification of the activities of financial market entities (e.g. banks) due to their impact on sustainable development. Taxonomy will assess in which areas such investments will have a positive impact on the environment. A sustainable investment must be considered sustainable by contributing to at least one of the six taxonomy objectives while not harming the others. The objectives of the taxonomy are: (1) climate change mitigation, (2) adjustment to climate change, (3) sustainable use and protection of water and marine resources, (4) emission control and reduction of pollution, (5) transition to a circular economy and (6) protection of biodiversity and ecosystems. The taxonomy, which is mandatory from 2022, will have a significant impact on the future of classification of energy investments. Priority treatment of investments in RES and energy efficiency will be supported by taxonomy.

EU strategies and legislative proposals of the Fit for 55 package create a plan for energy transition in the EU countries. The aim is to implement the European Green Deal. Their strength lies in their coherent incorporation into the overall EU legislation, which is the main framework for changes in various energy sectors in the member state countries. The most important, however, is a strong link with the principles of functioning of financial institutions as well as Union funds.

References

BloombergNEF (2019). *Battery power’s latest plunge in costs threatens coal, gas*, https://www.bloomberg.com/professional/blog/battery-powers-latest-plunge-costs-threatens-coal-gas/ (access: 22.04.2021).

European Commission (2020a). Communication from the European Commission “Powering a Climate-Neutral Economy: An EU Strategy for Energy System Integration” of 8 July 2020, COM(2020)299, https://eur-lex.europa.eu/legal-content/PL/TXT/?qid=1598287046418&uri=CELEX:52020DC0299 (access: 22.04.2021).

European Commission (2020b). Communication from the European Commission “A Hydrogen Strategy for a Climate Neutral Europe” of 8 July 2020, COM(2020)301, https://eur-lex.europa.eu/legal-content/PL/TXT/HTML/?uri=CELEX:52020DC0301&from=EN (access: 22.04.2021).

European Commission (2020c). Commission Staff Working Document. Assessment of the final national energy and climate plan of Poland of 14 November 2020, https://energy.ec.europa.eu/system/files/2021-01/staff_working_document_assessment_necp_poland_pl_0.pdf (access: 22.04.2021).

European Commission (2020d). European Commission Communication “A renovation wave for Europe – greening our buildings, creating jobs, improving lives” of 14 October 2020, COM(2020)662, https://eur-lex.europa.eu/legal-content/PL/TXT/HTML/?uri=CELEX:52020DC0662&from=EN (access: 22.04.2021).European Commission (2020e). Communication from the European Commission “EU Strategy on Offshore Renewable Energy for a Climate Neutral Europe” of 19 November 2020, COM(2020)741, https://eur-lex.europa.eu/legal-content/PL/TXT/HTML/?uri=CELEX:52020DC0741&from=EN (access: 22.04.2021).

European Commission (2021a). Proposal of a Directive amending Directive (EU) 2003/87 of 14 July 2021, https://ec.europa.eu/info/sites/default/files/revision-eu-ets_with-annex_en_0.pdf (access: 22.04.2021).

European Commission (2021b). Proposal of a Directive amending Directive (EU) 2018/2001 of 14 July 2021 and Directive (EU) 2018/2002 of 14 July 2021, https://ec.europa.eu/info/sites/default/files/amendment-renewable-energy-directive-2030-climate-target-with-annexes_en.pdf, https://ec.europa.eu/info/sites/default/files/proposal_for_a_directive_on_energy_efficiency_recast.pdf (access: 22.04.2021).

European Commission (2021c). Proposal for a Regulation establishing the Social Climate Fund of 14 July 2021, https://ec.europa.eu/info/sites/default/files/social-climate-fund_with-annex_en.pdf (access: 22.04.2021).

European Court of Auditors (2020). *Energy efficiency in buildings: greater focus on cost-effectiveness still needed*, https://www.eca.europa.eu/Lists/ECADocuments/SR20_11/SR_Energy_efficiency_in_buildings_EN.pdf (access: 22.04.2021).

Ewa Mataczyńska
The Ignacy Łukasiewicz Institute for Energy Policy

Chapter V

Energy Sector Transition as a Way to Accelerate Decarbonisation

Abstract

The current energy system is designed on the basis of parallel and vertical energy value chains, rigidly assigning specific energy resources to specific end-use sectors. Coal and natural gas are, for example, mainly used for the production of electricity and heat, electricity and gas networks are designed and operated separately, while transport is based on petroleum products. It is necessary to create an energy sector that is as well integrated as possible to focus as much as possible on mutual benefits and the services provided by developing a strategy that will allow for a greater flexibility for all possible links and interactions within the new structure. Such a scheme would meet the objectives of the transition and, on the one hand, accelerate decarbonisation by enabling a more cost-effective way of implementing it, and on the other hand, provide a solution that will improve the overall efficiency and resilience of the system, allowing for greater integration of renewable energy sources. This leads to a vision of a system in which electricity becomes the leading energy carrier, with electricity grids as the basis for achieving decarbonisation of the energy sector.

Keywords: integration of the energy sector, coupling sector, electrification, hydrogen, energy market

1. Background of the issue and major targets of implementation

For many years, the European Commission has been adapting the European Union energy and climate policy in the fields of climate, energy, land use, transport and taxation in such a way as to create conditions for sustainable socio-economic development, mutually respectful, improving the environment, with a rational use of resources and innovativeness. A development that will primarily lead to a reduction in net greenhouse gas emissions of at least 55% by 2030 (compared to 1990 levels) [European Commision, 2021].

Such a reduction in emissions over the next decade is aimed at accelerating the pace of transition towards a zero-emission economy, developing without the use of fossil fuels. It is also a key determinant for Europe to become the world’s first climate-neutral continent by 2050, based on the provisions of the *European Green Deal* published in December 2019 [European Commission, 2019]. In the context of these provisions, sector coupling was considered one of the key concepts accelerating the transition.

From a theoretical point of view, this term means combining processes occurring in traditionally separate sectors in order to achieve synergy and mutual benefits. The main objective of the interaction is to optimise the relevant asset base using the substitution effect (e.g. an optimal investment mix in one of the two related sectors or the minimum cost of operating modular systems). Such a direction assumes an increase in the use of electricity (i.e. electrification), coming from the cheapest form of its generation, i.e. wind and solar power plants, so as to replace energy from fossil carriers.

This integration scheme of the energy sector became feasible thanks to the decreasing costs of technologies related to the production of green energy, a rapid development of energy storage technologies, also in the form of the use of hydrogen-related technologies. [1] In addition, market developments in the promotion of electric vehicles and increasing digitalisation are factors that naturally contribute to the self-integration of the sector. It may be expected that the integration of the energy sector understood in this way will also be of great importance for other economic processes and phenomena. The use of innovative processes and tools that will accompany this integration will also be a driver of new investment, job creation and economic growth.

2. Sector coupling as a response to changes on the energy market

Energy system integration refers to the planning and operation of the energy system as a whole, taking into account different energy carriers, infrastructures and sectors of energy consumption, by creating stronger links between them in order to provide society with low-carbon, reliable and resource-efficient energy services at the lowest possible cost [European Commission, 2020a, p. 3].

Such a perception of the integration of the energy system implies a holistic approach to the elements and processes specific to the sector as a whole, but not only to this sector. The vision of integration proposed by ETIP SNET goes beyond the energy sector, involving other sectors, including cross-sectoral processes, such as transport [ETIP SNET, July 2021, p. 53]. This approach finds its source in the definition of a holistic perception of processes based on

---

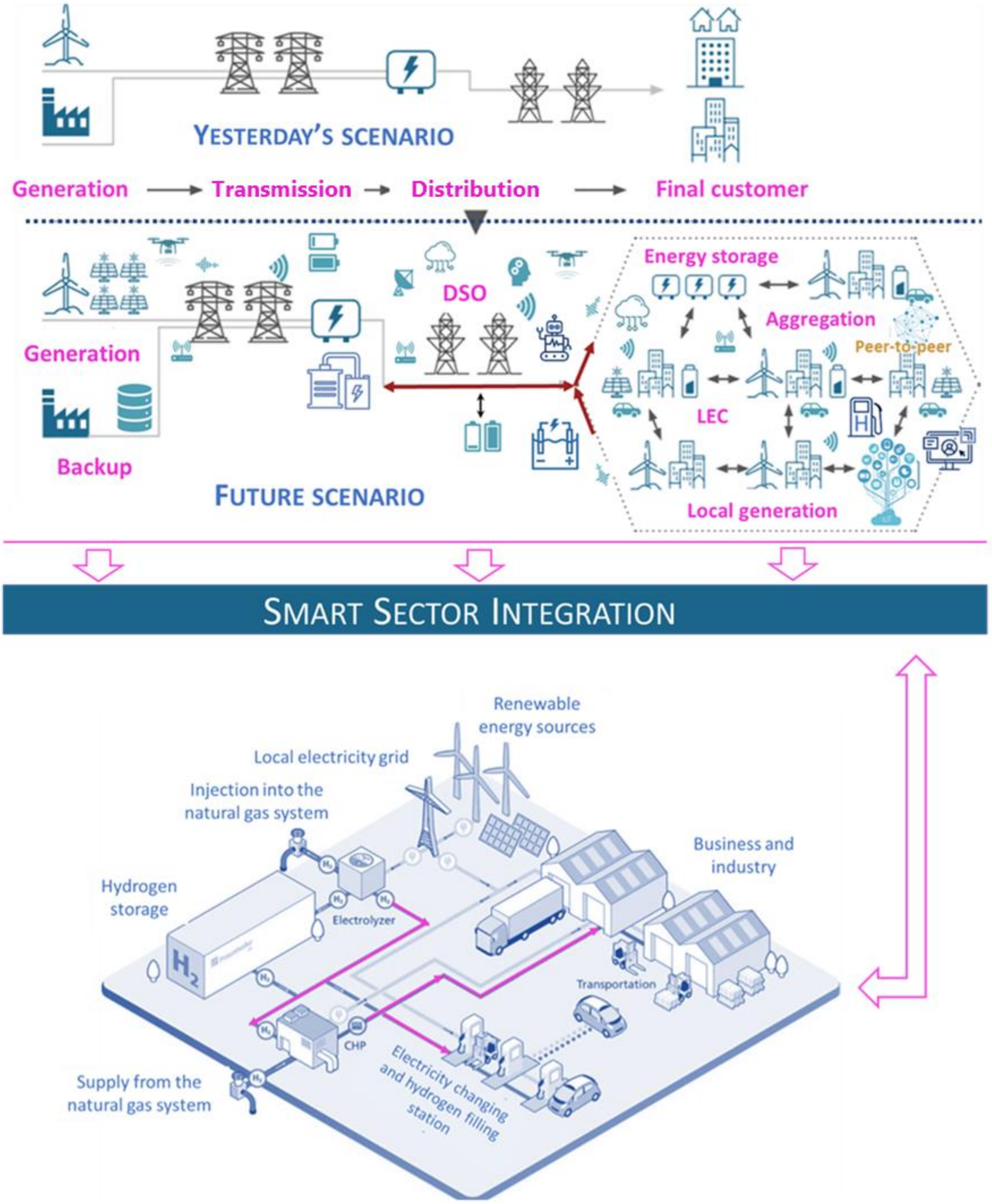
[1] A more detailed discussion of the possibilities and necessary measures to increase the use of hydrogen in the context of an integrated energy system is available in the Europe Hydrogen Strategy [European Commission, 2020b].

the belief that all occurring phenomena make up holistic systems are subject to certain dependencies, which should not be judged on the basis of the regularities governing the individual components which make them up. The final approach should be integrated, seeking to conclude that the whole is not equal to the sum of its components.

The need to integrate the energy sector is not only a promotion of the idea of decarbonisation, but also an independent and progressive process, resulting from the changes taking place in the environment in which the energy sector operates, but also from the need to constantly and keep up with these changes. The main drivers of these changes undoubtedly include a very rapid development of various types of new technologies related not only to the production or storage of energy, but also to the progressive digitisation.

Digitisation, with its effective use, will be a boon to the activities of companies struggling with numerous problems resulting from operation in an environment saturated with data carrying huge amounts of various information. These data come from a variety of sources, from devices owned by companies, but predominantly from the environment in which the company operates. Often potentially irrelevant (unrelated to the company’s business) information can significantly affect the final effects of the implementation of individual business processes, projects or the achievement of assumed goals through various types of connections (difficult to determine by a human).

Figure 1. Future energy market model scenario combined with hydrogen elements in the smart sector integration



Source: Author's own study based on IRENA, 2019; Mataczyńska, Sikora, Lewandowski, 2019.

This means that despite being aware of the existence of this information, the company is not able to use it effectively and efficiently. In such a situation, the methods of accessing properly processing information and its protection in a constantly changing environment are gaining in importance [Mataczyńka, Mataczyński, 2020, p. 2].

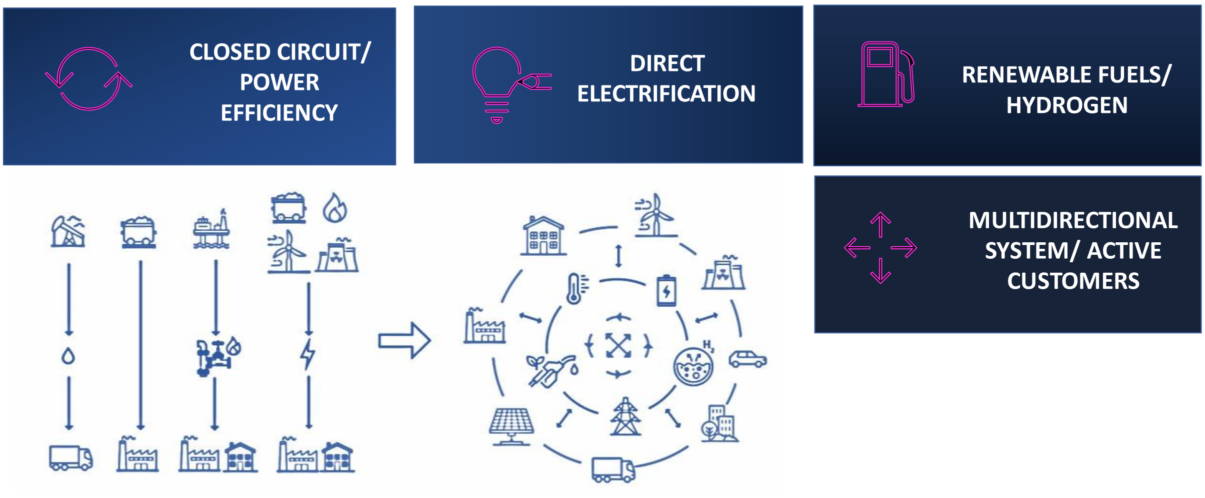
Thus, digitisation is a powerful tool in the hands of an integrated sector, while bringing previously unknown threats and challenges (for example in the area of cybersecurity). It is also a prerequisite for the effective implementation of integration. Thanks to digitisation, but also thanks to the universality of knowledge, there is a growing awareness of society, whose increasing activity in various fields is not without significance for the integration processes of the energy sector.

3. Major assumptions of the energy system integration and their significance

The energy system integration is based on three complementary and supportive concepts [European Commission, 2020a, 299]:

- a more circular energy system, whose energy efficiency is a key element;
- a more broadly designed direct electrification of various end-use sectors;
- the use of renewable and low-carbon fuels, including hydrogen, for end-uses where direct heating or electrification is not possible;
- a more integrated system will also be a “multidirectional” system in which consumers play an active role, supporting the market on the one hand, and setting, verifying and moderating the directions of change on the other.

Figure 2. Major assumptions of the energy system integration



Source: Author’s own study based on: European Commission, 2020a, 299.

3.1. Close circuit/energy efficiency

Climate concerns have become a stimulus to change traditional economic and business models based on the linear principle of “take, produce, throw away”. Models that promote circularity, which separates economic activity from the consumption of materials and energy, are gaining importance. It is a closed circuit, in which waste is minimised or eliminated completely, and the remaining resources are reused. The new approach to the circular economy through the use of its elements can also be used in companies whose business profile is related to crude oil or extraction, i.e. based on a traditional linear model. The design and maintenance of such a model at a highly effective level, while maintaining the required final quality of manufactured goods or services provided is not easy. Each type of activity should have a separate scheme specific to a particular type of activity that fits into the circular economy model. Circular economy is considered a tool to gain a competitive advantage for diversification, market expansion and cost reduction, by finding the best ways to maximise the benefits for the involved industrial value chains, the environment and society as a whole [Pichlak, 2018, pp. 74–85]. Defining and monitoring the operational aspect of circular economy is essential to find the best ways to maximise the benefits for the involved industrial value chains, the environment and society as a whole [Schulte, 2013]. This idea is based on:

- use of energy from renewable sources;
- use of recyclable materials or materials that are easily biodegradable without adversely affecting the environment;
- use of materials which, during end-of-life, can gain the so-called new life through recycling or regeneration and be reused;
- extended lifetime compared to their normal cycle;
- increased intensity of use by sharing individual elements used in one process with other processes;
- increased possibility of using waste heat from various industrial processes and data processing centres;
- supporting capacity building in circular energy communities, in particular in rural areas.

Many European countries still lack a national strategic roadmap that would transform the circular economy into a driver of transformation at the national level, recognising the circular economy as a game changer and not just an environmental issue. A uniform understanding of the concept of energy efficiency throughout energy chains, including the generation adequacy assessments, is also a challenge.[2] The involvement of consumers in the production of electricity from renewable sources often does not mean a reduction in the future demand for electricity in the system. The system of electricity production from the RES sources, which fits the definition of energy efficiency, while using new installations to heat buildings based on heat pumps, will lead to an increase in electricity consumption compared to the period when heat pumps were not installed in the building. Therefore, it is worth remembering that the transition to heating from heat pumps, on the one hand, supports decarbonisation and effective use of produced electricity as well as heat itself, on the other hand, it is an element of electrification, which requires taking care of the increased needs of future demand for electricity. In this context, it is important to compare the achievable savings with regard to each energy carrier. This can be done by the primary energy factor, which should reflect the real savings that electricity may bring in combination with thermal energy.[3]

3.2. Direct electrification

Direct electrification means the change of energy carriers used in various areas of the economy (industry, transport, also the final needs of consumers) to electricity, directly produced from renewable energy sources or low-carbon sources.

The European Union target assumes that electricity in 2050 will account for 50% of all energy consumption in industrial processes and 63% in transport and buildings. Power-to-X technologies[4], heat pumps and electric vehicles will be required to achieve this goal. The greatest potential for electrification is undoubtedly in transport, where electric vehicles will reach 130 million in 2050 (compared to 0.5 million in 2015). On the one hand, electric cars will contribute to the decarbonisation of the transport sector, on the other hand, thanks to the opportunities that arise with the integration of the sector, the batteries of these cars will allow the storage of excess electricity. Ultimately, thanks to intelligent charging systems, this energy will make electric vehicles respond to price and network signals, actively participating in the processes of managing the power system [Eurelectric & EY, Brussels, pp. 15–16].

Another element indicated as a great potential for electrification is the residential area (buildings), especially heating and cooling, which account for 50% of the final energy demand

---

[2] Energy efficiency, its directions and objectives, as well as the scope have been defined, e.g. in the EU Directive 2018/2002 of 11 December 2018 on energy efficiency, which is one of the elements of the package of EU regulations called Clean Energy for All Europeans.

[3] This factor indicates the amount of primary energy used to produce a unit of final energy (electricity or heat).

[4] The technology consists in converting electricity into another energy carrier, in this case gas. In particular, this technology can be understood in the context of the production of hydrogen from electricity using electrolysers.

in the European Union (most of this heat is generated by burning fossil fuels). In this area, particular importance is attached to emission-free, digital and cost-effective technologies such as heat pumps (electric and hybrid), which are three to five times more energy efficient than traditional fossil fuel boilers and are cheaper to operate and maintain. Also in industry, where heat accounts for more than 60% of energy consumption, large-scale heat pumps can be used, contributing to the decarbonisation associated with heat demand [Staniszek, 2021].

3.3. Renewable fuels/hydrogen

Renewable and low-carbon fuels include sustainable biogas and biomethane, low-carbon renewable hydrogen or synthetic fuels. They can be a substitute in those processes in which, for various reasons (even technological reasons), the transition to direct electrification is difficult to carry out or completely impossible.[5]

The greatest hopes are related to hydrogen, which will undoubtedly become an integral part of a climate-neutral energy mix. In particular, it will be necessary when direct electrification reaches its limits:

- in the area of long-term storage of electricity necessary to overcome periods with too low solar radiation and too weak wind force;
- as a fuel for cars, aviation, maritime transport, heavy road transport or public passenger transport, including rail;
- in some industrial processes. Currently, hydrogen used in Poland in industrial processes (production of steel, ammonia, refineries) is not green hydrogen, i.e. produced from energy from RES. Hydrogen production is carried out with fossil raw materials, hence it is not pure hydrogen.

In the context of energy sector integration, hydrogen is an example of a technology whose effective functioning is based just on the integration of the energy sector (produced from RES generated electricity, transmitted with a certain level of doping through existing gas networks). Hydrogen can be transported to destinations (road transport, ships, trains), stored e.g. as a result of surplus power in the power system (source of flexibility), processed to other forms (ammonia), which are an essential component of production in various industries. It can also be reprocessed into electricity and fed into the power grid in situations where there is not

---

[5] In accordance with Directive (EU) 2018/2001, it is recommended to use advanced biofuels and biogas (derived from certain residues and products derived from agricultural and forestry activities, industrial waste, municipal waste and other lignocellulosic materials) meeting sustainability requirements.

enough power in the system to cover demand or as a power that supports a safe system operation.

The above processes, depending on the form, type and number of conversions of the basic carrier of electricity to its final consumption, are fraught with large losses. Hydrogen technologies, especially in the area of the use of green hydrogen, are not yet advanced enough to achieve a competitive advantage in the market. However, they are a promising element of the future decarbonisation of the economy, especially as a renewable fuel [IEA, 2019].

It is important to determine it clearly that hydrogen can only be a solution if direct heating or electrification is not technically possible (or is only possible at a higher cost). In addition, with a view to accelerating decarbonisation, hydrogen production should take place with electricity produced from RES sources, which is a surplus in the power system.

3.4. Multidirectional system/active customer

System integration requires a completely new configuration of energy markets to promote the energy produced by prosumers and strengthen the position of consumers. The definition of active customer[6] is introduced by Directive on the Internal Market in Electricity [Directive (EU) 2019/944]. And the Renewable Energy Directive promotes the activity of consumers operating in various forms [Directive (EU) 2018/2001] (renewable energy community,[7] renewable energy group prosumers).[8]

The integrated energy system is to be a multidirectional system, but first of all decentralised. In this system, distributed generation will play a major role [9]and consumers will play an active role in the security and security of energy supply, contributing to the overall balance and flexibility of the system. The system integration will be much faster if market participants connected to the electricity grid can fully and non-discriminatorily exercise their rights, helping to manage the increasing complexity of processes operating in the energy

---

[6] Directive (EU) 2019/944: Point (8) of Article 2 active customer means a final customer or a group of jointly acting final customers who consume or store electricity produced on their territory with defined boundaries or, if authorised by a Member State, on another site, or sell self-generated electricity or participate in flexibility or energy efficiency schemes, provided that this activity does not constitute their own basic business or professional activity.

[7] Directive (EU) 2018/2001: Article 2(16), a legal entity whose primary purpose is rather to bring environmental, economic or social benefits to its shareholders, members or local areas, Article 22(2). They should have the right to: (a) produce, consume, store and sell renewable energy, including through renewable electricity purchase agreements; (b) the allocation, within a given renewable energy community, of renewable energy produced by production units owned by that energy community, (c) access to all relevant energy markets, either directly or through concentration (aggregation).

[8] Directive (EU) 2018/2001: Article 2(15) means a group of at least two renewable self-consumers acting jointly located in the same building or in a multi-apartment building.

[9] Directive (EU) 2019/944: Article 2(32) means generating installations connected to a distribution system.

market. It is worth remembering that such an integration should apply only to those parts of the energy system where it is beneficial for consumers in a cost-effective, easily achievable and sustainable way, achieving the assumed decarbonisation goals at the same time.

4. Opportunities, challenges and barriers

The energy sector integration, if successfully and intelligently conducted, will become an element creating a cost- and fuel-efficient energy system that exploits achievable synergies and complementarity. Moreover, the integration creates new opportunities for energy storage in various forms. The use of this energy can take place at any time after its storage, allowing, e.g. for a greater penetration of variable renewable energy sources in the energy system. In addition, the conversion of energy to other carriers, e.g. ammonia or hydrogen, creates additional opportunities for their transport (for example, an existing or new gas infrastructure to transport hydrogen).

Such a perception of the energy sector brings challenges in the area of effective management of processes functioning in it as a whole. Effective management, on the other hand, depends on having enough data appropriate to identify threats and make decisions aimed at optimising processes and mitigating risks. In order to be able to collect the required data, devices are necessary to acquire these data and send them through dedicated (protected against unauthorised access) transmission channels. The last issue is algorithms and applications tailored to the requirements of individual processes in the integrated sector.

These are elements of digitisation, without which it is not possible to carry out the assumed integration in an intelligent and effective way. It should be remembered that as digitisation increases, there will also be cybersecurity challenges for which the sector must be prepared.[10]

A significant reduction in costs associated with renewable energy generation technologies and the prospects for maintaining this trend give hope for rapid development of investments. Nevertheless, in order to fully implement investments, in order to achieve climate goals, it is necessary to remove barriers that prevent the global use of renewable energy in all economic sectors. These include immature supply chains along with the need to expand or even build intelligent energy infrastructure that effectively connects different sectors. Accelerating the removal of these barriers should begin with the removal of administrative and regulatory

---

[10] ACER has prepared a framework guidance document on sector-specific rules on cybersecurity aspects for cross-border flows of electricity, in accordance with Article 59(2)(e) of Regulation (EU) 2019/943 and on the basis of a proposal from the European Commission [ACER, 2021].

barriers, but also with public acceptance. Equally important, and perhaps the most important, is the removal of financial barriers, especially at the initial stage of shaping individual elements of the sector integration (e.g. support for the development of hydrogen). It is necessary to eliminate the unequal operation conditions within different elements of the sector. Each element (energy, gas, storage, transport, heating, buildings) operates on the basis of specific tariffs for end-users (for regulated activities), taxes and charges, as well as with significant regional and national variations. Moreover, the expenses incurred by the customer do not only reflect his costs, as they also include system costs, often resulting from the past, distorting the principles of the functioning of the market.

An important element in the future integrated energy system is interoperability, which should not be understood only as data formats used in the integration process. Interoperability between European markets may be jeopardised by the lack of modernisation of electricity or gas networks or the decommissioning of (sunk) assets that may be useful at the member state level but harm cross-border interoperability and also affect future tariff components. In addition, the introduction of new energy carriers, such as hydrogen, has the potential to increase regional fragmentation of products and markets, which challenges pan-European interoperability and cost optimisation.

Conclusions

In order to move towards a smooth implementation of smart sectoral integration, future activities should be based on the following recommendations:

- it is worth developing large-scale regulatory sandboxes with flexible timeframes for their operation and with transparent conditions for assessing the results achieved along with a precise implementation schedule in the event of a positive final assessment. Such sandboxes may include projects within the framework of the integration of the renewable electricity market with the production of renewable hydrogen;
- avoid tariff restrictions, incentives and taxes that favour individual energy carriers. The fulfilment of such demands should concern those elements of the integrated market whose functioning has reached a level of development going beyond the conditions classifying them for participation in regulatory sandboxes;
- it is necessary to analyse the taxation of individual energy carriers in order to eliminate unnecessary or double elements of taxation, creating a fair system of equal opportunities;

- activities should be taken to accelerate the learning process based on the conclusions drawn from the implemented pilot projects. It is worth creating platforms for generally available information in this area. A prerequisite for any pilot project should be the need to periodically present the results of individual stages of the project (defined before launching the project). Such mechanisms are already taking place at the European level, for example as part of projects co-financed from H2020 funds. In Poland, unfortunately, a belief to come across is that the knowledge gained in similar projects remains the property of sponsors;[11]
- consumer activity is one of the key factors for accelerating the integration of the energy sector and achieving its objectives. Measures should be taken to increase consumers' awareness of the fact that their individual needs and behaviours are creating the future energy market. At the same time, they can bring measurable benefits seen both from the individual level (additional opportunities to reduce energy bills, receiving remuneration from services provided at the request of the power grid operator) and general (support in managing the energy system, accelerating decarbonisation).;
- encouraging stakeholders to cooperate in the development of common solutions, collaborative platforms on the use of flexibility in the system and available storage capacity. This cooperation should focus on developing efficient, secure and partnership policies between electricity transmission and distribution operators and aggregators.

References

ACER (2021). *Framework Guideline on sector-specific rules for cybersecurity aspects of crossborder electricity flows*. Ljubljana: European Union Agency for the Cooperation of Energy Regulators.

Directive (EU) 2018/2001 of 11 December 2018 on the promotion of electricity from RES sources (OJ EU 2018, L 328/82).

Directive (EU) 2018/2002 of 11 December 2018 on energy efficiency (OJ EU 2018, L 328/210).

Directive (EU) 2019/944 of 5 June 2019 on common rules for the internal market in electricity (OJ EU 2019, L 158/123).

ETIP SNET (2021). Smart Sector Integration, towards an EU System of Systems. Building blocks, enablers, architectures, regulatory barriers, economic assessment, *Position Paper*, July, p. 53.

Eurelectric & EY (2021). *Accelerating fleet electrification in Europe: When does reinventing the wheel make perfect sense?* Brussels.

European Commission (2019). Communication from the Commission to the European Parliament, the Council of Europe, the Council, the Economic and Social Committee and the Committee of the Regions. European Green Deal, Brussels, 11.12.2019.COM (2019) 640 final.

---

[11] For a project example, see https://euniversal.eu/ (access: 20.08.2021).

European Commission (2020a). Communication from the Commission to the European Parliament, the Council of Europe, the Council, the Economic and Social Committee and the Committee of the Regions. *Hydrogen strategy for a climate-neutral Europe*. Brussels, 8.7.2020 COM (2020) 301 final.

European Commission (2020b). Communication from the Commission to the European Parliament, the Council of Europe, the Council, the Economic and Social Committee and the Committee of the Regions. *Powering a Climate-Neutral Economy: An EU Strategy for Energy System Integration* of 8 July 2020, Brussels, 8 July 2020. COM (2020) 299 final.

European Commission (2021). *Climate package "Fit for 55"*, https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1940 (access: 18.07.2021).

IEA (2019). *The Future of Hydrogen. Seizing today's opportunities*. Japan.

IRENA (2019). *Innovation landscape for a renewable-powered future*.

Mataczyńska, E., Sikora, M., Lewandowski, W. (2019). *Wykorzystanie usług elastyczności przez Operatora Systemu Dystrybucyjnego (Use of flexibility services by the Distribution System Operator)*, XXV Scientific and Technical Conference. The Electricity Market, Kazimierz Dolny, 7–9 October 2019, https://newagemetals.com/pgm-based-fuel-cells-applications-for-industry/ (access: 15.07.2021).

Pichlak, M. (2018). Gospodarka o obiegu zamkniętym – model koncepcyjny (Circular economy – a conceptual model), *Ekonomista*, 3, pp. 74–85.

Schulte, U.G. (2013). New Business Models for a Radical Change in Resource Efficiency, *Environmental Innovation and Societal Transitions*, 9.

Staniaszek, D. (2021). The Road to climate neutrality, Are National long-term Renovation Strategies Fit for 2050? *Buildings Performance Institute Europe (BPIE)*, March.

Katarzyna Stala-Szlugaj

Mineral and Energy Economy Research Institute, Polish Academy of Sciences

Chapter VI

Is Carbon-Neutral Poland Feasible in the Perspective of 2050?[1]

Abstract

The chapter presents the role of coal in the domestic consumption of primary energy carriers in the years 2010–2020, focusing on the place of this fuel in the production of electricity. It discusses the main users of coal, i.e. energy, small customers sector and coking plants as well as coal supply (domestic production, imports). In order to answer the question regarding the future of coal in Poland (horizon 2050), the author considers essential EU and national legal determinants. She also compares coal consumption forecasts according to the two most important documents: the National Energy and Climate Plan in the years 2021–2030 and the Energy Policy of Poland to 2040.

Keywords: coal, production, import, consumption, decarbonisation, Poland

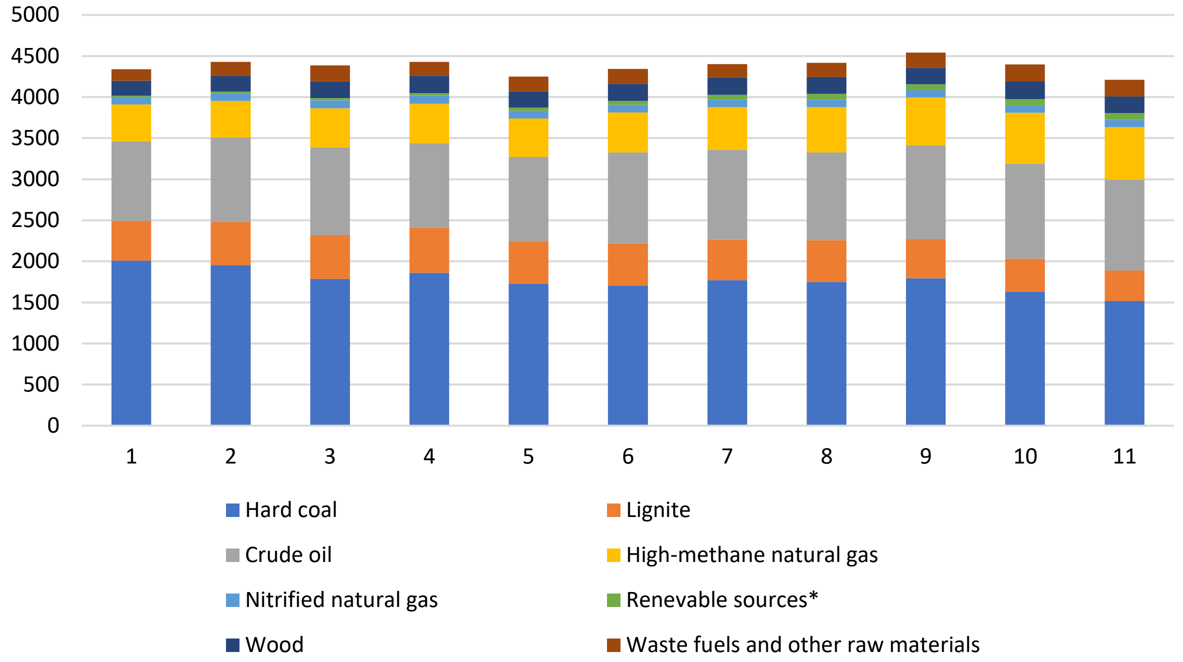
Introduction

Coal, along with crude oil and natural gas, is one of the main primary energy carriers used in Poland (see Figure 1). Although in the years 2010–2020 as much as 45–57% of the global consumption of these carriers was coal (hard coal and lignite), a downward trend is visible. In between the analysed years, the total coal use decreased by 24% (to 1,888 PJ), recording a decrease of 605 PJ. This downward trend was also due to the growing imports of electricity since 2014 [ARE, 2021, p. 11], which limited the use of domestic energy carriers.

---

[1] The text was written within the statutory research of the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences.

Figuret 1. Balance of global consumption of primary energy carriers in Poland (2010–2020, in PJ)

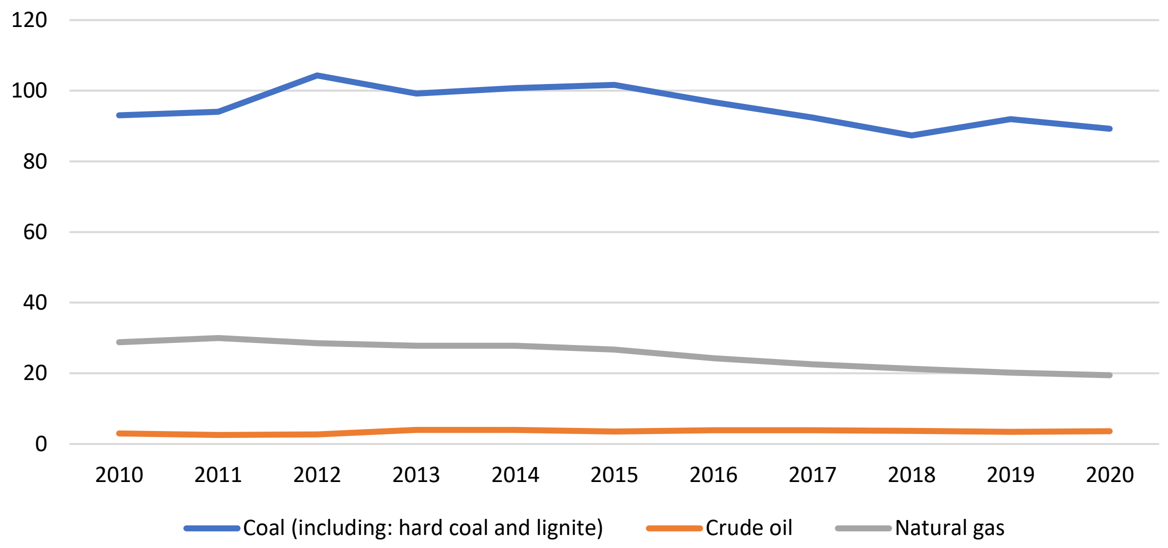


* Water, wind, solar, geothermal energy and ambient heat.

Source: Author's own material based on data in ARE, 2021, p. 9.

Of all the primary energy carriers consumed in Poland, only coal production (hard and lignite) met a significant part of the internal demand (see Figure 2). In the analysed 11 years, the share of domestic coal production in internal consumption was 87–104%. Interestingly, the level of stocks of the raw material have changed. In the years 2012–2015, there were high stocks of hard coal accumulated on the mine dumps. At that time, they reached 6–8 million tonnes, which translated into a high share of domestic production in global consumption. In addition, another 13–17 million tonnes were accumulated in power plants and thermal power plants. This high level of stocks was caused by many factors. One of them was relatively warm winter seasons [Stala-Szlugaj, 2022, p. 66], which may have translated into a reduced demand on the domestic market. In addition, low coal prices on international markets [Ozga-Blaschke, 2021, p. 129; Stala-Szlugaj, Grudziński, 2021, p. 185] were not in favour of exports of this raw material. On the international coal markets, the years 2012–2015 were characterised by a slowdown in the global economy and a tightening decarbonisation policy (which translated into a reduction in the demand for coal) as well as changes in the exchange rates of the US dollar against national currencies.

Figure 2. Share of domestic coal, oil and gas production in global primary energy consumption (2010–2020, in %)



Source: Author's own material on the basis of data in ARE, 2021, p. 9.

1. Balance of coal in Poland

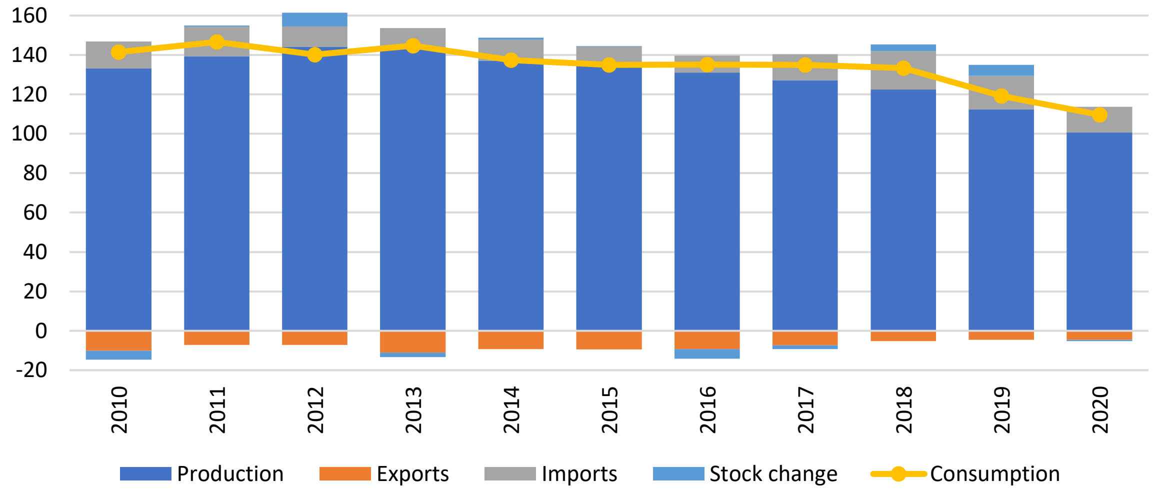
Poland has its own deposits of hard coal and lignite, which are the main source of this fuel on the internal market. Between 2010 and 2020, domestic coal production (hard coal and lignite, at the level of 101–144 million tonnes per year) met more than 90% of the national needs for this raw material (see Figure 3). Coal imports (9–20 million tonnes per year) completed the domestic production and their share in hard coal consumption has consistently exceeded 20% since 2018 (when a record amount of almost 20 million tonnes was imported) (see Figure 4). In these years, the main supplier of hard coal was Russia (with a total share of 57–74%), Australia (2–13%), Colombia (1–8%) and the USA (2–13%).

The impact of such factors as decarbonisation policy, improvement of energy efficiency transferring to lower energy intensity, warm winter seasons, caused that coal consumption was on the decline. Between 2010 and 2020, it decreased by 22%, and in volume by 32 million tonnes. The main buyer – both hard coal and lignite – was the commercial electrical industry (see Figure 4). Its share in the domestic consumption in the case of hard coal was 50–55% (i.e. 32–44 million tonnes per year). Other important groups of hard coal recipients were (combined): industry, construction and coke industry (23–25%, i.e. 16–19 million tonnes per year) and the small customers sector (15–17%, i.e. 10–13 million tonnes per year). In the latter sector, households were the main group of users. In the case of lignite, the power industry consumed about 98–99% (i.e. 46–65 million tonnes/year), and small amounts were directed to other user groups, for example, agriculture or households.

In the years 2010–2020, according to data [ARE, 2011–2021, p. 45], annual electricity production fluctuated in the range of 157.7–170.5 TWh. In the analysed 11 years, there was a decrease in the share of generation in coal-fired power plants in Poland. In the years 2010–2014, the share of coal-fired power plants (hard coal and lignite) in power generation exceeded 80%; in the years 2015–2019, it decreased to more than 70%; and in 2020, it fell below 70%. The change in the structure of generation was caused by an increase in the share of energy from renewable sources. In 2020, the share of RES generation amounted to 18%, and compared to 2010 it increased by 11 percentage points (i.e. an increase of 16.8 TWh to 28.2 TWh).

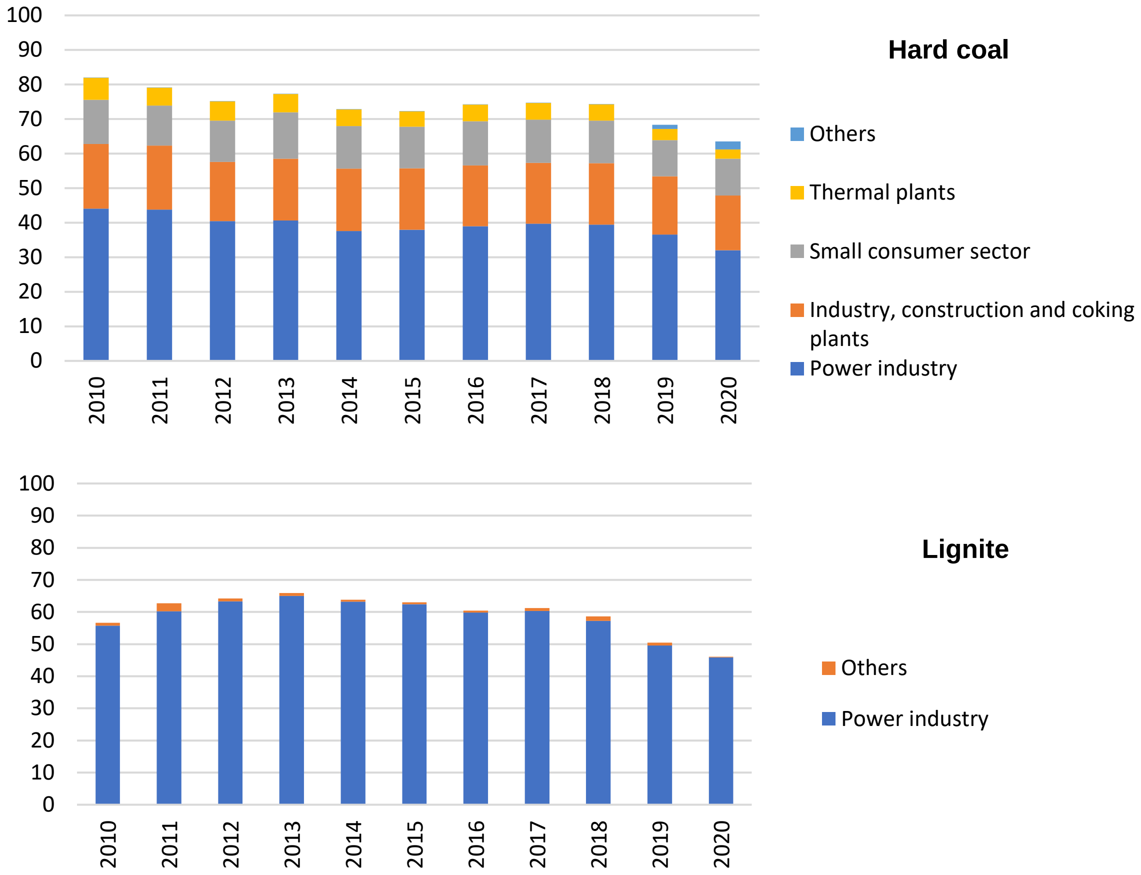
The small consumer sector is an important user of coal in Poland (see Figure 4), using primarily hard coal. This sector consists of households, agriculture and some other customers. The share of this sector in total coal consumption in the years 2010–2020 was 15–17% (i.e. 10–13 million tonnes per year). It is also worth mentioning a statistical group: industry, construction and coking plants, which together consumed 23–25% (i.e. 16–19 million tons per year) of domestic coal consumption. At the same time, coking plants used hard coal for coking (used in the metallurgical, steel and coke industries), annually at the level of 11–13 million tonnes.

Figure 3. Coal balance in Poland in the years 2010–2020 (in millions of tonnes)



Source: Author’s own material based on data in ARE, 2021, p. 9.

Figure 4. Main coal users in Poland in the years 2010–2020 (in millions of tonnes)



Source: Author's own material based on data in ARE in 2021, p. 9; GUS, 2011–2021, p. 11.

2. Major directions of climate and energy policy

An important element affecting the consumption of energy carriers, including coal, in Poland is international regulations, especially at the level of the European Union, but also national regulations. Important EU regulations introducing mechanisms to achieve a low-carbon economy since 2010 include:

- the European Union climate and energy package till 2020, also known as the "3x20 package", assumes that by 2020 the Union will reduce greenhouse gas emissions by 20% compared to 1990, increase the share of RES in the final energy consumption by 20%, and increase energy efficiency by 20% compared to forecasts for 2020. This package also includes the following Directives: EU ETS, non-ETS, RES [EC, 2022, p. 1; PEP, 2021a, p. 3];

- the European Union 2030 climate and energy package assumes that by 2030, the European Union will have reduced greenhouse gas emissions, compared to 1990, by at least 40%, increased the share of RES in final energy consumption by 27%, to increase energy efficiency by 27% compared to forecasts [EC, 2022, p. 1; PEP, 2021a, p. 3];
- Clean Energy for All Europeans Regulation Package introduces a new EU governance system in the field of energy and climate (five dimensions of the Energy Union, transition from centralised to prosumer energy) [Clean Energy, 2019, p. 13; PEP, 2021a, p. 3];
- the European Green Deal strategy – by 2030 assumes an increase in greenhouse gas emission reductions in the European, Union compared to 1990, to 55% and achieving climate neutrality by 2050 [PEP, 2021a, p. 4; EP Resolution, 2021, p. 5];
- the Fit for 55 package proposes that the sectors covered by the EU Emissions Trading System (EU ETS) should reduce their emissions by 61% by 2030, compared to 2005 [Fit 55, 2022, p. 1].

At the national level, Poland has also introduced many legal regulations and financial support mechanisms that implement the emission reduction goals set by the European Union. They include:

- amendment to the Environmental Protection Law, also known as the Anti-Smog Act, which gives the opportunity to local governments to limit or prohibit the operation of installations in which fuels are burned as well as to identify the types and quality of fuels allowed for combustion [Anti-Smog Act, 2015, p. 1];
- National Energy and Climate Plan 2021–2030 – this document sets the following climate and energy targets by 2030: reduction to 56–60% of the share of coal in electricity production [KPEiK, 2019, p. 40]; a 7% reduction in greenhouse gas emissions in non-ETS sectors compared to 2005 levels; obtaining a 21–23% share of RES in gross final energy consumption [KPEiK, 2019, pp. 20, 40];
- energy policy of Poland by 2040 – this document sets the following targets: by 2030, achieving a 30% reduction in greenhouse gas emissions compared to 1990 levels, natural gas will be a transitional fuel in the energy transition; in 2030, obtaining at least a 23% share of RES in gross final energy consumption; move away from burning coal in urban households by 2030 and rural areas by 2040 [PEP, 2021a, p. 7].

Of the programmes offering financial support (in the form of grants or low-interest loans), some are addressed to individual customer (including: households, farmers). These customers financially support the replacement of non-class coal-fired boilers with low-emission sources. They can obtain financial support from various types of programmes, e.g. Energy Plus, My Electricity, Clean Air, Agri energy. Of course, the list of these documents or financial programmes does not fully exhaust this issue. There are also many other national policies or programmes that also implement the transition towards a low-carbon economy in other sectors. For example, the Polish New Industrial Policy Project [PPP, 2021, p. 8] takes into account the green transition towards reducing its own energy intensity in industry.

3. Forecast of coal consumption in Poland

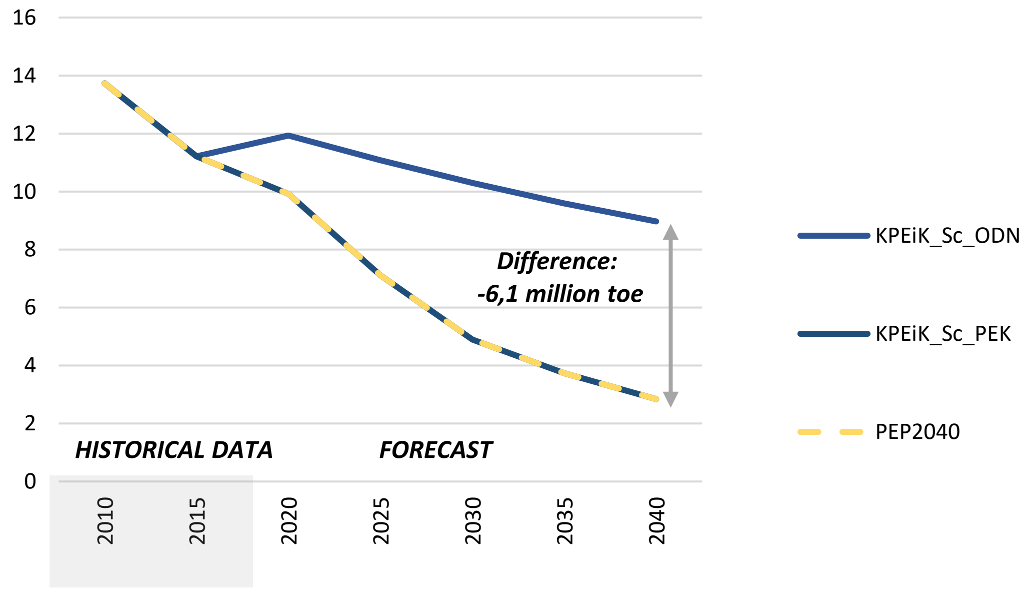
In order to assess the future of coal in Poland in the perspective of 2050, the forecasts of coal consumption are compared according to the two most important documents in Poland, namely: the National Energy and Climate Plan for 2021–2030 (KPEiK) and the Polish Energy Policy till 2040 (PEP 2040).

Analysing the forecast of coal consumption in final energy consumption in Poland, it can be seen that in the perspective of 2040 – both according to two scenarios of the KPEiK, as well as PEP 2040 – there is a significant reduction in it (see Figure 5). Compared to the base year 2015, according to the baseline scenario (KPEiK_Sc_ODN), consumption decreases by 25%, falling to the level of 9.0 million toe (tonnes of oil equivalent), and according to the energy and climate policy scenario (KPEiK_Sc_PEK) – it declined by 75% to 2.8 million toe. Due to the fact that the PEP 2040 document appeared later than NECP and had to comply with the assumptions adopted in it, the forecast of coal consumption according to PEP 2040 is consistent with the energy and climate policy scenario: KPEiK_Sc_PEK. In the case of forecasts according to PEP 2040, in the perspective of 2040, there is a 75% decrease in coal consumption to the level of 2.8 million toe. The difference between the KPEiK_Sc_ODN baseline scenario and PEP 2040 and the energy and climate policy scenario: KPEiK_Sc_PEK is 6.1 million toe.

Looking at the forecasts of the KPEiK and PEP 2040 reaching 2040 and beyond the next decade, i.e. until 2050, it can be assumed that the trend of decreasing the share of coal is most likely to continue. The demand for coal from domestic customers – both according to the assumptions of the KPEiK and PEP 2040 – is to be met primarily by domestic producers, and imports are to be complementary. In the case of the largest user of coal, i.e. the commercial power industry, it will be in a downward trend. According to PEP 2040 [PEP, 2021b, p. 22], in

2030, a total of 7.8 GW (net) of capacity of units generating on hard coal and lignite is to be discontinued, and in the next ten years a total of 12.1 GW (net) is to be reduced by a further 12.1 GW (net). The total share of coal-fired power plants and thermal and power plants (both existing and new) in the structure of installed capacity (net) according to [PEP, 2021b, p. 41] will systematically decrease, to reach only 16% (i.e. 9.6 GW net) in 2040. According to Mazanek, Świat [2022, p. 61], such a large withdrawal of coal units, with a simultaneous risk of delays related to the construction of new units using other fuels (e.g. gas, nuclear, wind offshore farms) may result in lack of availability of power in the National Power System. In addition, [Tokarski, 2021, p. 28] showed that in 2030, we will be short of as much as 108 TWh to balance electricity generation. Tokarski [2021, p. 26] also considered whether high prices of CO_2 emission allowances will allow Poland to run coal-fired power plants with carbon capture and storage technology.

Figure 5. Comparison of forecasts of coal consumption in final energy consumption in Poland (2010–2040, in millions of toe)



Notes: KPEiK_Sc_ODN – National Energy and Climate Plan 2021–2030 – Baseline Scenario; KPEiK_Sc_PEK National Energy and Climate Plan 2021–2030 – Energy and Climate Policy Scenario; PEP 2040 – Polish Energy Policy till 2040.

Source: Author’s own study based on data in KPEiK ODN, 2019, p. 45; KPEiK PEK, 2019, p. 54; PEP, 2021a, p. 10.

Conclusions

Work is still underway on the development of new power generation and storage technologies. The use of hydrogen fuel can also play an important role in the decarbonisation of the energy sector in Poland [Chmielniak et al., 2022, p. 20]. However, it is difficult to determine what will be the pace of change, and whether a carbon-neutral Poland is possible till 2050 – in the face of a strongly changing political situation in the world as well as the coronavirus pandemic. The pandemic lasting since 2020 did not only shake the pace of energy demand in many countries, but also shook the supply chain of many raw materials. It seemed that the tightening climate policy of the European Union accelerating emission reduction targets and accelerating decarbonisation, which was observed in 2021 (Fit for 55 package), would lead to an even faster, than assumed in planning documents, e.g. PEP 2040, abandonment of coal in Poland. However, the limitations in the availability of Russian natural gas in Western Europe observed in 2021, together with the rapidly increasing prices of this carrier, made many European economies restart coal-fired power plants so as to retain electricity supplies. In addition, the events of February 2022 related to the armed aggression of the Russian Federation against Ukraine, resulting in the introduction of sanctions on goods from the Russian Federation and Belarus, showed how important it is to ensure the energy security of the state and to rely by a country on its own energy resources.

Poland has its own resources of hard coal and lignite. According to BP [2021, p. 46], at the end of 2020, the total coal proved reserves amounted to 28.4 billion tonnes, constituting 2.6% of the world's coal reserves. Their sufficiency (calculated by the ratio of resources to production in a given year) is estimated at 282 years. National statistics show that at the end of 2020, the geological balance resources of lignite [Balance, 2021, p. 35] amounted to 23.2 billion tonnes, and hard coal – 64.4 billion tonnes [Balance Sheet, 2021, p. 42]. Thus, Poland has the basis to provide fuel for the production of electricity from its own coal mines. In addition, it should be emphasised that commercial power plants, thanks to the introduction of appropriate systems for reducing pollutant emissions and increasing the efficiency of power units, reduce their emissions.

References

Anti-smog law (2015). Act of 10 September 2015 amending the Environmental Protection Law (Journal of Laws of 2015, item 1593), http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu20150001593 (access: 9.03.2022).

ARE (2011–2021). *Statistics of the Polish power industry*. Warsaw: Energy Market Agency.

ARE (2021). *Primary energy balance in the years 2005–2020*. Warsaw: Energy Market Agency.

Bilans (2021). *Balance of mineral resources in Poland as of 31 December 2020*. Warsaw: National Geological Institute – National Research Institute.

BP (2021). *BP Statistical Review of World Energy 2021*, https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html (access: 15.02.2022).

Chmielniak, T., Skorek-Osikowska A., Bartela Ł. (2022). The potential of hydrogen application in the Polish energy system, *Scientific Workbooks of the Institute of Mineral and Energy Management of the Polish Academy of Sciences*, 1(110), pp. 7–22.

Clean energy (2019). *Clean energy for all Europeans. European Commission*, https://data.europa.eu/doi/10.2833/954 (access: 15. 02. 2022) .

EP resolution (2021). *The European Green Deal*, European Parliament resolution of 15 January 2020 on the European Green Deal (2019/2956(RSP)), Official Journal of the European Union (2021/C 270/01).

Fit 55 (2022). *The European Green Deal. Ready for 55*, https://www.consilium.europa.eu/pl/policies/green-deal/eu-plan-for-a-green-transition/ (access: 9. 03.2 022).

GUS (2011–2021). *Consumption of fuels and energy carriers in Poland*. Warsaw: Central Statistical Office.

KE (2022). *European Commission. Climate objectives and strategies*, https://ec.europa.eu/clima/eu-action/climate-strategies-targets_pl (access: 15. 02. 2022) .

KPEiK (2019). *National Energy and Climate Plan 2021–2030. Assumptions and objectives as well as policies and activities*, https://www.gov.pl/web/aktywa-panstwowe/krajowy-plan-na-rzecz-energii-i-klimatu-na-lata-2021-2030-przekazany-do-ke / (access: 20.02.2022).

KPEiK ODN (2019). Annex 1 to the National Energy and Climate Plan 2021–2030. Baseline scenario (ODN). Current situation and forecasts for policies and measures existing at the end of 2017 (without implementation of the KPEiK), https://www.gov.pl/web/aktywa-panstwowe/krajowy-plan-na-rzecz-energii-i-klimatu-na-lata-2021-2030-przekazany-do-ke / (access: 20.02.2022).

KPEiK PEK (2019). Annex 2 to the National Energy and Climate Plan 2021-2030. Energy and climate policy scenario (PEK). Impact assessment of planned policies and measures, https://www.gov.pl/web/aktywa-panstwowe/krajowy-plan-na-rzecz-energii-i-klimatu-na-lata-2021-2030-przekazany-do-ke / (access: 20.02.2022).

Mazanek Ł., Świat M. (2022). Polish Energy Policy till 2040 – perspectives and challenges, *Scientific Workbooks of the Institute of Mineral and Energy Management of the Polish Academy of Sciences*, 1(110), pp. 51–63. DOI: 10.24425/140525.

Ozga-Blaschke, U. (2021). Dynamics of Coking Coal Pricing in International Trade in 1980–2020, *Gospodarka Surowcami Mineralnymi – Mineral Resources Management*, 37(3), pp. 125–138.

PEP (2021a). *Polish Energy Policy till 2040. Annex to Resolution No. 22/2021 of the Council of Ministers of 2 February 2021*, https://www.gov.pl/web/klimat/polityka-energetyczna-polski (access: 15.02.2022).

PEP (2021b). *Polish Energy Policy till 2040. Appendix 2 Conclusions from forecasting analyses for the energy sector*, https://www.gov.pl/web/klimat/polityka-energetyczna-polski (access: 15.02.2022).

PPP (2021). *Industrial policy Polish*, https://www.gov.pl/web/rozwoj-technologia/polityka-przemyslowa-polski / (access: 20.02. 2022) .

Stala-Szlugaj, K. (2022). Solid fuels market for households in Poland, *Scientific Workbooks of the Institute of Mineral and Energy Management of the Polish Academy of Sciences*, 1(110), pp. 65–74.

Stala-Szlugaj, K., Grudziński, Z. (2021). Price trends on the international steam coal market in 2000–2020, *Gospodarka Surowcami Mineralnymi – Mineral Resources Management*, 37(4), pp. 177–198.

Tokarski S. (2021). *Problems of the power generation sector – where is the place for coal?*, https://szkolaeksploatacji.pl/video/problemy-sektora-wytwarzania-energii-gdzie-jest-miejsce-dla-wegla/ (access: 20.02.2022).

Dorota Niedziółka
Warsaw School of Economics

Chapter VII

Determinants and Barriers to the Development of Green Energy in Poland

Abstract

Contemporary considerations about energy markets indicate a significant change in the philosophy of their perception. Energy produced from renewable energy sources plays an increasingly important role, and their use is also accompanied by the development of technology, scientific progress as well as the development of public awareness. A widespread use of RES as a source of primary energy is not only an element of diversification of energy carriers or creation of energy security but an impulse for economic development.

Keywords: green energy, energy transition

Introduction

Considerations about green energy are entering a decisive phase. The changes taking place today in the energy markets require decisions about the scale and profile of transformations. The choice of energy carriers, technologies and the volume of energy production determines not only the competitiveness of the economy, but also the possibilities of creating development impulses in all sectors of economy.

New solutions used in the production of electricity create jobs, change the philosophy of business entities, expand the scope of activity and finally affect positive changes in the natural environment.

Thus, it is worth looking at what has a positive impact on the development of green energy in Poland, and where the barriers to its development are.

1. Concept of green energy

Green energy is a concept that has not been clearly defined. It is most often identified with energy produced on the basis of renewable energy sources, such as water, wind, biomass or sun. Its acquisition is treated as an ecological, sustainable way of producing secondary energy, where the environmental footprint is insignificant. Secondary energy produced in devices using these energy sources contributes less to exhaust emissions and carbon dioxide, no toxic waste is left. The use of renewable energy sources is more environmentally friendly then. The emission of green electricity amounts only to about 40 grams per kilowatt hour. Electricity generated by conventional systems generates more than 600 grams.

This concept is most often referred to the power industry due to the method and technological conditions of electricity generation and the size of the volume. In the case of heat and fuels, the term alternative or renewable is rather used. However, the definition of green energy needs to be clarified in order to indicate development opportunities and support mechanisms. One way to determine what belongs to this type of energy is through certificates, guarantees of origin, labels or quality marks that identify green electricity.

Green certificates are digital certificates that confirm the production of electricity using renewable energy sources. Energy companies are required to demonstrate an appropriate share of green energy in the overall balance of electricity supplied to electricity consumers. An energy company can purchase green energy directly from a renewable energy producer or purchase green certificates on the Polish Power Exchange. If you do not show the right number of green certificates, it results in the need to pay a substitute fee. Such actions are aimed at forcing more pro-ecological activities.

The guarantee of origin is a document certifying to the final customer that the amount of electricity specified in this document entering the distribution network or transmission network has been generated from renewable energy sources in RES installations.

Most often, energy-using entrepreneurs who want to strengthen their eco-image, e.g. the real estate industry, apply for guarantees: investors, owners and managers of buildings can raise the quality standard of the property and demonstrate its energy efficiency. Guarantees of origin give evidence of activities aimed at protecting the environment and sustainable development.

Labels on household appliances confirm, for example, energy efficiency. They provide important information for consumers making choices on the basis of the information on the label. And for manufacturers, they are one of the factors reflecting a competitive advantage.

2. Determinants of green energy development

The development of green energy is a consequence of the increase in public awareness of the negative effects of the energy and climate policy conducted so far.

Growing needs for acquisition of energy resources affect the depletion of resources and raise questions about the costs of reaching for hard-to-reach deposits as well as a probability of a resource limit.

A growing demand for electricity as a consequence of the growing population (7933 million people), of which almost 900 million are still deprived of access to electricity and the growth and economic development of countries. Social and economic changes require not only an increase in the volume of generation, but also an assessment of the technology used and the cost of electricity generation.

The use of energy from hydrocarbons contributes to an increase in emissions of CO_2 and other harmful compounds. In 2021 alone, CO_2 emissions from the use of coal for electricity generation resulted in emissions of 15.3 billion tonnes [IEA, 2022].

The emission of gigantic amounts of CO_2 and other greenhouse gases into the atmosphere through the greenhouse effect has already led to an increase in the average temperature on Earth by one degree Celsius compared to the state before the industrial era. Currently, the fight is being fought not to exceed the threshold of 1.5 degrees.

The reason for the changes in thinking about energy sources comes also from the awareness that ecological issues are a global problem and require global solutions. Hence, since the 1970s, the ideas of sustainable development and actions to change the Energy mix of countries, regions and the world. Subsequent meetings of the United Nations Conference on Environment and Development contributed to the discussion and pace and possible scenarios of changes.

Some countries have also taken formal initiatives for the development of RES. It may be exemplified by the European Union, whose policy is to develop green energy. In 2018, the Union adopted new rules on renewable energy sources. They set a new, higher target for the member states regarding the share of RES in total energy production by 2030. They also impose an obligation to introduce many facilitations for the development of renewable sources, including the expanded activities of prosumers and energy communities [Directive 2009/28/EC].

Directive 2009/28/EC of 23 April 2009 set targets to be achieved by 2020. Within it, the European Union countries committed to increase the share of RES to 20% in total consumption.

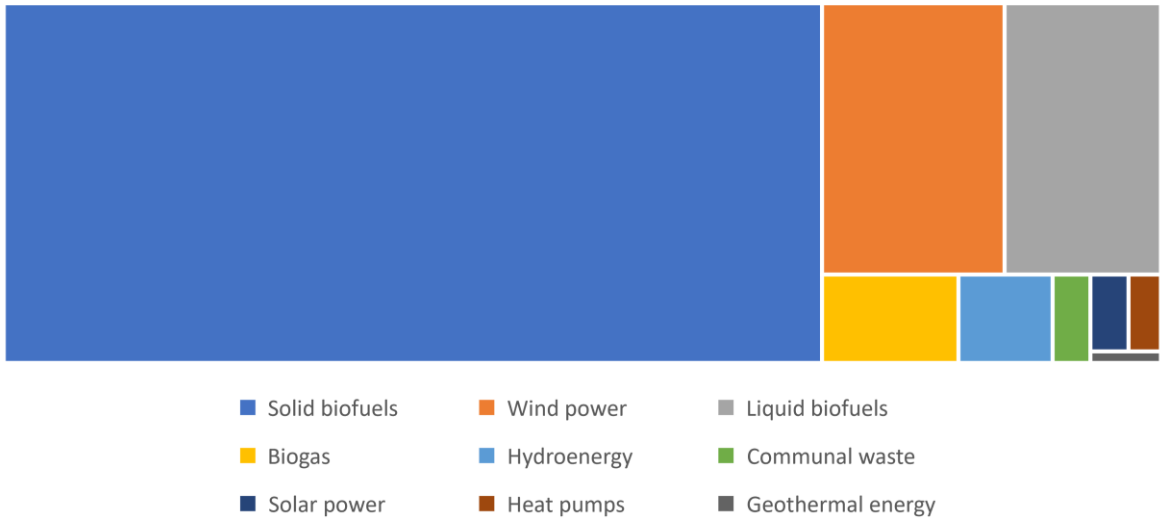
For Poland, this target was set at 15%. According to the GUS data for 2018, this share was only 11.3%. The Directive established an obligation to remove administrative and legislative barriers as well as to facilitate access to the electricity grid.

The 2018 European Union Directive on the promotion of the use of energy from renewable sources replaces and amends the previous 2009 Directive. The new document sets out a common framework for the promotion of energy from RES and sets a binding EU target of at least 32% of renewable energy in the Union's gross final consumption of energy in 2030. The European Union climate and energy target is to reduce greenhouse gas emissions by at least 40% by 2030 compared to 1990 levels. In the National Energy and Climate Plan for 2021–2030 submitted to the European Commission in December 2019, Poland declared to achieve a 21–23% share of RES in gross final energy consumption, at a level significantly lower than the assumed value for the entire European Union.

3. Limitations to the development of green energy in Poland

The assessment of the level of development of RES indicated that Poland has difficulties in achieving the assumed goal [NIK, 2018]. Already in June 2015, the European Commission, in another progress report on the implementation of the directive on the promotion of renewable energy sources, warned Poland that it may not meet its RES targets for 2020.

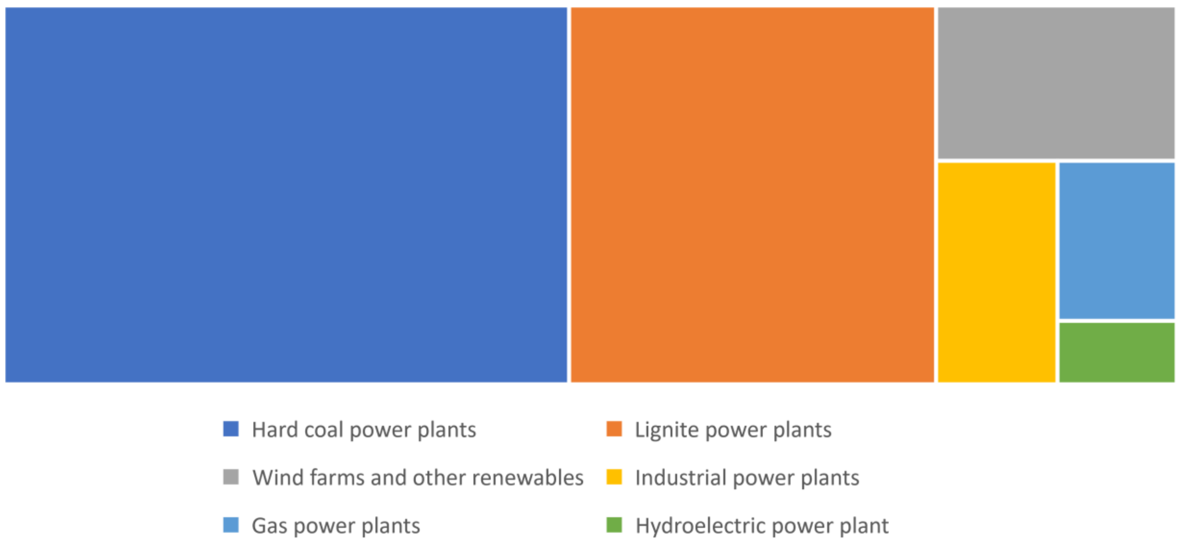
Figure 1. Structure of obtaining primary energy from RES in 2016 (in %)



Source: NIK, 2018.

The development of renewable energy was also adversely affected by the lack of a consistent state policy towards renewable energy sources, delays in issuing executive regulations and the lack of a stable and friendly legal environment, ensuring the safety and predictability of investments in RES, especially in the electricity sector.[1]

Figure 2. Share in the domestic electricity production of different types of power plants (in %)



Source: NIK, 2018.

Many of the investments planned in the RES sector have not been implemented due to:

1) low prices of green certificates,
2) the auction system, which weakened the ability to compete, the costs of preparing for the auction,
3) location limitation for wind farms.

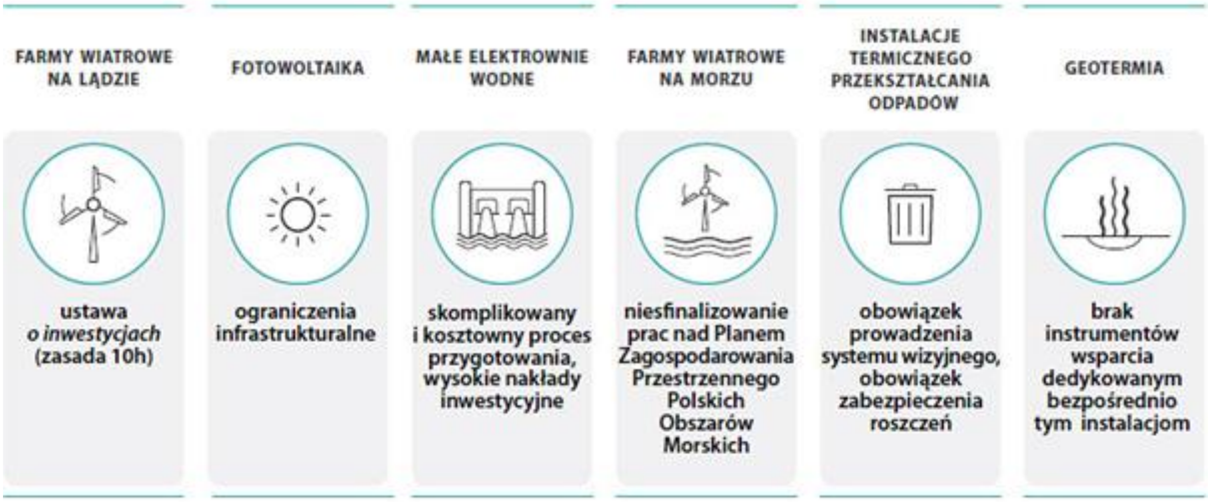
In a NIK report of 2021, the following were indicated as the main barriers to the development of green energy: limited possibilities of financing investments by entrepreneurs, legal support regulations, administrative and procedural difficulties as well as problems related to the performance of transmission networks.

The conducted analyses indicated the problems of only a selective group of participants in this market segment.

---

[1] A negative role of the Act on Investments in Wind Power Plants of 20 May 2016.

Figure 3. Barriers to market development



Source: NIK, 2021.

After 2018, efforts to reduce barriers were intensified, the RES laws were amended, a new division of auction baskets and new rules for settling auctions were introduced, e.g. eliminating the possibility of winning the auction by all its participants, a support system consisting in a fixed, guaranteed purchase price was established for producers with micro, small and medium-sized installations using hydropower or biogas. A prosumer appeared on the market, i.e. a producer of electricity from renewable sources in a micro-installation, at the same time an entity with the ability to store it and transfer the surplus to the power grid. The concept of an energy cooperative was also introduced, which is a kind of collective prosumer.

4. Energy transition

The following years brought a change in the way of perceiving the concept of green energy development. The idea of transition emerged, which was meant to be a holistic approach to transformations in energy markets. A sequence of actions resulting in the achievement of sustainable economies with renewable energy sources, increased energy savings and increased energy efficiency.

The energy transition will require the involvement of many entities and incurring significant investment outlays, the scale of which in the years 2021–2040 may reach about PLN 1600 billion.

The projected expenditure in the electricity generation sector will reach about PLN 320–342 billion, of which about 80% will be allocated to zero-emission capacities, i.e. RES and nuclear energy.

The energy policy of Poland 2040 contains the prerequisites for these changes. It includes, e.g. the assumption of the role of RES in the growth and striving for energy transition through diversification of the energy mix and emission reduction as well as contribution to the EU-wide 32% RES target in gross final energy consumption.

Poland declares to achieve at least 23% of the share of RES in gross final energy consumption in 2030, while in the power industry – at least 32% net.

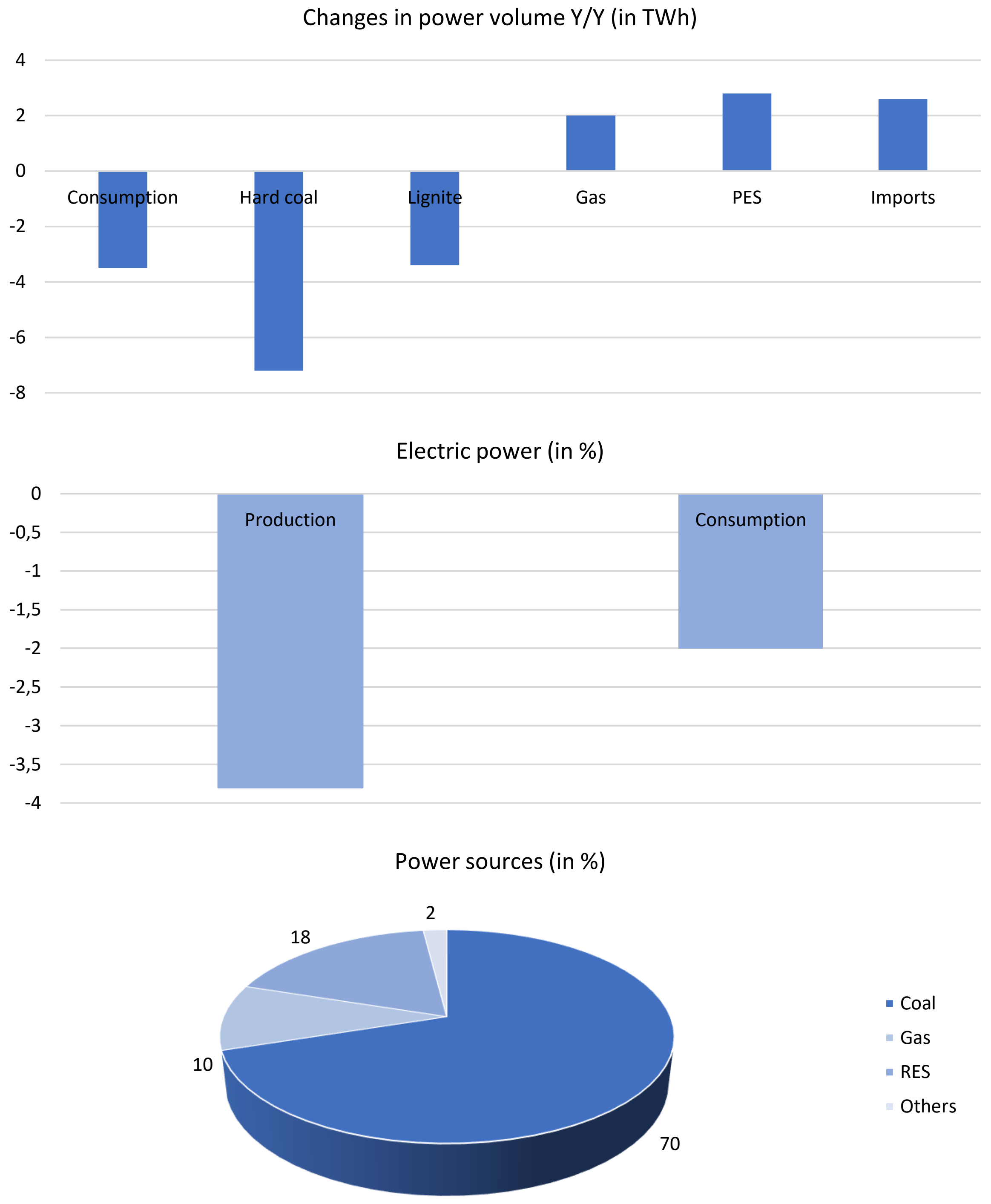
Offshore and onshore wind farms, photovoltaics, biomass and biogas will play a special role in achieving these objectives.

Conditions are to be created for the development of distributed energy based on the production of energy from RES, sale, storage or participation in DSR programmes by individual entities (e.g. active customers, renewable energy prosumers and others) and energy communities (e.g. energy clusters, energy cooperatives).

5. Characterstics of the Polish electric energy market

In 2020, electricity consumption in Poland decreased by 2%. The largest decrease in production was recorded by power plants and thermal power plants fired with hard coal (by 9%, or 7.2 TWh, to 71.6 TWh) and lignite (by 8%, or 3.4 TWh, to 38.3 TWh). As a result, the share of hard coal in electricity production fell in 2020 to 46%, while the share of lignite to 24%.

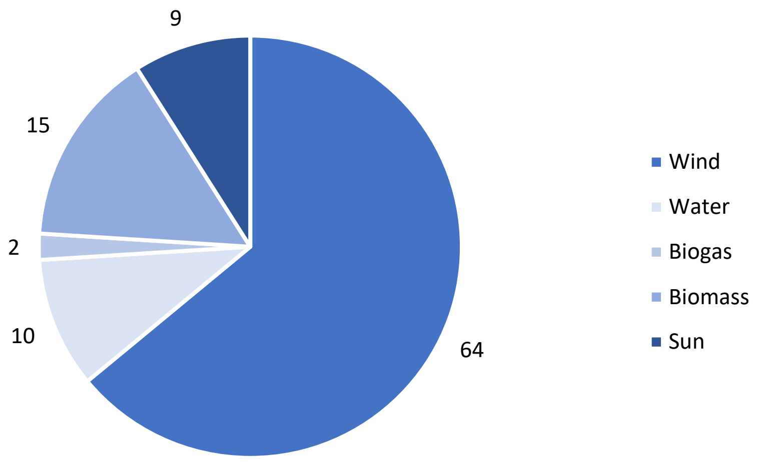
Figure 4. Characteristics of the Polish electricity market in 2020



Source: Derski, 2021.

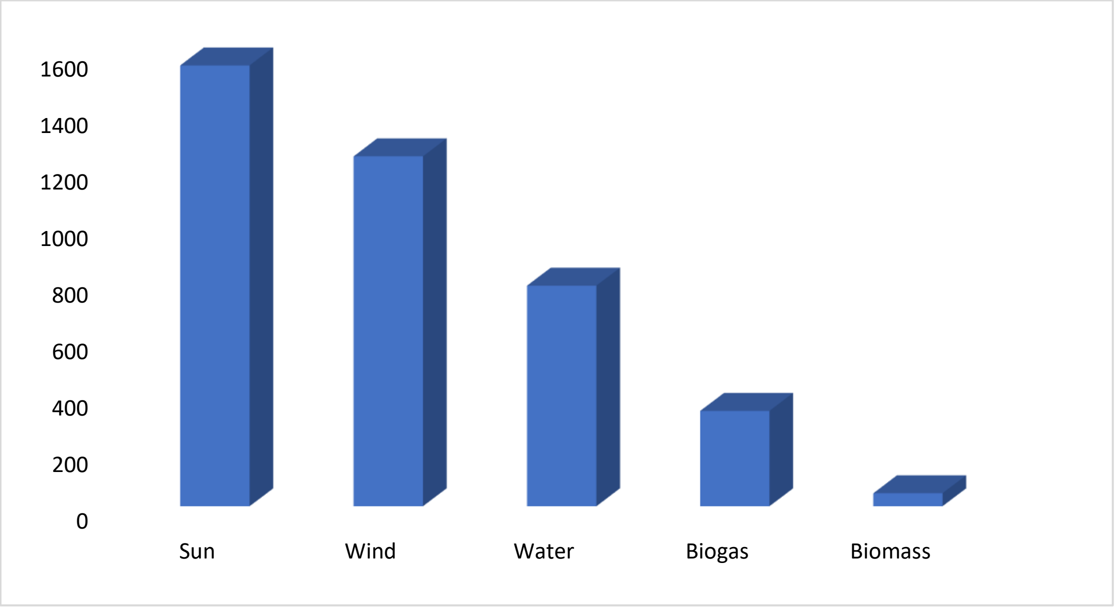
At the same time, the production of energy from RES increased, including primarily in photovoltaic installations. Solar power plants supplied the system with as much as 176% more energy year-on-year (2 TWh). Co-firing of biomass and coal increased by 20% (to 2.2 TWh), which was facilitated by a high price of CO_2 emission rights. The next places in terms of development dynamics among “green” power plants were taken biogas plants (an increase of 10% to 1.2 TWh) and hydroelectric power plants (by 8% to 2.1 TWh). Pumped-storage hydroelectric power plants were also more often used, mainly due to the increased share of variable energy sources (wind and photovoltaics), which the transmission system operator had to balance more often with the stored energy in water resources.

Figure 5. Share of RES in installed capacity in 2020



Source: based on data from URE, 2021.

Figure 6. Number of installations by RES source



Source: based on ERO, 2021.

Conclusions

Until a few years ago, electricity generated from RES was much more expensive than electricity produced in power plants using fossil fuels. Technological progress and economies of scale have changed economic conditions and the level of profitability.

Changes may be also seen in the philosophy of business entities, ensuring energy supplies from RES is one of the pillars of active peformance. Thus, they carry out investments in solar or wind projects or sign long-term purchase agreements from independent suppliers.[2]

At the same time, support for the idea of energy transition will change not only the conditions for the development of each sector of economy, but also the shape of energy markets in a sustainable way.

Differences in the conditions of electricity generation and the price of final energy will further expand the differences in the level of economic and social development and contribute to the polarisation of the world. Highly developed countries will take advantage of differences in the prices of both primary and secondary energy and in response will make geographical changes for the location of energy-absorbent activities. As a consequence, we will get a new picture of the world, in which in countries with a higher level of development we will record lower levels of CO_2 emissions and in underdeveloped countries there will be an increase in emissions of harmful substances into the atmosphere. These countries will remain a place of waste storage and the location of environmentally burdensome production activities.

References

Derski B. (2021). *Źródła energii w Polsce w 2020: mniej węgla, więcej gazu i OZE (Energy sources in Poland in 2020: less coal, more gas and RES)*, https://wysokienapiecie.pl/35619-zrodla-energii-w-polsce-w-2020-mniej-wegla-wiecej-gazu-oze/ (access:3.03.2022).

Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

EuroPAP News (2021). *Renewable energy in the EU – the present state and development prospects*, https://europapnews.pap.pl/analiza-energia-odnawialna-w-ue-stan-obecny-i-perspektywy-rozwoju (access: 3.03.2022).

IEA (2022). *Global CO_2 Emissions Rebounded to Their Highest Level in History in 2021*, https://www.iea.org/news/global-co2-emissions-rebounded-to-their-highest-level-in-history-in-2021?utm_content=bufferfe6d0&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer (access: 3.03.2022).

---

[2] Microsoft has been using only green energy since 2014, Google – since 2017, and Apple – since 2018.

NIK (2018). *Zielona energia dostała zadyszki (Green energy got short of breath)*. Warszawa: Najwyższa Izba Kontroli.

NIK (2021). *NIK o barierach rozwoju odnawialnych źródeł energii (NIK on barriers to the development of renewable energy sources)*. Warszawa: Najwyższa Izba Kontroli.

Sommer M. (2021). *Rząd nie nadąża za transformacją energetyczną The government cannot keep up with the energy transition*, https://serwisy.gazetaprawna.pl/energetyka/artykuly/8309604,rzad-nie-nadaza-za-transformacja-energetyczna.html (access: 3.03.2022).

Tabaka M. (2020). *A może to startupy pozbędą się brudnego węgla z Polski? Pod względem kreatywności nikt nam nie podskoczy (Or perhaps startups will get rid of dirty coal from Poland? In terms of creativity, no one will give us a cheek)*, https://spidersweb.pl/bizblog/energia-usluga-start (access: 3.03.2022).

URE (2021). *Report – aggregated information on the production of electricity from renewable energy sources in a small ERO 2021 installation*.

WEF (2021). *Fostering Effective Energy Transition 2021*, https://www.weforum.org/reports/fostering-effective-energy-transition-2021(access: 3.03.2022).

Józef Paska
Warsaw University of Technology

Chapter VIII

Renewable and Distributed Energy Sources in the National Power System – Determinants and Challenges

Abstract
The article presents selected problems of the growing share of renewable and distributed energy sources in the National Power System and the associated determinants and challenges. It describes basic technologies of renewable and distributed energy sources and discusses the problems of integration and operation of renewable and distributed generation units in the National Power System. It also highlights essential economic aspects of renewable and distributed energy sources in the power system.

Keywords: renewable energy sources, dispersed generation, power system, determinants and challenges, reliability and availability

1. Definitions and classification

According to European Union directive 2018/2001/EC, the term “energy from renewable sources” means energy from renewable non-fossil sources, namely wind energy, solar radiation, aerothermal, geothermal and hydrothermal energy and ocean energy, hydropower, energy from biomass, gas from landfills, sewage treatment plants and from biogases.

According to the Energy Law: Renewable energy source – a renewable energy source as defined by the Law of 20 February 2015 on renewable energy sources (RES Act, Journal of Laws of 2015, item 478).

According to the RES Act of 20 February 2015, (consolidated text of 2020): renewable energy source refers to renewable, non-fossil energy sources including wind energy, solar energy, aerothermal energy, geothermal energy, hydrothermal energy, hydropower, wave, tidal and tidal energy, energy obtained from biomass, biogas, agricultural biogas and bioliquids.

Distributed generation (distributed energy sources, distributed generation, distributed energy) refers to small (with a rated capacity of up to 50–150 MW) generating units or facilities, connected directly to distribution networks or located in the consumer's power grid (behind a control and settlement device), not subject to central planning of development and disposal of power, often producing electricity from energy from renewable sources or unconventional, equally often in combination with heat generation [Paska, 2017].

There are two classifications of distributed generation units [Paska, 2017].

By the capacity installed:

- micro distributed generation 1 W 5 kW÷,
- small distributed generation 1 kW 5 MW÷,
- average distributed generation 5 MW 50 MW÷,
- large distributed generation 50 MW 150 MW÷.

By the technology used:

- renewable distributed generation,
- modular distributed generation,
- associated distributed generation.

Distributed energy sources, distributed generation, distributed generation, distributed energy are synonyms defining the dynamically developing, more or less since the beginning of the 1990s, the field of electrical power engineering, well suited to the idea of sustainable development.

2. Technologies of renewable and distributed energy sources

Renewable energy generation and/or distributed generation (RES & GR) technologies include [Paska, 2017]:

- piston engines, turbines and micro gas turbines, Stirling engines;
- fuel cells;
- cogeneration based on gas turbines, piston engines, Stirling engines and fuel cells;
- small hydroelectric power plants;
- wind power plants;
- geothermal power plants;
- photovoltaic systems;
- heliothermal systems (with central receiver and decentralised);

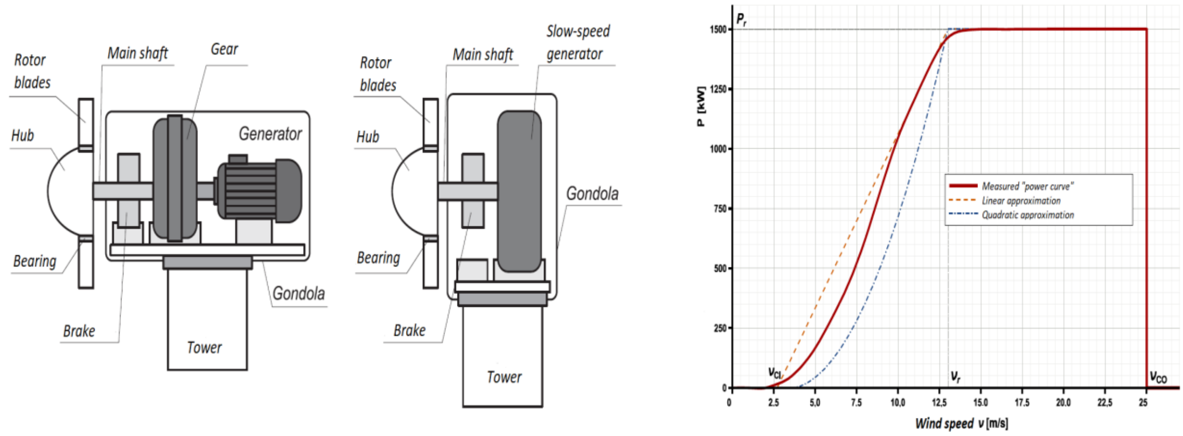
- technologies using biomass and waste;
- technologies using tides, currents and waves of seas and ocean heat;
- energy storage.

Some of these are renewable energy (RES) technologies, while others belong to distributed generation (GR), while the two sets are not separate. It may be debatable to mention energy storage tanks here, but they can undoubtedly be used as energy sources.

From among various RES & GR technologies, the following will be briefly characterised: onshore wind power plants, offshore wind power plants/wind farms, photovoltaic (PV) solar power plants; due to their large and growing importance in the world and in Poland.

In wind power plants (onshore and offshore), wind energy is converted in wind turbines into electricity (Figures 1a, 3) according to a characteristic called a "power curve" (Figures 1b, 2).

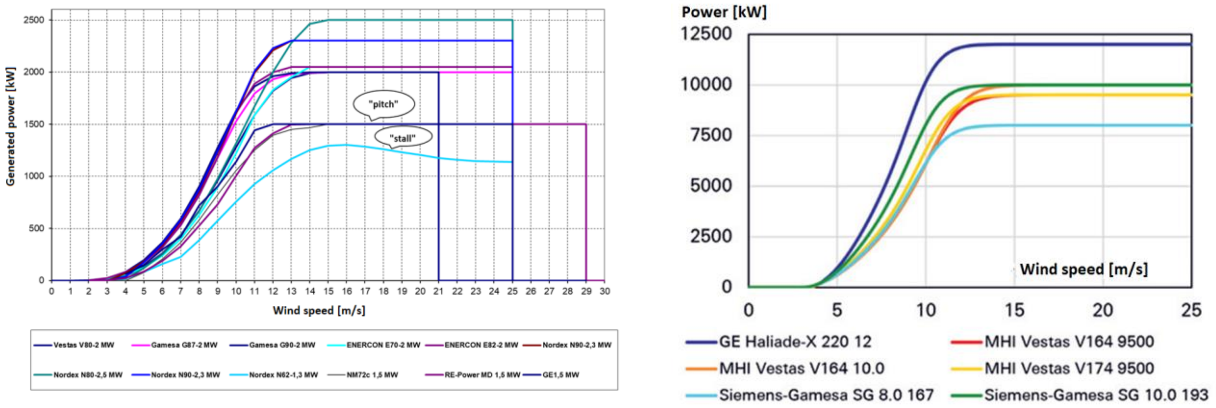
Figure 1. Cross-section of a wind turbine with a horizontal axis of rotation, (a) and the "power curve" of the Leitwind LTW77 turbo generator and its approximations (b)


a)

b)

Source: Author's own material based on Paska, 2017.

Figure 2. Power curves of wind turbine generators identified in Poland (a) and large offshore wind turbine sets of leading producers (b): pitch, stall – dominant methods of wind turbine set power control

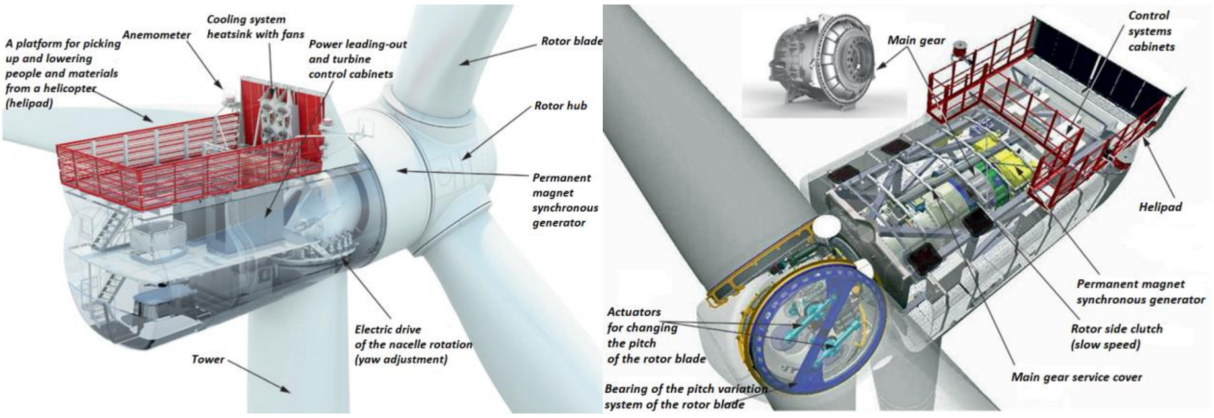

a)
b)

Source: Author's own material based on Paska, 2017; Nowicki, 2021.

Three characteristic wind speeds can be distinguished on the power curve:

- υ_r (υ_{ci}) – starting speed (switching on, starting, *cut-in*), i.e. wind speed at which a non-zero output power of a wind turbine is obtained (usually 3÷4 m/s);
- υ_o (υ_{co}) – cut-off speed, i.e. the wind speed at which the wind turbine is switched off due to the possibility of its damage (usually it is 20÷25 m/s, usually about 25 m/s);
- υ_N (υ_r) – rated power speed, i.e. the wind speed at which the wind turbine reaches the rated power (usually 10÷16 m/s).

Figure 3. Examples of an offshore wind turbine design: a) without gear, by Siemens Gamesa, b) with gear, by MHI Vestas

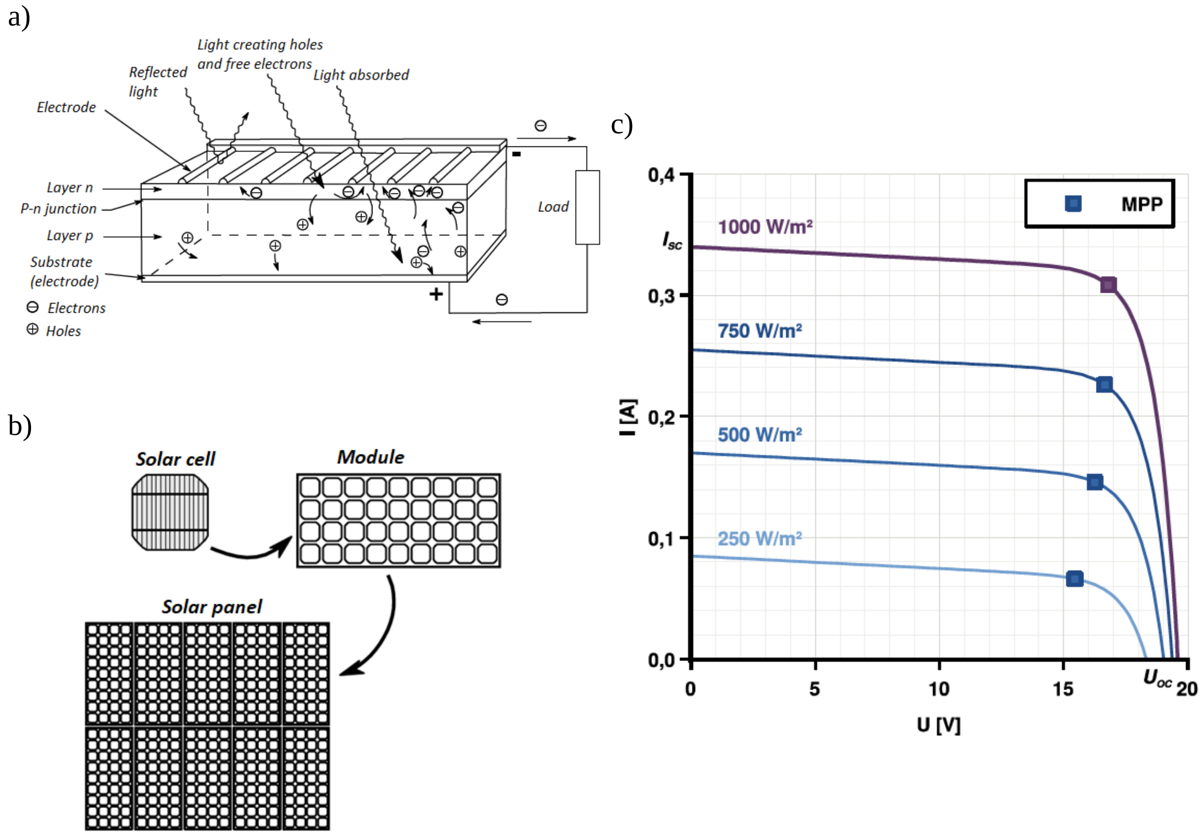

a)
b)

Source: Author's own material based on Nowicki, 2021.

In PV power plants, an internal photoelectric phenomenon is used (discovered by A.C. Becquerel in 1839), consisting in the release of electrons from the crystal lattice of a body exposed to light (solar) radiation, as well as in the formation of a photo electromotor force on the connector of two different semiconductors (in current solutions) (Figure 4a).

Single transducers – solar cells are combined into modules, from which PV panels are created (Figure 4b). The amount of electricity produced depends on the power of solar radiation (Figure 4c).

Figure 4. Principle of operation, elements and characteristics of PV power plants: a) construction and principle of operation of a photovoltaic (solar) cell; (b) PV cell, module and panel; c) current-voltage characteristics of the cell (MPP – maximum power point)



Source: Author's own material based on Paska, 2017.

3. Renewable and distributed energy sources and the power system

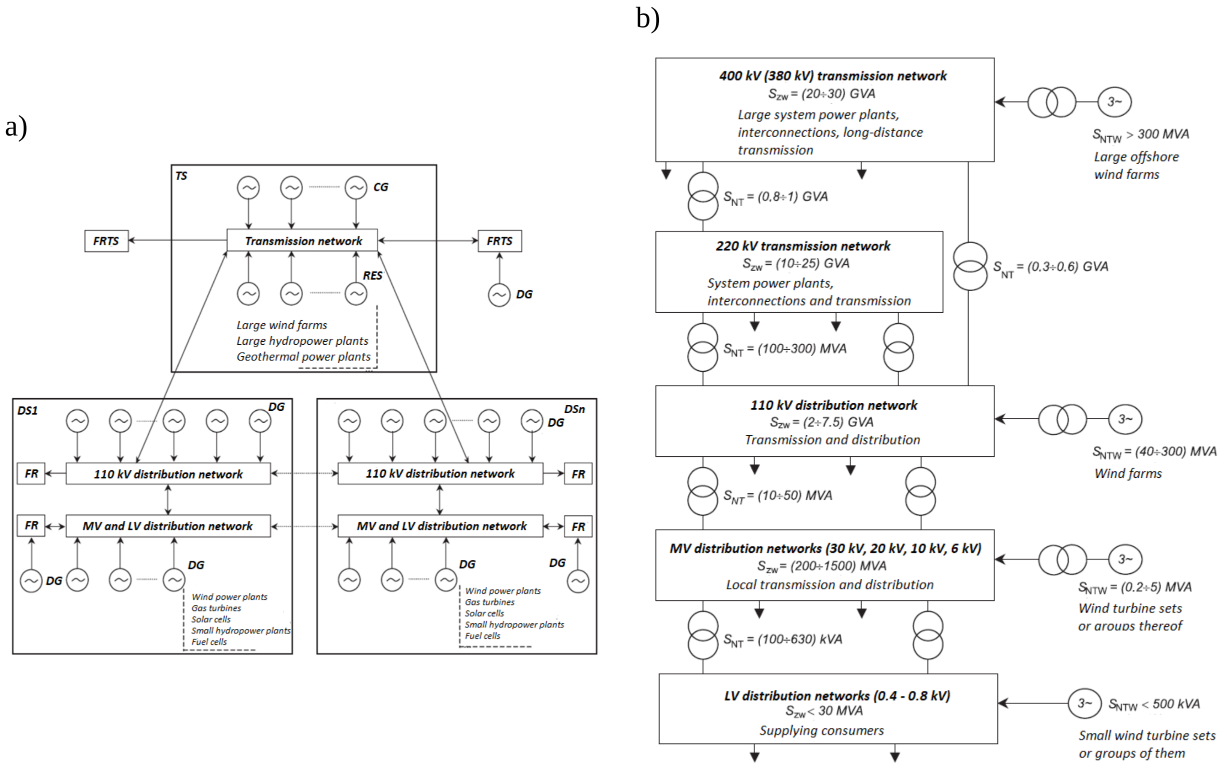
The power system (PS) of each country, including the Polish system (PPS), operates to fulfil the primary objective of ensuring the supply of electricity to private and institutional entities that report demand for this energy. Therefore, the aim of PS is to meet the demand for electricity of customers in quantitative and qualitative terms and to meet the specificity of this demand, i.e. high variability of demand during the day and depending on the season.

Figure 5 shows the location of renewable and distributed energy sources in the power system and the possibilities of their inclusion in the PS on the example of wind farms.

The basic technological requirements to be met by energy sources, including renewable and distributed, connected to the power system are:

- providing energy of an appropriate quality;
- guarantee of reliable power supply;
- providing full control and monitoring;
- possibility of forecasting production and load;
- cooperation with security automation.

Figure 5. Structure of the power system with the participation of renewable energy sources and distributed generation (a) and the possibility of including RES & GR sources in PS on the example of wind power plants (b): TS – transmission system, DS – distribution system, CG – centralised (systemic)generation, GR – distributed generation, RTS – recipient of energy from the transmission system, FR – final recipient



S_{NTW} – apparent rated power of a wind power plant (farm),
S_{zw} – short-circuit power,
S_{NT} – rated power of a coupling transformer.

Source: Author’s own material based on Paska, 2017.

In view of an increasing share of renewable and distributed energy sources in the power system, their presence should be considered in the areas listed and characterised in Table 1 [Strip, 2017].

Table 1. Issues to consider the share of renewable and distributed energy sources in the power system

Issue	Description (impact)
Power system reliability	Depending on the share of renewable and distributed energy sources, the type of units and their reliability characteristics, and future power reserves in the power system, its reliability may decrease or increase.
Frequency control	Local frequency control equipment may need to be used, and new techniques for maintaining frequencies in interconnected power systems may be needed.
System control	When using distributed control systems, some conflicts with superior control systems may occur.
System Modeling	Currently applied methods of power system analysis use assumptions that may not be valid with a significant share of renewable and distributed energy sources – it may be necessary to develop new methods and tools of analysis (e.g. stability).
Development planning	With a high share of renewable and distributed energy sources, new methods and tools may be needed to plan a system development (e.g. regional planning).
Load forecasting	Methods applied should enable accounting for the increased share of renewable and distributed energy sources – extended use of artificial intelligence methods should be expected.
Planning of repairs, selection of the composition of units and load distribution	Current methods should be reviewed and possibly modified to take into account the introduction of renewable and distributed energy sources into the power system.
Operational safety of the power system	Tools for assessing the operational safety of the system should be properly modified (e.g. the list of potential disturbances should be completed with failures of renewable and distributed energy sources).
Electric power quality	Account should be taken of the presence of variable speed drive systems and power electronic devices (e.g. inverters) on the source side. New tools will be needed to analyse and control the quality of electricity in the power system.
Security automation	Occurrence of distributed sources in distribution networks (e.g. at the ends of radial lines) will complicate the issues of selection and coordination of security.

Source: Author's own material based on Paska, 2017.

It should be assumed that the development of renewable and distributed generation is a source of new problems for transmission and distribution system operators, the solution of which they should be properly prepared to make. It is not surprising that they are afraid of connecting too many (in their opinion) units of renewable and distributed generation to the grid and attempt to attach additional requirements to the connection conditions [EU Commission, 2021; Paska and Marchel, 2021; PSE, 2020a].

Despite some inhibitions, the installed capacity and production of renewable and distributed energy sources is systematically growing and currently RES & GR already account for 42.6% of the installed capacity of the PPS and 15.7% of the electricity production of the

PPS (Table 2) and in the perspective of 2040 their importance will increase even more [PEP'2040, 2021].

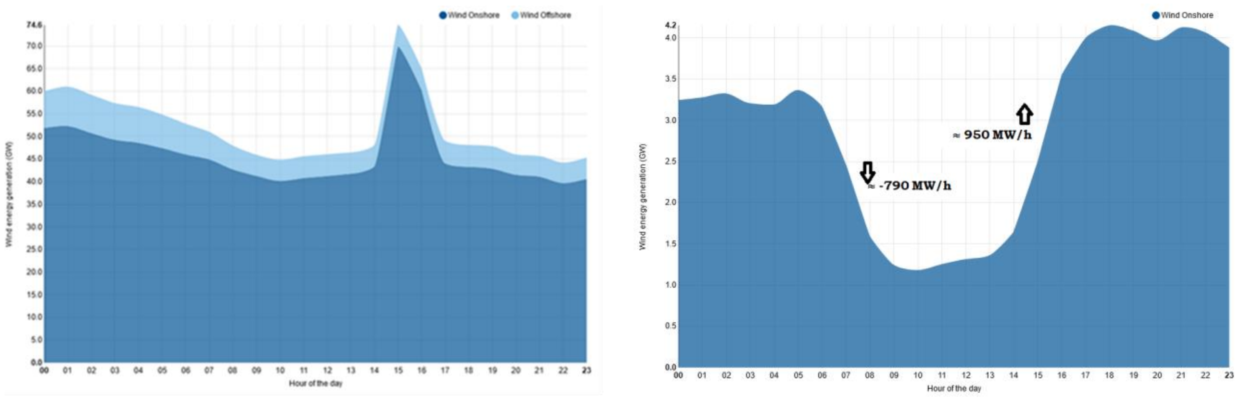
Table 2. Installed capacity and production of PPS power plants in 2021

Fuel/Technology	GW	%	TWh	%
Lignite (WB)	9.1	15.8	41.4	25.7
Hard coal (WK)	24.2	41.9	80.1	49.8
Other thermal	0.6	1.0	2.6	1.6
Gas	3.3	5.7	12.2	7.6
Biomass	1.2	2.1	1.9	1.2
Water	2.4	4.2	1.8	1.1
Wind on land	7.9	13.7	15.2	9.5
PV	7.3	12.6	4.6	2.9
Water pumped storage (ESP)	1.7	2.9	1.0	0.6
TOTAL	**57.7**	**100**	**160.8**	**100**

Source: Author's own material based on Jagiellonian Institute, 2022.

It should be borne in mind that electricity generation by wind and photovoltaic power plants is subject to significant variability and even significant geographical dispersion does not always mean less variability in FW and PV generation; the examples are shown in Figure 6 and Table 3. Also, constantly improved IT tools to forecast the production of eclectic energy from wind and solar energy are not yet ideal and do not provide sufficiently high accuracy of forecasts.

Figure 6. Electricity production by European (ENTSO-E) wind farms 23.11.2021 (a) and by Polish wind farms 29.10.2021 (b)



a)

b)

Source: Author's own material based on Windeurope, 2021.

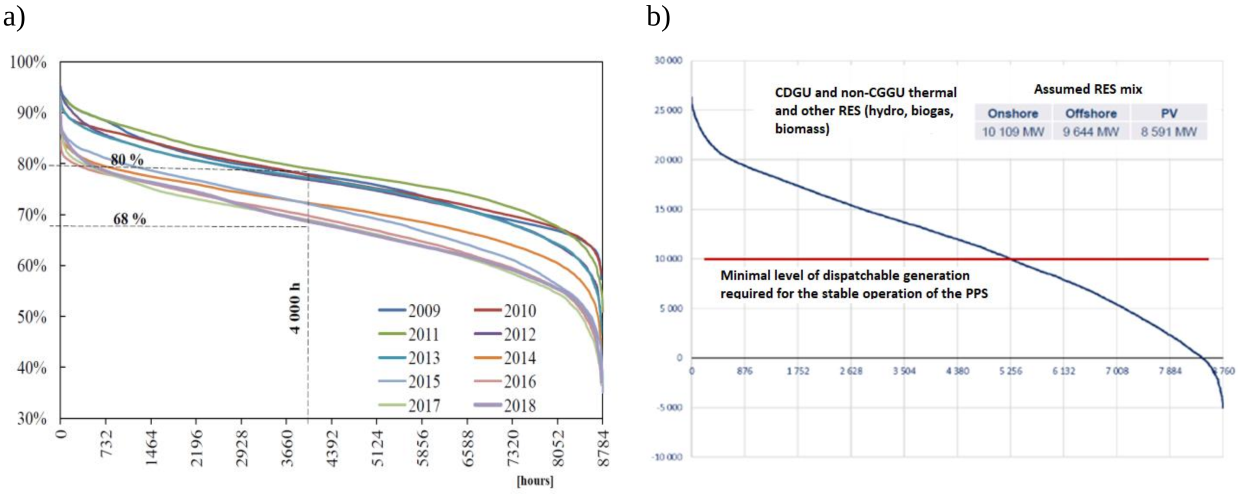
Table 3. Results of statistical analysis of the generation of Polish LFFs in 2016–2020

Parameter	2016	2017	2018	2019	2020
Installed capacity (MW)	5807.42	5848.67	5864.44	5917.24	6271
Power generation (TWh)	11.642	14.411	12.326	14.566	15.214
Annual utilisation rate of installed capacity (%)	22.82	28.13	23.99	28.10	27.60
Average hourly generation (MWh)	1325.37	1645.19	1407.08	1662.76	1732
Maximum generation per hour (MWh)	4891.73	5234.34	5195.93	5222.08	5729
Generation standard deviation (MWh)	804.23	946.83	838.06	945.85	?

Source: Author's own material based on PSE data.

A growing share of RES & GR affects the change in the nature of the work of conventional turbo generators. They, previously operating at the base of the power demand curve (centrally dispatched generation units – CDGU), are shifted towards sub-peak operation both in terms of the degree of utilisation of installed capacity (operating time about 1500–4500 h/year) and the number of start-ups per year (Figure 7a). Irregular operation of CDGU reduces their efficiency and durability, and the change in the nature of the work of conventional turbo generators also affects the costs of electricity generation.

Figure 7. Annual ordered curves of the CDGU share of power demand coverage in 2009–2018, CDGU base load (≥ 4000 h/a) decreased from 80% to 68% (a) and an ordered graph of power demand to be covered by sources other than RES in 2030 (for the conditions of the 2015 climate year) (b)



a) b)

Source: Author's own material based on PSE, 2020b.

Assuming that 2030 will be similar to 2015 from the point of view of climatic conditions, with the expected RES & GR mix (IMF, LFW, PV) in Poland, the PPS needs the capacity to cover the net demand for power at the level of about 26 GW (Figure 7b). Coverage of the PPS energy demand, with the expected RES & GR mix will mean [PSE, 2020b]:

- a large number of hours with a very low energy price,
- pushing unsubsidized disposable units out of the market,
- without these units, it is impossible to ensure the security of the PPS.

Selected phenomena in the operation of the transmission network against the background of the development planned till 2030 are as follows: [PSE, 2021]:

- with low wind generation, the concentration of electricity generation in the centre and south of the country. The dominant direction of electric power transmission south – north;
- high generation of wind sources located mainly in the north of the country. The direction of power flow is reversed, the dominant direction of transmission of electric power is north–south;
- acceleration of the process of abandoning coal sources while further increasing renewable sources. Increase in demand for transmission of electric power in the north–south direction;
- operation of wind sources at a level that meets the energy demand of consumers in the north of the country. Transmission lines are poorly loaded, they become sources of reactive power and cause an increase in voltages in the PPS above the limit values;
- operation of wind sources at a very high level, including the construction of offshore wind farms with a capacity of about 10 GW. Transmission lines are very heavily loaded, they become reactive power consumers, which causes underestimation of voltages in the PPS below the limit values;
- demand for electricity in the country is fully covered by renewable sources. There is a shortage of reactive power sources in the PPS, which is currently provided by synchronous generators in system power plants.

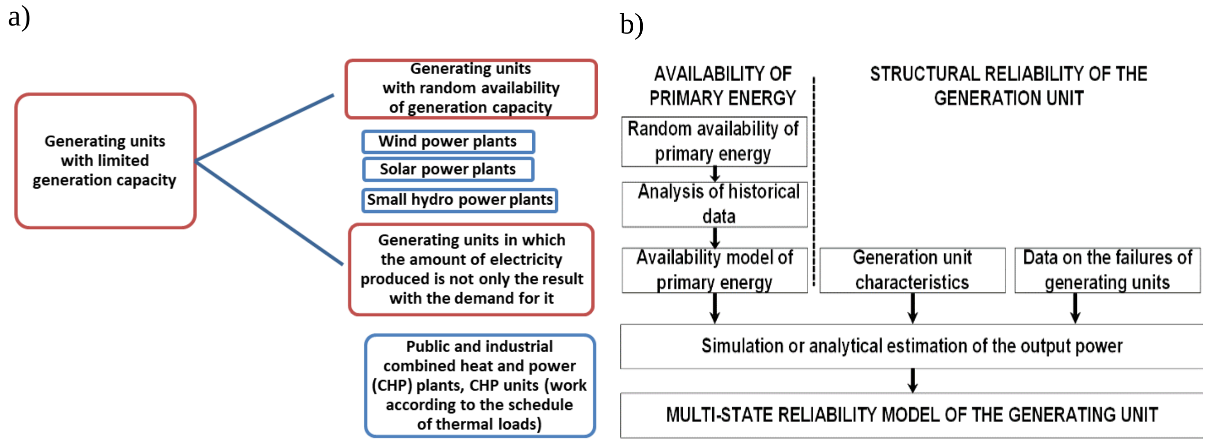
Terms used in relation to electric power turbo generators define their ability to meet the demand for power and to be subject to the instructions of the electricity system operator in which and for which they work shall be used. These terms are: “availability”, “controllability”, “stability”, etc.

Renewable energy sources such as wind, solar and small hydropower power plants are often referred to as indispositional, uncontrollable, unstable; against which their supporters protest by proposing the term “weather-dependent” (which should rather be “climate-dependent”).

It should be acknowledged that the concepts of controllability and stability should not be used in the context of the capacity of generating units to meet power demand and be subject to the instructions of the electricity system operator, while the concept of availability has been present for many years as an element of the operational and reliability characteristics of generating units, used by many countries and international organisations [Paska, Marchel, 2021].

However, classical operational and reliability indicators do not allow for substantively adequate modelling of the reliability of generating units with random availability of primary energy (using renewable energy resources) or subject to other capacity limitations, such as cogeneration sets, where the capacity to generate electricity is related to the demand for useful heat (Figure 8a). The modelling and analysis of the reliability of generating units with generation capacity limits should take into account both classical structural reliability (resulting from the functional structure of the unit and the failure rate of its elements) and production reliability resulting from the availability of primary energy (Figure 8b) or limitations in electricity generation, e.g. caused by cogeneration.

Figure 8. Division of generating units with capacity limitations (a) and a proposed universal algorithm for the creation of reliability models of generating units with generation limitations resulting from the random availability of primary energy (b)



Source: Author’s own material based on Paska, Marchel, 2021.

The issues of adequate modelling of the reliability of generating units are particularly important due to the decrease in the level of adequacy of domestic generation capacities signalled after 2030 [Ministry of Climate and Environment, 2021], limited “disposability” of climate-dependent generating units, not translating their installed capacity into capacity credit

[Milligan et al., 2016], the need to align national adequacy analyses with ENTSO-E [ENTSO-E, 2021].

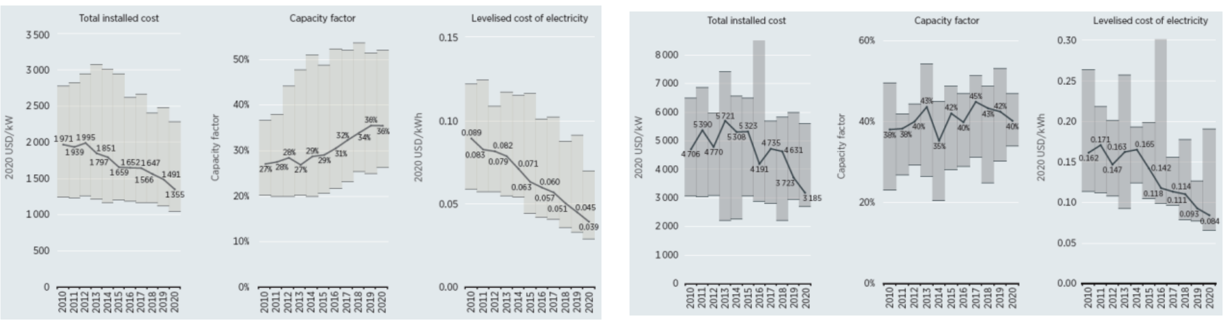
4. Economic aspects of renewable and distributed energy sources in the power system

There are many methods to assess the cost of producing energy from different sources. The LCOE (Levelised Cost of Electricity) method is still very popular, in which the unit leveled cost of power generation is determined by account for the whole lifetime of the power plant.

Figure 9 shows the values of unit capital expenditures, the degree of utilisation of installed CF capacity and the unit averaged cost of LCOE electricity generation for onshore wind farms, offshore wind farms, PV power plants and LCOE for various electricity generation technologies.

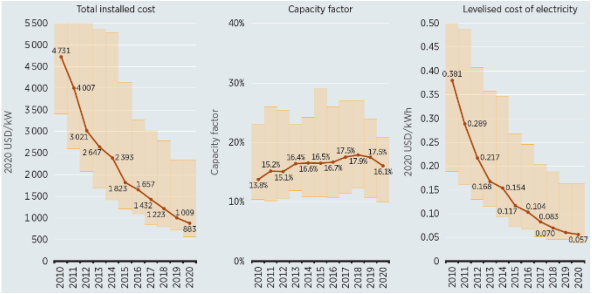
The LCOE method quite well reflects the reality of a situation when the share of climate-dependent RES in power systems is small. It is currently undergoing modifications worldwide to calculate the total cost of energy supply to consumers [Ueckerdt et al., 2013; ARE, 2016]. The methodology partially accounting for a full bill for the customer has been used for several years, e.g. by the International Energy Agency OECD (IEA/OECD) [IEA, 2020] and the US Department of Energy (US DoE). An appropriate database for renewable energy sources is maintained and performed by IRENA [IRENA, 2021].

Figure 9. Capital expenditures, CF and LCOE for commercial onshore wind farms (a), offshore wind farms (b) and PV power plants (c) projects completed between 2010 and 2020; (d) LCOE for various electricity generation technologies (discount rate of 7%, operation from 2025, LTO – extension of the service life of existing nuclear power units)

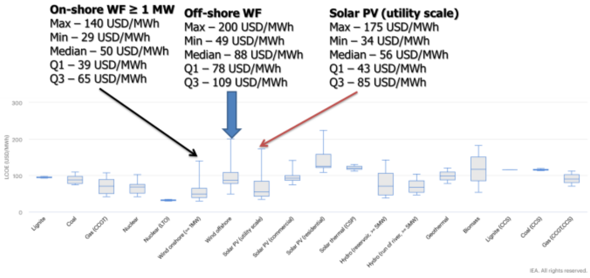

a)

b)

c)



d)



Source: Author's own material based on IRENA, 2021; IEA, 2020.

The total cost of energy supply to consumers includes, in addition to the traditional LCOE, the costs of integration in the power system of climate-dependent RES. Their estimation in the Polish conditions is presented in Table 4.

Table 4. Costs of integration of wind and solar PV power plants in SEE

Year	2020	2030	2050
Balancing costs (euro/MWh)			
Wind power plants	2.0	3.0	4.0
Solar PV Power Plants	0.0	1.0	2.0
Grid costs (euro/MWh)			
Wind power plants	2.0	3.0	5.0
Solar PV Power Plants	0.0	1.0	2.0
"Profile costs" (euro/MWh)			
Wind power plants	8.0	12.0	17.0
Solar PV power plants	0.0	2.0	16.0
Total integration costs (euro/MWh)			
Wind power plants	12.0	18.0	26.0
Solar PV Power Plants	0.0	4.0	20.0

Source: Author's own material based on ARE, 2016.

Additional balancing costs related to the operation of unstable sources (weather/climate dependent) are caused by:

- the need to maintain generation units to meet the criteria of national generation capacity adequacy (it is about maintaining generating units that lose the opportunity to obtain sufficient revenues on the energy market due to the takeover of energy production by unstable sources);
- the need for additional commissioning of condensing thermal generation units necessary to ensure the required regulation of the PPS (it refers to night shutdowns of large power units, very harmful for their service life);
- the need to periodically reduce unstable sources (compensation) in order to maintain the

minimum technical operation of other generation sources and to meet the required grid operating conditions.

These costs are not included in the price of energy created in a competitive energy market and must be transferred to the TSO tariff.

Conclusions

Renewable and distributed energy (RES & GR) is a dynamically developing energy sector. In Poland, according to PEP'2040, by 2040 the offshore wind farms installed capacity will be almost 10 GW, the installed capacity of onshore wind farms will be almost 7 GW, and the PV installed capacity will be about 10 GW.

Renewable and distributed energy sources have reached technological maturity and economic competitiveness, they are the carrier of many innovative solutions.

The growing share of renewable and distributed energy in the PPS may pose a problem for the transmission system operators due to: limited "disposability" of climate-dependent generation units, failure to translate their installed capacity into capacity credit, the need to use the JWCD regulatory capabilities to the maximum extent.

References

ARE (2016). *Update of the comparative analysis of the costs of electric power generation in nuclear, coal and gas power plants and renewable energy sources*.

ENTSO-E (2021). *European Resource Adequacy Assessment 2021 Edition. Annex 2 Detailed Results*.

European Commission (2016). Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for the connection of generating units to the network (OJ EU 2016, p. EU L 112/1).

IEA (2020). *Projected Costs of Generating Electricity 2020 Edition*. Paris: IEA/NEA/OECD.

Instytut Jagielloński (2022). Analiza cen paliw i kluczowych wskaźników w sektorze energetycznym (Analysis of fuel prices and key indicators in the energy sector), *Energetyka w liczbach – przegląd wydarzeń* (Energy in Numbers – Overview of Events), 1.

IRENA (2021). *Renewable Cost Database*.

Milligan, M., Frew, B., Ibanez, E., Kiwiluoma, J., Holttinen, H., Söder, L. (2016). *Capacity value assessments of wind power*. WIREs Energy Environ.

MKiŚ (2021). *Report on the results of monitoring the security of electricity supply for the period from 1 January 2019 to 31 December 2020*.

Nowicki, J. (2021). *Five key groups of energy technologies in the perspective of 2050*, Conference of the Scientific and Technical Committee of Energy Management FSNT-NOT "EnergoMiting – Transition of Energy to Electroprosumerism", November 22, 2021.

Paska, J. (2017). *Rozproszone źródła energii (Distributed energy sources)*. Warsaw: Oficyna Wydawnicza Politechniki Warszawskiej.

Paska, J., Marchel, P. (2021). *Bezpieczeństwo elektroenergetyczne i niezawodność zasilania energią elektryczną (Electric energy security and reliability of electricity supply)*. Warsaw: Oficyna Wydawnicza Politechniki Warszawskiej.

PEP’2040 (2021). *Energy policy Polish until 2040* (M.P. of 2021, item 264).

PSE (2018). General application requirements resulting from Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for connecting generating units to the grid (NC RfG), https://www.pse.pl/dokumenty (accessed: 18.12.2018).

PSE (2020a). *Transmission Network Operation and Operation Manual*, version dated 7.04.2020, https://www.pse.pl/dokumenty (access: 18.12.2018).

PSE (2020b). *Market and power system 2030. Energy 2030. New energy for change*.

PSE (2021). *Connection of offshore wind farms to the PPS. EnergoMiting Conference – energy transition to Electroprosumerism*.

Ueckerdt, F., Hirth, L., Luderer, G., Edenhofer, O. (2013). *System LCOE: What are the costs of variable renewables?* Potsdam-Institute for Climate Impact Research.

Windeurope (2021). *Wind Power Numbers Daily. Hourly wind energy generation*, https://windeurope.org/about-wind/daily-wind/hourly-generation (3.03.2022).

Tomasz P. Wiśniewski
Warsaw School of Economics

Chapter IX

Energy Transition and Technological and Socio-Economic Progress

Abstract
The current energy transition is an issue that receives a lot of attention. For the accuracy of its analyses, the issue of energy transition should be approached in such a way as to consider its multifaceted nature and treated as a phenomenon that has already taken place in the history of mankind. A plane to affect it is, next to socio-economic progress, technological determinants moderating (limiting or intensifying) energy policy choices within the energy trilemma. The importance of this plane is mainly due to the fact that although energy transitions are not a new socio-economic phenomenon, the technical (technological) possibility of separating the effects of civilisational development from the increase in energy demand within the ongoing transition is a kind of novelty for the global economy. This separation of development from energy demand is based on several pillars, among which technological readiness and energy efficiency play and will play a significant role. Their main though non-exclusive aspects are: the electrification of end-users; basing the power industry on renewable energy sources; development of the possibility of, *sensu largo,* energy storage and the acquisition and storage of unconventional energy carriers.

Keywords: energy transition, technological progress, primary energy consumption, energy efficiency

Introduction

The energy transition is currently an issue that receives a lot of attention both in the practice of economic turnover and on the scientific plane. Deliberations on the issues that it entails are particularly lively in the context of economic policy. In Poland, the energy transition is basically identified with decarbonisation, and more precisely with the departure of the Polish economy from coal. This can be justified by the fact that the Polish dependence on coal is in relative terms, not absolute, one of the highest in the world [Ritchie, Roser, 2020]. However, the issue of energy transition should be approached more broadly than just the process of reducing the role of hard coal and lignite in the energy sector and, what is fundamental, it should be treated as a phenomenon that has already taken place in the history of mankind. At the same time, energy transition studies can be conducted in the context of technological and development determinants, which allows for showing many interconnections, including those of a causal nature.

1. Energy transitions

In the literature, energy transitions are understood as changes in fuel, e.g. from wood to coal or from coal to oil and related technologies, e.g. from a steam engine to an internal combustion engine [Hirsh, Jones, 2014] or as changes in the structure of fuels used in energy production and changes in technologies applied to use them [Miller et al., 2015]. In addition, the energy transition can be described as a particularly significant series of changes in the way society uses energy, which potentially affects its sources, carriers, processing and related services [O'Connor, 2010]. It is pointed out that since the beginning of the industrial revolution, there have been several energy transitions, some of which are still in progress. The first major energy transition was to replace the limitations of the local availability of conventional renewable sources (i.e. biomass in the form of wood) with commonly available fossil fuels, which have become the object of international trade. A natural increase in energy demand along with the concentration of energy demand in urban areas led to further transitions in energy supply. In their case, the change consisted in replacing the direct use of fossil fuels (especially coal) with cleaner, versatile sources of energy from the grid (natural gas and electricity). These transformations are part of a long-term transition towards a more efficient and cleaner energy supply and its use by end-users. At the same time, according to experts, these changes will be continued, albeit with varying intensity in different regions [Grubler, 2015]. However, the study of the current energy transition and the discussion about its problems should take into account the fact that energy transitions were in the past fundamentally rare phenomena, whose long and complex processes developed over decades or even centuries. It means that the acquisition of quantitative and qualitative data necessary to study the energy transition should not be limited to the experience of the recent past. In addition, discovering the regularities in energy transitions within a given country (economy) not between countries (economies) may require an analysis of events over several hundred years [Fouquet, Pearson, 2012]. Melosi [2010] states that the concept of energy transition is based on the notion that a given source or group of energy sources dominates the market during a specific period to eventually be replaced (dominated) by another leading energy source or sources. Smil [2010] even sets a specific level in his definition of the energy transition, claiming that the energy transition refers to the time it takes for a new energy source to achieve a 25% market share on a global or local scale. Similarly, Grubler [2012], who argues that great transitions occur when the market level achieved by a specific source or sources comes up to at least 50%.

2. Technological determinants of energy transitions. A historical approach

The determinants of energy policy, the emanation of which is the shape of the energy mix of a given economy or region, can be considered within the framework of the so-called energy trilemma, where aspects of security, economics and the natural environment and climate are determinants of such a policy. In such an approach, technology (technological progress) can be considered as a moderator of these determinants. The global level of demand for primary energy has been characterised since the second half of the nineteenth century, i.e. since the advent of the industrial revolution, by accelerating dynamics, which since the mid-twentieth century has been exponential dynamics. Estimates of such a consumption increased from about 30 EJ in 1850 to about 50 EJ in the early twentieth century, reaching a level of about 100 EJ in 1950.[1] Since then, i.e. the decade during which inventions and achievements, like a nuclear bomb, jet aircraft, radar, transistors, intercontinental missiles, guided missiles, synthetic oils, mass production of aircraft and tanks, invisible submarine technology, production of plastic, nylon or synthetic fibers and rubber have been created or developed [Galen et al., 2007] To date, estimates of global primary energy consumption have increased several times, to almost 600 EJ. Such an illustrative comparison of the increase in global primary energy consumption with technological development and technological and civilisational progress enables the identification of their coincidence and the said moderating role of technology, because the aspects of security, economics, environment and climate that determine energy policy within the trilemma are subject to limitation or intensification depending on technological readiness (or lack thereof). It is the technological readiness that determines what spectrum of choices between the priorities of the three poles of the energy trilemma is *de facto* available, because it is impossible to shape the energy policy in such a way that it is technologically infeasible.

---

[1] 1 EJ (exajoule) is a unit of energy corresponding to a value of 10^{18} joules. Estimated figures are based on Galen et al. [2007] and data at Our World in Data.

3. Technological determinants of the current energy transition

Trends in global energy consumption suggest that energy transitions are causing energy demand to increase, while the share of a given leading fuel is declining (wood for coal, coal for oil, oil for natural gas), the absolute volumes of consumption of these fuels are increasing, albeit more slowly than for newer energy sources [Fouquet, 2009]. It should be noted that, according to some experts, if the historical trend continues in the future, initiatives for the ongoing energy transition towards zero-emission energy do not guarantee a global decrease in fossil fuel consumption. In this context, there are also postulates that such a transition may simply increase energy consumption. It is also made more likely by the fact that there are large economies with a very low per capita energy consumption (especially India), which naturally implies a significant growth potential for the global energy consumption. Especially, that often the coincidence of the increase in global primary energy consumption with technological development and civilisational (socio-economic) progress is identified with its interdependence with economic growth [Li, Solaymani, 2021].

However, the Net Zero Emissions scenario developed by the International Energy Agency (IEA) assumes that the global GDP will grow by about 40% between 2020 and 2030, but total energy production will fall by about 7%. The reason for this is to be the electrification of end-users, more efficient technologies and behavioural changes that will enable "disconnecting economic growth from energy consumption" [IEA, 2021, p. 111]. Such a postulate seems to touch on one of the most important aspects of the current energy transition – energy efficiency. While energy transitions are not new socio-economic phenomena, the technical (technological) possibility of separating the effects of civilisational development from the increase in energy demand is a kind of novelty. This possibility results not only from the transformation of the ways of energy production, but also from the transformation of the ways in which it is used. It should be stressed that expert forecasts on the possibility of decoupling economic growth are already confirmed by trends observed in some economies, especially in Sweden [Ritchie, 2021]. At the same time, the disconnection of both these phenomena is not and will not only be the result of technological readiness but will also require significant behavioural changes of an efficiency nature among energy users. According to IEA forecasts, part of the decarbonisation of economies should be caused by such changes, among which the most important potential lies in the broadly understood transport sector, but also in other areas such as construction and housing [IEA, 2021].[2]

Returning to the technological determinants of disconnecting economic growth from the increase in energy consumption, the electrification of end-users should be a key issue. Electrification results in a significant improvement in energy efficiency understood as reducing primary energy losses observed in the case of technologies based on fossil fuels. However, the electrification expected under the current energy transition is not only about electrifying end-users (which is of course an efficiency direction), but also about basing the power industry on renewable rather than fossil energy sources (which increases the efficiency of primary energy use already at the stage of energy production). In this context, the key challenge is the technological ability to, *sensu largo*, store energy. From the economic point of view, of course, it should not be an objective to overcome the insurmountable limitations of the laws of physics in terms of the possibility of storing kinetic energy, but to overcome technological barriers to the storage of potential energy (especially chemical energy through batteries) and the acquisition and storage of unconventional energy carriers (especially green hydrogen). In addition to batteries and green hydrogen, obtained through electrolysis using renewable energy, there are, of course, other initiatives involving the storage of potential energy and the acquisition and storage of unconventional energy carriers. Examples to be quoted here may be, respectively, innovative, intelligent gravitational energy storage systems and the so-called pink hydrogen obtained when using nuclear energy. Other directions of obtaining hydrogen are also being undertaken (e.g. blue hydrogen obtained in the process of electrolysis using conventional energy from fossil fuels while capturing emissions that are associated with it). Energy storage is a key direction as it complements the technological advances associated with the production of energy from renewable sources. In addition, it is a partial mitigant of the challenges that arise in terms of the efficient transmission of electricity produced by renewable energy sources, which are characterised by natural instability.

In the past decade, significant technological progress was observed in the production of energy from renewable sources, which resulted in a significant reduction in the cost of generating such energy and an actual possibility of transformation of economies in the currently observed zero-emission direction. Expert estimates indicate that in the period 2010–2020, the

---

[2] The initiatives set up by the IEA to bring about behavioural changes towards energy efficiency include, e.g. restrictions on entry for vehicles with internal combustion engines to large cities, reduction of permissible speeds on motorways, limitations on the number of long-haul flights, or lowering the recommended space heating temperatures to 19–20 °C.

cost of generating a unit of electricity from solar energy in photovoltaic technology decreased by almost 85% (from \$0.38 to \$0.06 per kWh),[3] and in CSP technology, it fell by 68% (from \$0.34 to \$0.11 per kWh).[4] And the cost of generating a unit of electricity from wind power fell by about half for this period (from \$0.09 to \$0.04 per kWh in onshore wind farms and from \$0.16 to \$0.08 per kWh in offshore wind farms) [IRENA, 2021]. Such economic conditions significantly broaden the spectrum of choices within the other two poles of the energy trilemma – security and the natural environment and climate.

Conclusions

Over the past two centuries, there has been a significant, about twenty-fold increase in global primary energy consumption. This growth is determined by technological and socio-economic progress, but it also determines this progress. By operationalising such a relationship, it can be simply stated that the increase in global primary energy consumption is interdependent from economic growth. Historical trends in energy consumption suggesting that energy transitions cause an increase in energy demand may be broken as a result of the current energy transition and the technological advances that make it possible. This can consequently disconnect energy consumption from socio-economic development and enable the targeted sustainability and reduction of energy consumption. However, it should be emphasised that it is a possibility, not a guaranteed direction that does not require a specific effort of humanity, also at the technical (technological) level. According to experts, to finance the current technologically intensive energy transition, investments worth \$1–2 trillion will be needed each year for the next 30 years. Some even point to annual amounts of \$2–4 trillion by 2050 [Shell, 2021]. For comparison, the annual gross domestic product of the Netherlands is about \$1 trillion, and Poland’s about \$1.3 trillion. This shows a huge scale of financing needed to carry out the energy transition in accordance with the adopted civilisational ambitions in the form of net zero-emission goals of economies and societies.[5]

References

Fouquet, R. (2009). A brief history of energy. W: *International Handbook of the Economics of Energy*, J. Evans, L.C. Hunt (red.). Edward Elgar Publications.

---

[3] In terms of the so-called levelised cost of electricity (LCOE).

[4] Technology of generating electricity using solar thermal energy collectors (concentrated solar power, CSP).

[5] Based on World Bank data for 2020 (gross domestic product in terms of purchasing power parity in international dollars).

Fouquet, R., Pearson, P.J. (2012). Past and prospective energy transitions: Insights from history, *Energy Policy*, 50, 1–7. DOI: 10.1016/j.enpol.2012.08.014.

Galen, J.S., Truman, S.S. (2007). *The History of Energy. Academic Press*. DOI: 10.1016/B978-012370602-7/50019-3.

Grubler, A. (2012). Grand Designs: historical patterns and future scenarios of energy technological change. Historical case studies of energy technology innovation (Chapter 24). W: *The Global Energy Assessment*, A. Grubler, F. Aguayo, K.S. Gallagher et al. (ed.). Cambridge: University Press.

Grubler, A. (2015). Energy transition. W: *The Dictionary of Energ y*(Chapter E), C.J. Cleveland, C. Morris (red.). Elsevier.

Hirsh, R.F., Jones, C.F. (2014). History's contributions to energy research and policy, *Energy Research & Social Science,* 1, pp. 106–111. DOI: 10.1016/j.erss.2014.02.010.

IEA (2021). *World Energy Outlook*. Paris: International Energy Agency.

IRENA (2021). *Renewable Power Generation Costs in 2020*. Abu Dhabi: International Renewable Energy Agency.

Li, Y., Solaymani, S. (2021). Energy consumption, technology innovation and economic growth nexuses in Malaysian, *Energy*, 232, 121040. DOI: 10.1016/j.energy.2021.121040.

Melosi, M. (2010). Energy transitions in historical perspective. W: *The Energy Reader*, L. Nader (ed.). Blackwell: Wiley.

Miller, C.A., Richter, J., O'Leary, J. (2015). Socio-energy systems design: A policy framework for energy transitions, *Energy Research & Social Science*, 6, pp. 29–40. DOI: 10.1016/j.erss.2014.11.004.

O'Connor, P.A. (2010). Energy Transitions, *The Pardee Papers*, 12.

Ritchie, H. (2021). *A number of countries have decoupled economic growth from energy use, even if we take off shored production into account*, https://ourworldindata.org/energy-gdp-decoupling.

Ritchie, H., Roser, M. (2020, November 28). *Fossil Fuels*, https://ourworldindata.org/fossil-fuels.

Shell (2021). *The world and 1.5C: what will it take to finance the drive to a net-zero future? The Shell Energy Podcast*.

Smil, V. (2010). *Energy Myths and Realities: Bringing Science to the Energy Policy Debate First Edition*. AEI Press.

Hanna Bartosiewicz-Burczy
IEN Warsaw

Filip Schraube
Enea Operator

Chapter X

Technical and regulatory approaches to enhance the renewable energy capabilities to take part actively in the electricity services markets – DRES2Market

Abstract

The transition of energy sector towards more sustainable electric energy production increases the importance of distributed generation from renewable sources (RES), including photovoltaics (PV) and wind energy. A high integration of PV and onshore wind energy into the EU distribution grid is a key to a successful energy transition. Despite the achievement of significant progress in the regulations of the use of energy from renewable sources, especially the implementation of the RED II Directive, the development of photovoltaics and onshore wind energy is slowed down by a number of formal restrictions existing in the European Union countries. These are various types of market, regulatory, administrative, technological and social barriers.

The aim of this chapter is to discuss the main barriers inhibiting the development of distributed generation from renewable sources, such as photovoltaics and wind energy, in order to increase their share in the electric energy market of the EU countries. There are regulatory, technological, administrative, financial, social and environmental barriers, which inhibit the integration of a large number of PV and onshore wind energy sources into the distribution network in some European Union countries.

The authors present the results of work done within the project on the impact of a large amount of photovoltaic and onshore wind energy on the operation of the distribution grid as well as the grid limitations.

The presentation and text are based on the work carried out as part of the European Commission's project in the H2020 Programme: DRES2Market: Technical, business, and regulatory approaches to enhance renewable energy capabilities to take part actively in the electricity and ancillary services markets. Grant number: 952851.

Keywords: photovoltaics, wind energy, energy market, barriers to the development of PV and wind energy, grid limitations, flow analysis, energy storage, simulations

Introduction

Moving away from fossil fuels and developing renewable energy for a safer, more competitive and sustainable European energy system is one of the biggest challenges facing the European Union countries.

As a result of actions taken by the European Union, the use of energy from renewable sources, especially photovoltaic energy, has increased in all member state countries. The regulations of the European Commission and national legislations as well as significant technological progress have contributed to this. As a result, in most European Union countries we observe a steady increase in obtaining energy from photovoltaic installations and a rapid increase in the capacity installed in RES.

Despite significant progress in the field of RES regulation, especially the implementation of the "RED II" Directive, the development of photovoltaics and onshore wind energy is slowed down by many formal restrictions existing in the European Union countries. These are various types of market, regulatory, administrative, technical and social barriers.

1. Barriers to the development of renewable sources of energy

There are many market, regulatory, technical, administrative, financial and social barriers that contribute to a slowdown in the development of photovoltaic and onshore wind energy sectors in the European Union countries.

A proper design and implementation of each investment working in the grid system requires meeting many formal and legal requirements related to the functioning of other energy market users.

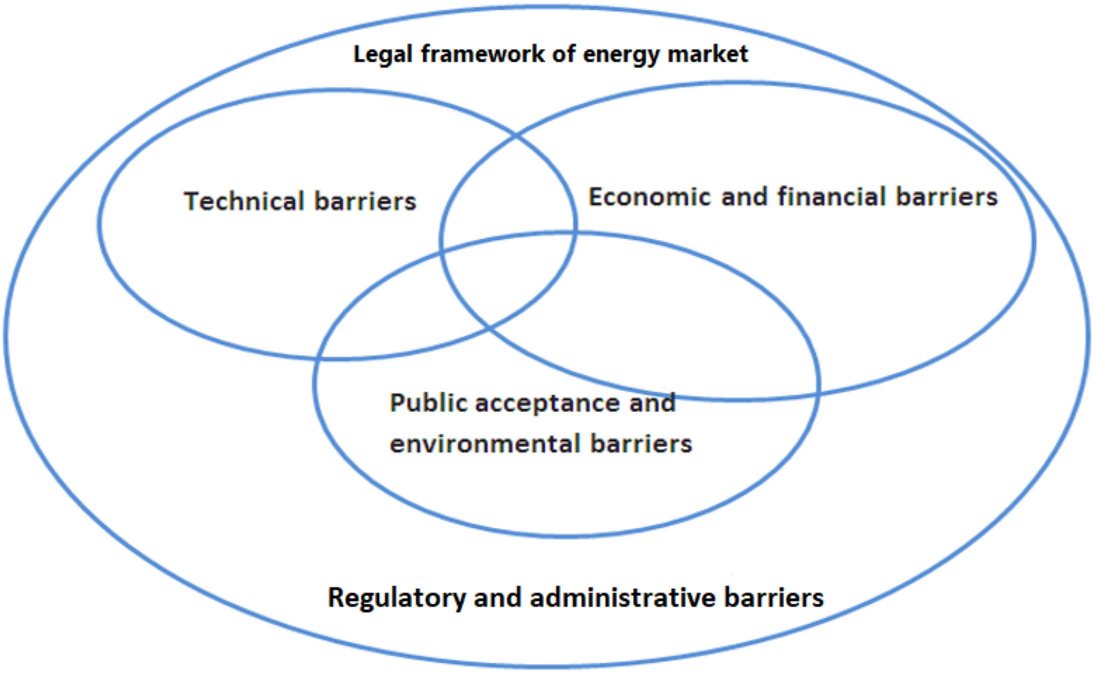
We can distinguish the following main categories of barriers that are related to the operation and organisation of the energy market [Felsmann, Vékony, 2021]:

- regulatory barriers – result from the general regulatory framework of the retail and wholesale electricity market. They refer to the impact of price regulation, regulatory burdens (grid charges, taxes), regulatory unpredictability and access to innovation. Uncertainty about the future direction of the regulatory framework, changes in digitisation and new technologies, as well as environmental obligations and generation capacity, slow down the development of photovoltaics and onshore wind energy;
- energy market architecture barriers – result from the entity and ownership structure of energy companies on the market. The dominance of large, vertically centralised energy

companies may lead to a competitive advantage for these market players and an unequal playing field for other market participants. If market rules do not regulate this, they can use their market power to treat other market participants in a discriminatory manner, restricting access to information, discouraging new entrants from investing and participating in the market;

- operational and procedural barriers – result from differences in national/regional standards and procedures, concerning, for example, procedures related to connecting photovoltaic installations to the distribution system and medium voltage lines and to the 110 kV grid. The lack of developed procedures hinders and prolongs the entry of new entities into the energy market and activities on it;
- unequal access to innovation, innovative pilot projects launched on the market and information on the development of innovative products.

Figure 1. Identification of barriers to the development of photovoltaics and onshore wind energy



Source: OECD, IEA, 2011.

Regulatory and legal stability is crucial for all investments in renewable energy sources. The complexity of regulatory and administrative procedures as well as the scope and stability of support for the development of renewable energy affect the attractiveness of these investments.

Regulatory and administrative requirements for new installations may limit the possibilities for expansion of these sources in many European countries. Frequent legal changes cause difficulties in the interpretation of provisions and increase the risk when implementing long-term development strategies.

In addition to support in the form of a stable regulatory framework, an important role is played by the possibility of obtaining financial support, including the possibility of obtaining credit funds for the construction of new installations.

The main obstacles delaying the development of photovoltaics and onshore wind energy in European countries related to administrative and legal procedures are:

- variability of legal regulations, including changes in the basic mechanisms of support for photovoltaic installations;
- uncertainty about the future shape of the market;
- interpretative ambiguities related to the newly introduced regulations;
- insufficient spatial planning, delays and limitations in planning or insufficient integration of RES in spatial planning;
- environmental permits and related issues, mainly the time taken by administrative formalities;
- long time taken by permit granting process for connection to the grid.

Administrative requirements and related legal procedures have a major impact on the sustainable development of photovoltaics and wind energy in many European Union countries. Most of the Union member countries have set maximum deadlines for permit granting procedures, as well as simplified procedures for micro-installations, including the possibility to submit applications online. However, bureaucracy and lengthy administrative procedures, both on the part of the authorities and grid operators, continue to be the main barriers to the rapid implementation of new installations in many EU countries, e.g. Poland, France, Spain and Greece.

Regulatory instability causes uncertainty for investors as to the conditions of support in the coming years and the level of current costs of their operations.

In France, the most significant administrative obstacle is the length of time it takes to install photovoltaic systems. The procedures take up to several dozen weeks depending on the location of the installation (whether for residential buildings or above-ground facilities), between the start of the project and the introduction of the first kilowatt hour into the grid. This period may be extended to approximately four years due to additional procedures for connecting the installation to the grid. Public consultation is required for any above-ground photovoltaic power plant with a capacity of more than 250 kWp (Articles L123-1 to L123-2 of Code de l'Environnement). Urban planning permits may also extend the deadlines given[1].

Regulatory barriers are currently key barriers to the development of RES despite the actions being introduced at the European, national and local levels.

1.1. Technological barriers

In most European countries, there is technical potential and infrastructure for the development of photovoltaics and onshore wind energy. The state of the electricity grid infrastructure is not perceived as a barrier to their growth, but the barrier is the grid capacity.

Photovoltaic and wind systems are already so well developed that there are basically no technological barriers to the systems themselves, and the limitations relate primarily to the integration of these systems into the local grid. The technical condition of distribution networks and infrastructure limitations are the basic factors determining the development potential of photovoltaics and onshore wind energy, and network capacity limitations may affect both the output power and the technical design of new installations.

In many countries, difficulties in obtaining conditions for connection to the grid result from the lack of adequate distribution infrastructure, including overloading of power grids.

The basic factors determining the development potential of photovoltaics and onshore wind energy include:

- technical condition of distribution networks;
- limited number of energy storage units;
- insufficient growth rate of smart grids and meters;
- limited capacity of cross-border connections.

The development of smart grids in all European Union countries will allow for optimal use of distributed energy systems, reducing network load, minimising power failures and emergency threats.

---

[1] Barriers to large scale integration of renewable energies on the electricity and ancillary services markets. Deliverable D2.3. 2021. Technical, business, and regulatory approaches to enhance renewable energy capabilities to take part actively in the electricity and ancillary services markets. Horizon 2020-LC – SC3 – 2020 – RES-IA-CSA. July 2021.

Currently, technical barriers are not the dominant group. PV technologies on a small and medium scale enable reliable and trouble-free operation of devices with fairly high efficiency.

1.2. Economic barriers

Relatively high initial costs of PV and onshore wind installations, long payback times, as well as insufficient fiscal mechanisms constitute an economic barrier to new installations.

Financial limitations, a high cost of obtaining a loan or lack of creditworthiness limit the development of photovoltaics and onshore wind energy. Capital limitations occur mainly in the case of micro-installations and small and medium-sized enterprises. Prosumers cannot always cover the investment costs from their savings, they may also have problems with showing a sufficiently high own contribution to apply for an investment loan. Currently, a rising inflation and a higher cost of obtaining a loan or lack of creditworthiness also significantly limit the investment opportunities of prosumers.

In 2015, the Consumer Federation conducted a survey on a sample of 1,597 consumers [Consumer Federation, 2016]. The research shows that the biggest barrier to installing RES in Poland was the financial barrier, i.e. high installation costs , which was indicated by over 70% of respondents. Other important barriers were: a long payback period, lack of information about the operating conditions of the PV system, problems with reaching information, lack of co-financing of the investment.

The results of the Consumer Federation's survey was confirmed by a survey conducted on a sample of 2,000 households from Lower Silesia [Ropuszyńska-Surma, Węglarz, 2017]. The majority of respondents (52.9%) indicated economic factors as the main barrier, i.e. the lack of financial resources to implement the investment.

Also, a survey conducted in Norway on photovoltaics indicated that for 34.6% of respondents, a high cost of installation, as well as limited financial support, were the main barrier [Yan, Lindkvist, Temeljotov-Salaj, 2021].

It should be emphasised that the policy of the European Union and member states has unequivocally supported projects in the field of building renewable energy sources. In order to increase the number of recipients willing to take their interest in prosumer activities, various types of incentives, subsidies, low-interest loans were introduced, which shortened the payback period.

1.3. Social and environmental barriers

At present, the most important and difficult problem on a global scale and in Poland is to stop climate change of the earth by reducing CO_2 emissions, which in recent decades have been growing rapidly.

The level of investment in renewable energy sources is directly influenced not only by political, legal, economic or technological determinants, but also by social factors, ecological and energy awareness of society, attitude to energy saving and ecological development.

The attitude of societies to photovoltaics is created by the ecological and renewable nature of this form of energy, i.e. clean energy, the use of which in the local and global dimension brings a number of social and environmental benefits. Photovoltaic systems are environmentally friendly, do not emit gases into the atmosphere, noise, vibrations, do not adversely affect the landscape. Photovoltaic systems are also perceived by societies as more environmentally friendly than wind farms.

PV investments are generally accepted by local communities, and social protests related to planned investments are rare.

Public acceptance of wind energy is a potential barrier to faster expansion of onshore wind energy, despite significant technological advances reducing the negative environmental impact of wind farms. In most European Union countries, wind farm projects are accompanied by strong local protests. There is also a lot of public opposition to the development of energy infrastructure and transmission lines in most European Union countries.

The European Union has adopted ambitious and binding targets for reducing greenhouse gas emissions, transforming energy systems and achieving climate neutrality. Moving away from fossil fuels and developing renewable energy, including photovoltaics and onshore wind energy, towards a safer, more competitive and sustainable development of the European energy system is one of the biggest challenges facing the European Union countries.

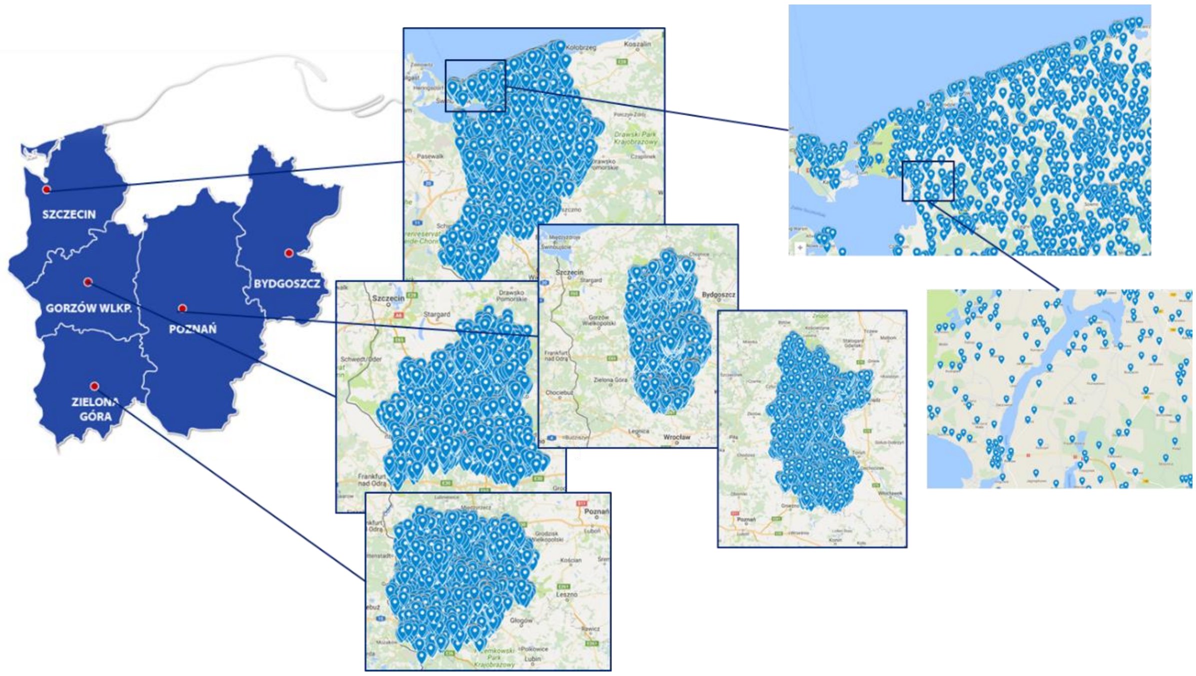
Photovoltaics and wind energy are the key to achieving the assumed environmental and energy goals, aimed at the sustainable development of the European Union countries, ensuring an energy-efficient model of energy management, and significantly contributing to the reduction of CO_2 emissions, and to increasing energy security.

Photovoltaics and wind energy are an opportunity for societies to actively participate in the energy market, the opportunity to use technological progress to improve the quality of life, environmental protection and energy security. An incentive to build a PV and wind installation may be a possibility of partial independence from the electricity supplier, reducing interruptions in energy supply, minimising transmission losses, as well as reducing the cost of purchasing electricity from the grid.

2. Company infrastructure

Enea Operator Sp. z o.o. covers the area of north-western Poland of nearly 60,000 km^2. With the help of over 120,000 km of power lines and over 38,500 transformer-distribution stations (Figure 2), it supplies at least 20 TWh of electricity to 2.7 million consumers of distribution services.

Figure 2. MV/LV transformer substations in the company area of operation



Source: Authors’ own material.

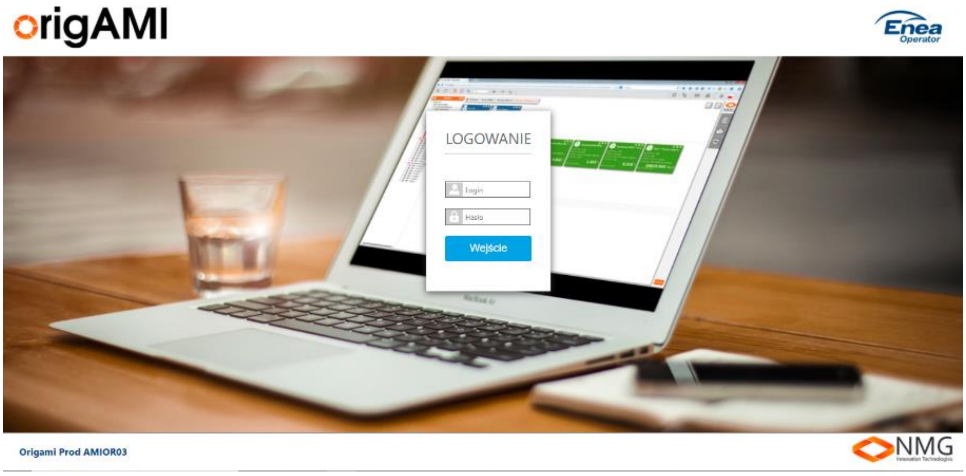
Nearly 98% of MV/LV balancing substations are equipped with remote reading meters, the so-called AMI (Advanced Metering Infrastructure – Figure 3).

Figure 3. An AMI meter with installation at MV/LV substations

Source: Authors’ own material.

Aggregation and analysis of data in the OrigAMI system (Figure 4) enables viewing the network parameters in a mode close to *real-time.* The system allows for an easier control of the process of settling end users and implementation of a number of technical algorithms such as: algorithm for selecting the tap switch, transformer selection algorithm, aggregate selection algorithm, optimal substation shutdown algorithm, etc.

Figure 4. OrigAMI login interface

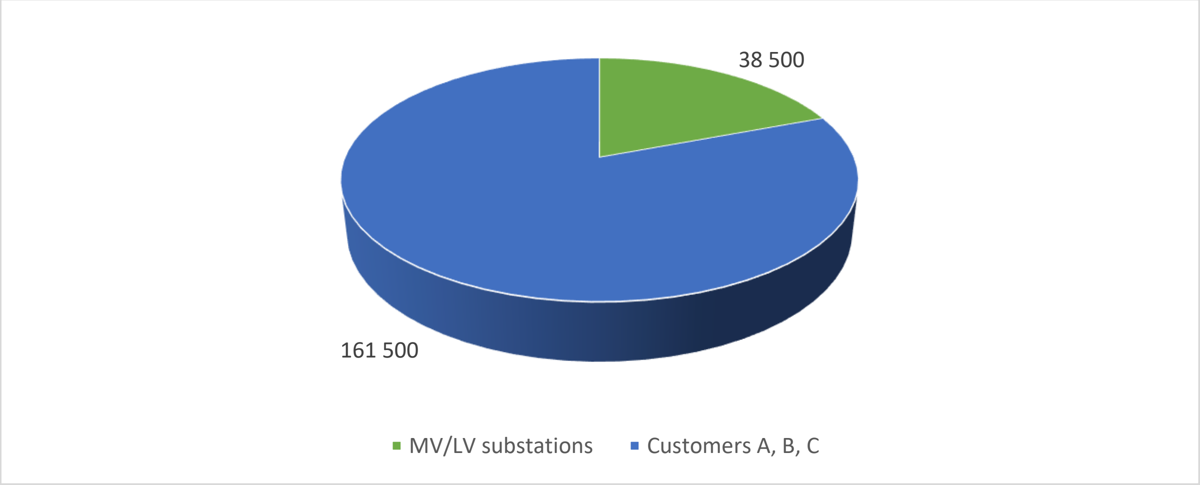


Source: Authors’ own material.

According to the amendment to the Energy Law of 3 July 2021, the company is obliged to install AMI meters at customers up to 1 kV according to the following schedule:

Currently, the best equipped group of customers with remote reading meters are customers in tariff groups A, B, C and prosumers in tariff group G (Figure 5).

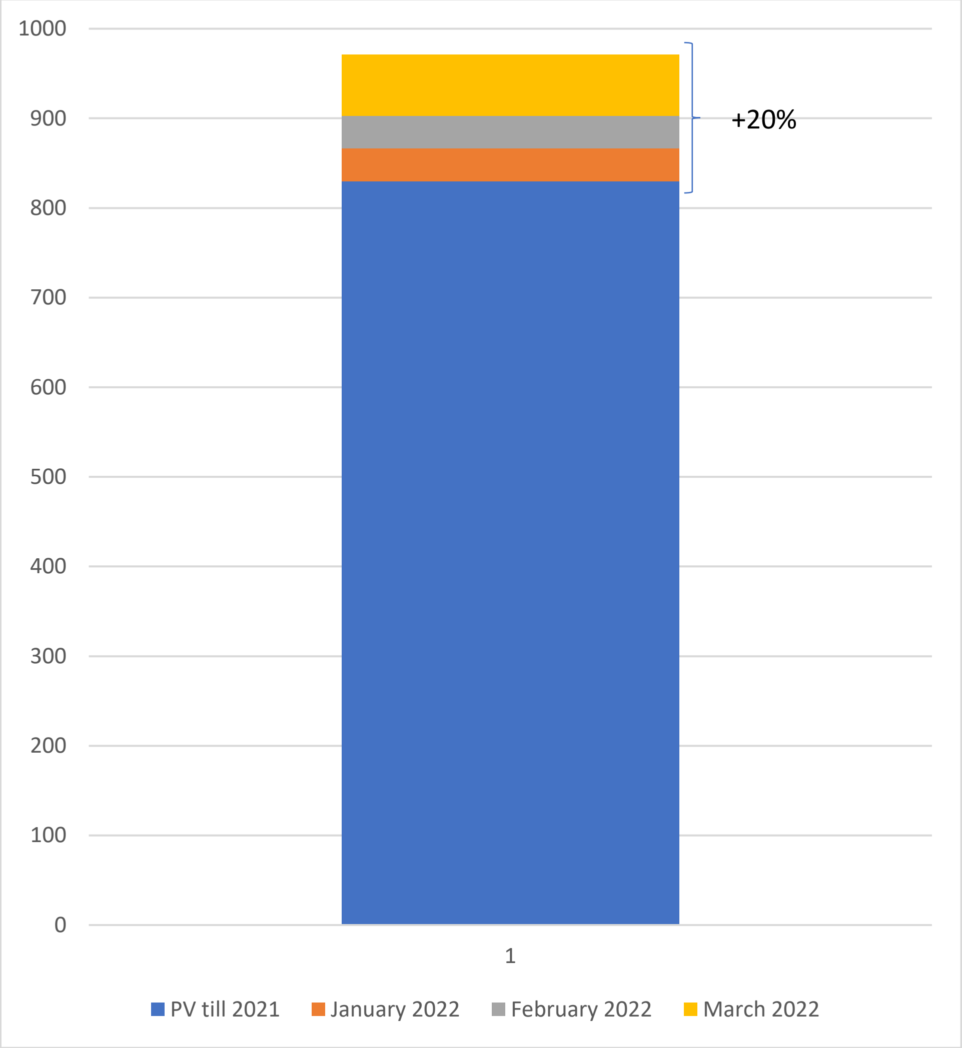
Figure 5. Distribution of installed AMI meters



Source: Authors’ own material.

Some of the biggest challenges faced by the Distribution Network Operator is an unprecedented pace of development of distributed energy resources installations in the medium and low voltage networks. As of 31 March 2022, Enea Operator had 124 849 micro-installations with a total capacity of over 970 MW (Figure 6). This capacity is slightly lower than the largest power unit in Poland, owned by Enea Wytwarzanie, i.e. the coal-fired power plant in Kozienice.

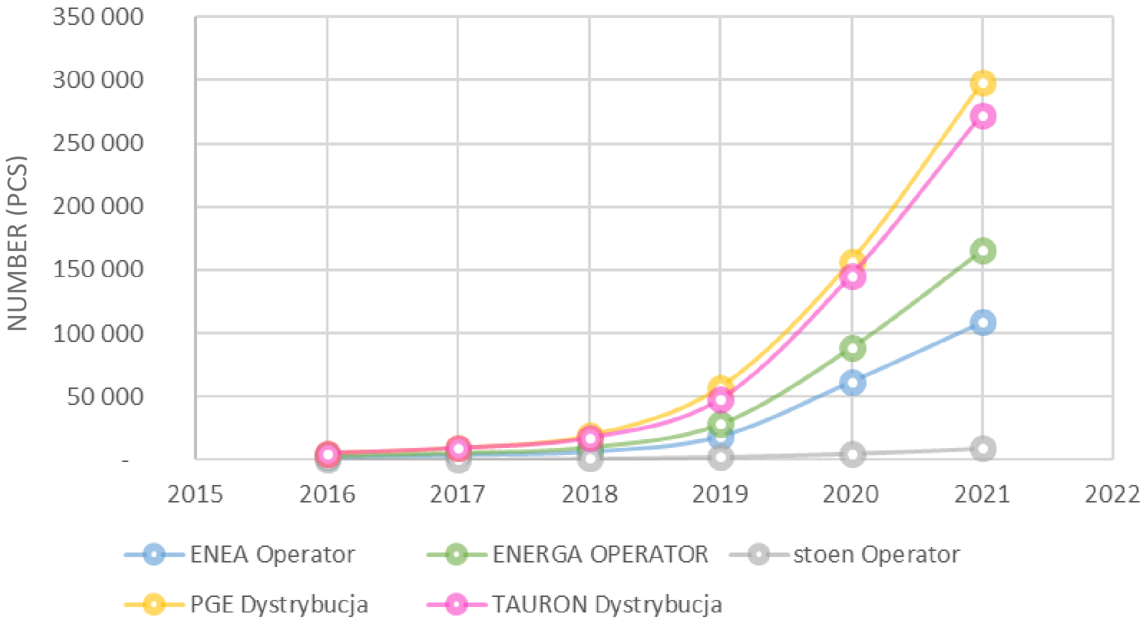
Figure 6. Installed capacity [MW] of RES in the Enea Operator network



Source: Authors’ own material.

The issue of a significant increase in micro-installations in Enea Operator’s distribution networks is not an isolated case. This trend is also maintained throughout Poland and even Europe. The average percentage growth of micro-installations in Poland compared to the level of 2016 amounted to 5,127% (Figure 7).

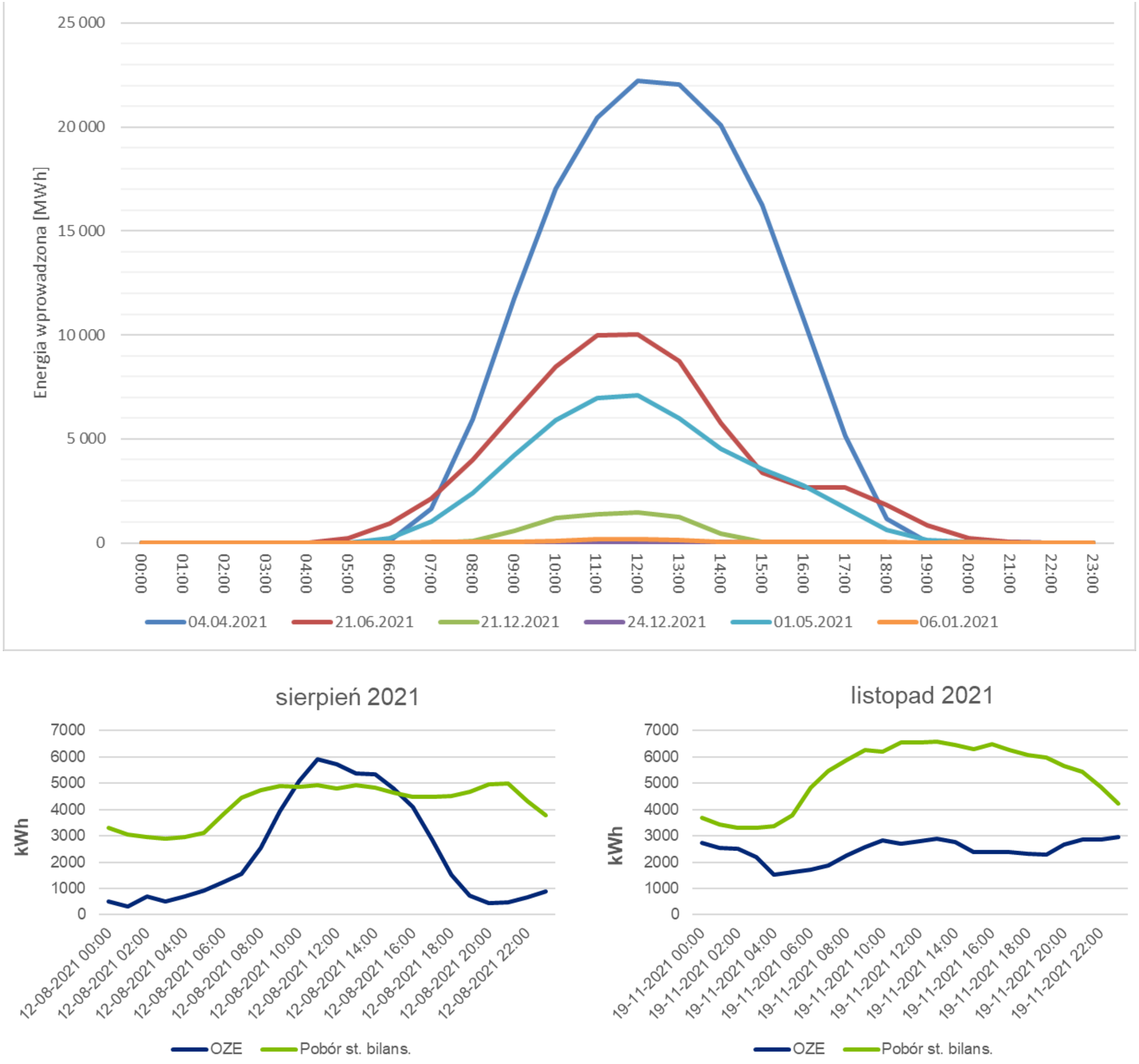
Figure 7. Growth (in numbers) of micro-installations connected to the DSO network in 2016–2021



Source: ENEA, 2022.

The number of connected prosumer sources, and consequently their power, causes significant balance differences in electric energy along with the co-occurring reverse flow of electricity from the low-voltage networks to the medium-voltage networks, and sometimes even to the highest voltage networks. Indeed, a noticeable difference in energy exported to the grid by micro-producers is definitely cyclical in nature daily and seasonal. Consequently, in the extreme case of the sunny summer south, production from photovoltaic sources is maximum and electricity consumption by end users is minimal (Figure 8). This results in balance differences, which directly translate into qualitative parameters of electricity, such as voltage and frequency fluctuations in the network.

Figure 8. Characteristics of energy transferred by micro-installations in the selected days of the year



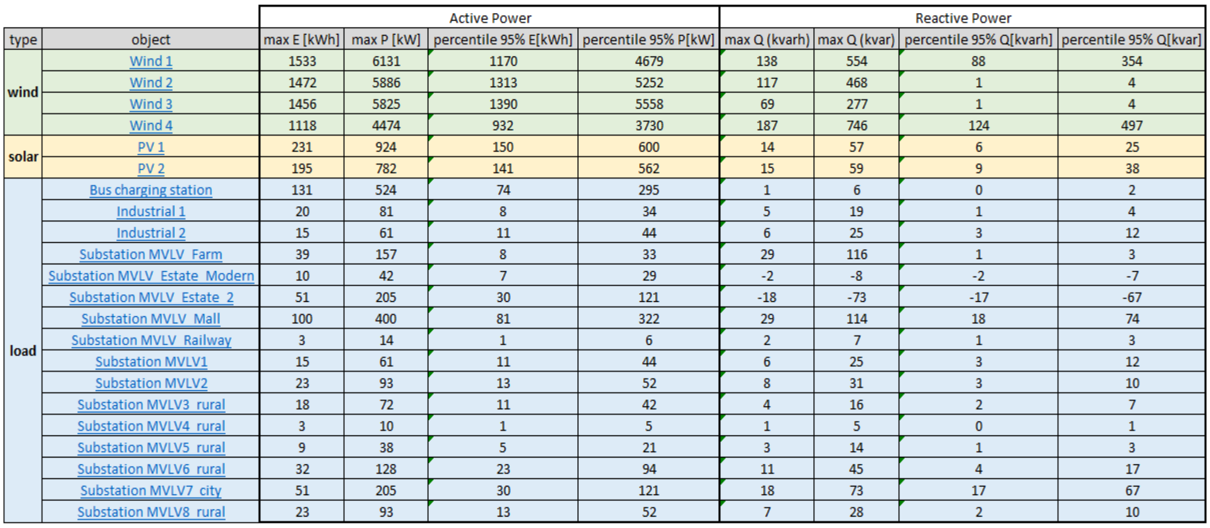
Source: ENEA, 2022.

3. Analysis in PowerFactory (digSilent) – Test Case 1 – Analysing the impact of RES large penetration for grid congestions

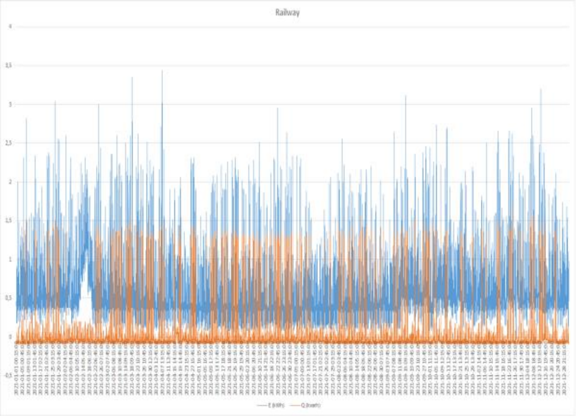
The following factors were used to perform the simulation in PowerFactory,:

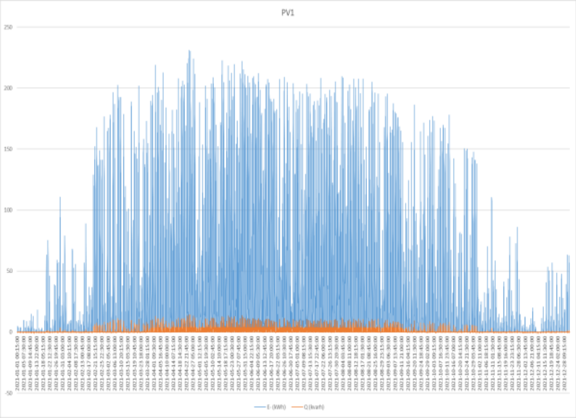
- CIGRE Network,
- OrigAMI Software,
- 15-minute active and reactive energy profiles (Table 1).

Table 1. List of characteristics used for the analysis with examples



type	object	Active Power				Reactive Power			
type	object	max E [kWh]	max P [kW]	percentile 95% E[kWh]	percentile 95% P[kW]	max Q (kvarh)	max Q (kvar)	percentile 95% Q[kvarh]	percentile 95% Q[kvar]
wind	Wind 1	1533	6131	1170	4679	138	554	88	354
	Wind 2	1472	5886	1313	5252	117	468	1	4
	Wind 3	1456	5825	1390	5558	69	277	1	4
	Wind 4	1118	4474	932	3730	187	746	124	497
solar	PV 1	231	924	150	600	14	57	6	25
	PV 2	195	782	141	562	15	59	9	38
load	Bus charging station	131	524	74	295	1	6	0	2
	Industrial 1	20	81	8	34	5	19	1	4
	Industrial 2	15	61	11	44	6	25	3	12
	Substation MVLV Farm	39	157	8	33	29	116	1	3
	Substation MVLV Estate Modern	10	42	7	29	-2	-8	-2	-7
	Substation MVLV Estate 2	51	205	30	121	-18	-73	-17	-67
	Substation MVLV Mall	100	400	81	322	29	114	18	74
	Substation MVLV Railway	3	14	1	6	2	7	1	3
	Substation MVLV1	15	61	11	44	6	25	3	12
	Substation MVLV2	23	93	13	52	8	31	3	10
	Substation MVLV3 rural	18	72	11	42	4	16	2	7
	Substation MVLV4 rural	3	10	1	5	1	5	0	1
	Substation MVLV5 rural	9	38	5	21	3	14	1	3
	Substation MVLV6 rural	32	128	23	94	11	45	4	17
	Substation MVLV7 city	51	205	30	121	18	73	17	67
	Substation MVLV8 rural	23	93	13	52	7	28	2	10



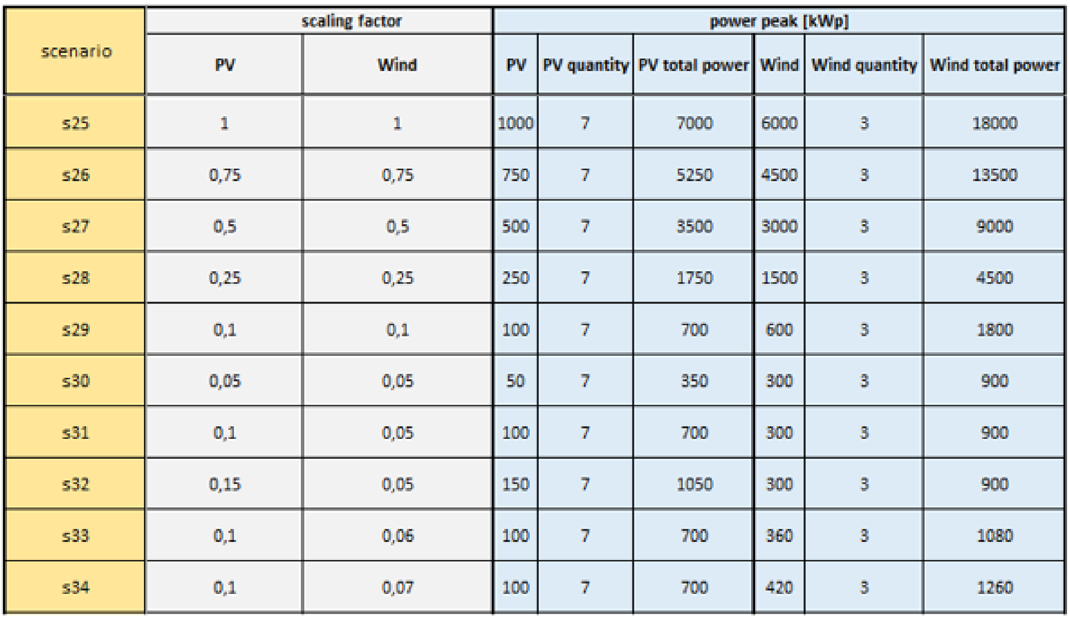


Source: Source: Authors' own material.

The basic assumptions used in the analysis are:

- application of PowerFactory tools: Load Flow Analysis and Quasi Dynamic Simulation;
- use of annual electricity profiles (1 value per 15 min = 35 thousand values per year);
- assuming a rated power of a single PV source at the level of 1,000 kWp, and a wind source at 6,000 kW;
- using the scaling factor parameter to select different scenarios of the amount of installed power of sources;
- concept of multi-scenario analysis – each scenario is built on the basis of different configurations of installed capacity of generated sources (Table 2).

Table 2. Excerpt from the list of scenarios used for scenario analysis

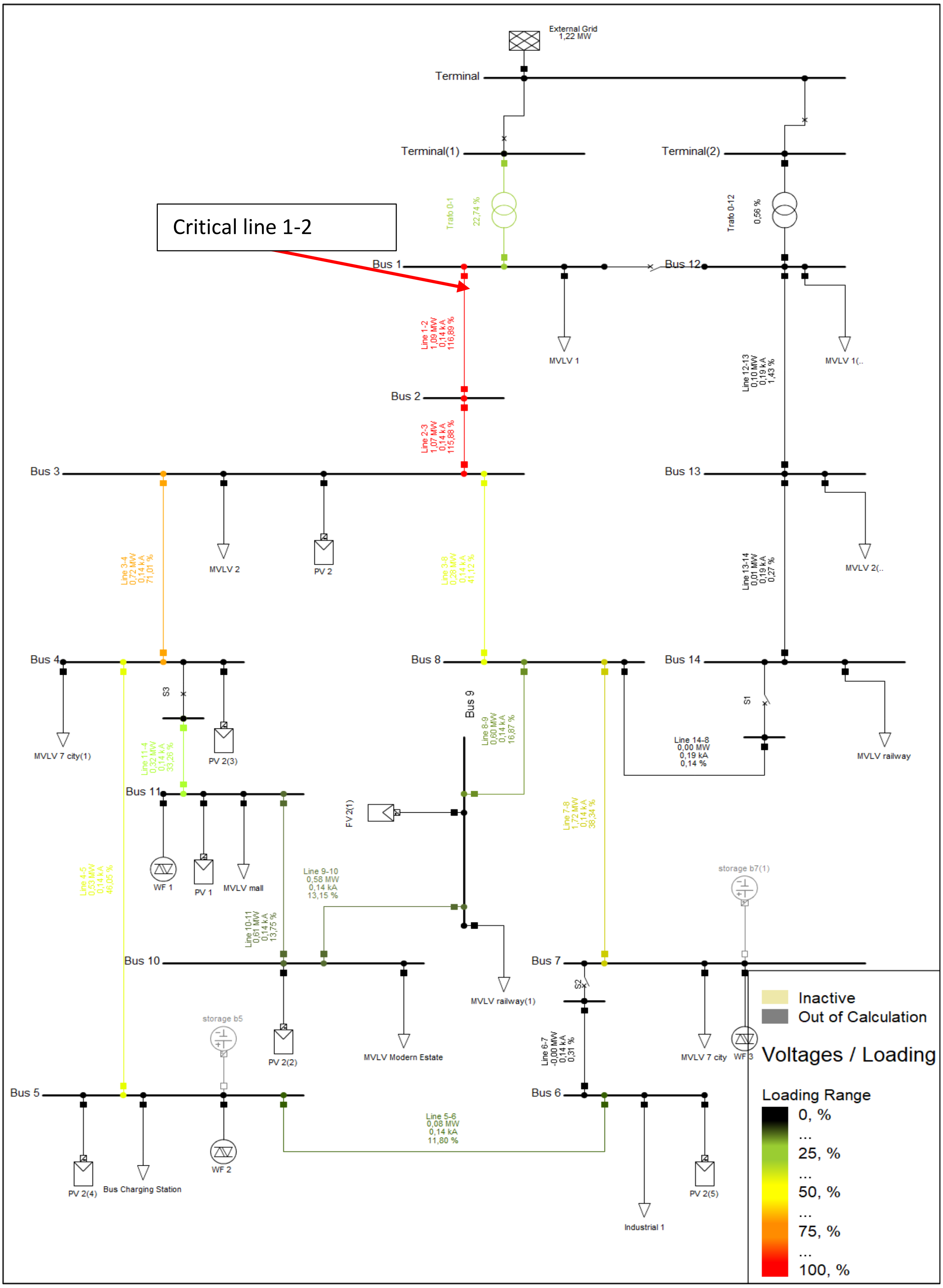


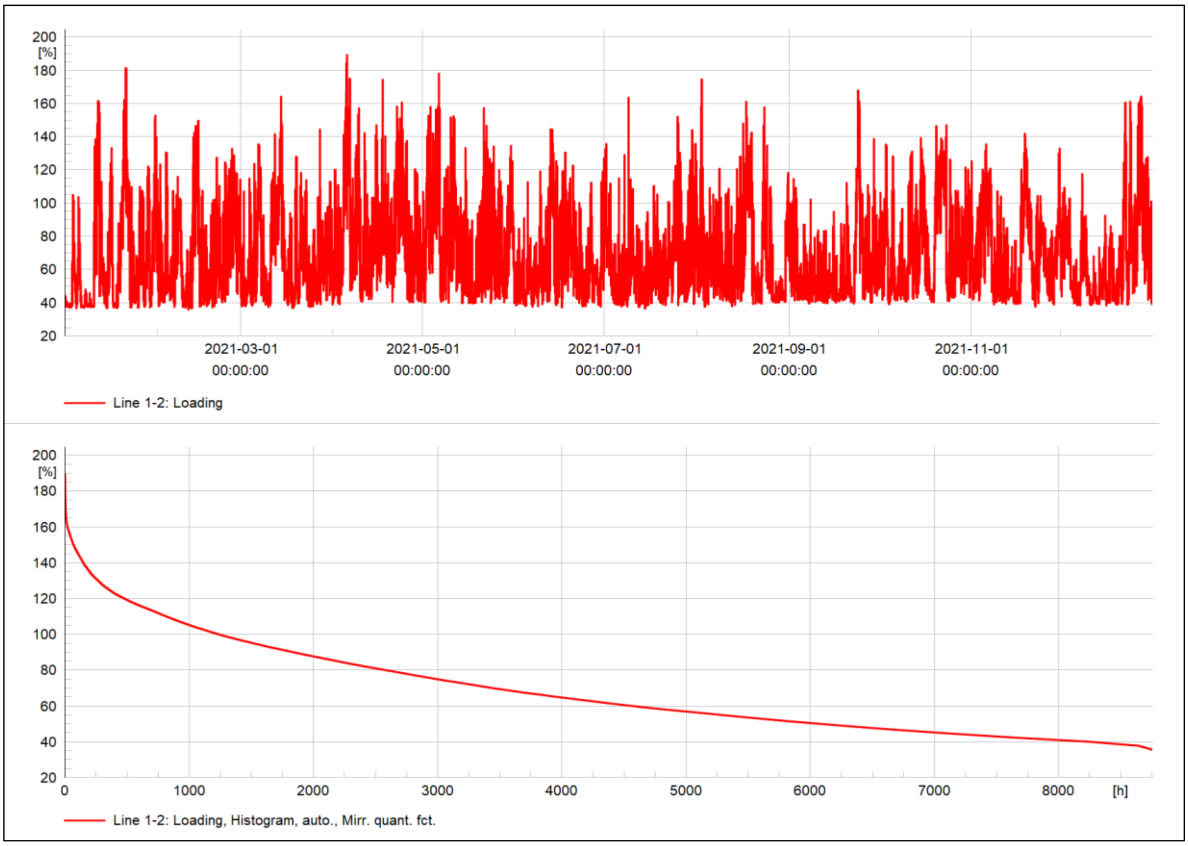
scenario	scaling factor		power peak [kWp]					
	PV	Wind	PV	PV quantity	PV total power	Wind	Wind quantity	Wind total power
s25	1	1	1000	7	7000	6000	3	18000
s26	0,75	0,75	750	7	5250	4500	3	13500
s27	0,5	0,5	500	7	3500	3000	3	9000
s28	0,25	0,25	250	7	1750	1500	3	4500
s29	0,1	0,1	100	7	700	600	3	1800
s30	0,05	0,05	50	7	350	300	3	900
s31	0,1	0,05	100	7	700	300	3	900
s32	0,15	0,05	150	7	1050	300	3	900
s33	0,1	0,06	100	7	700	360	3	1080
s34	0,1	0,07	100	7	700	420	3	1260

Source: Authors' own material.

The main result expected in the analyses is to obtain line loads (%) for each of the programmed scenarios. The load level of 100% should be interpreted as the maximum permissible value for long-term operating current. The topology of the CIGRE network used for the analysis and the distribution of receptions and generation determines that the most loaded line in each scenario is Line 1–2, consequently identified as a critical line from the point of view of the power supply path of this network (Figure 9).

Figure 9. Example of a load distribution view in the PowerFactory programme



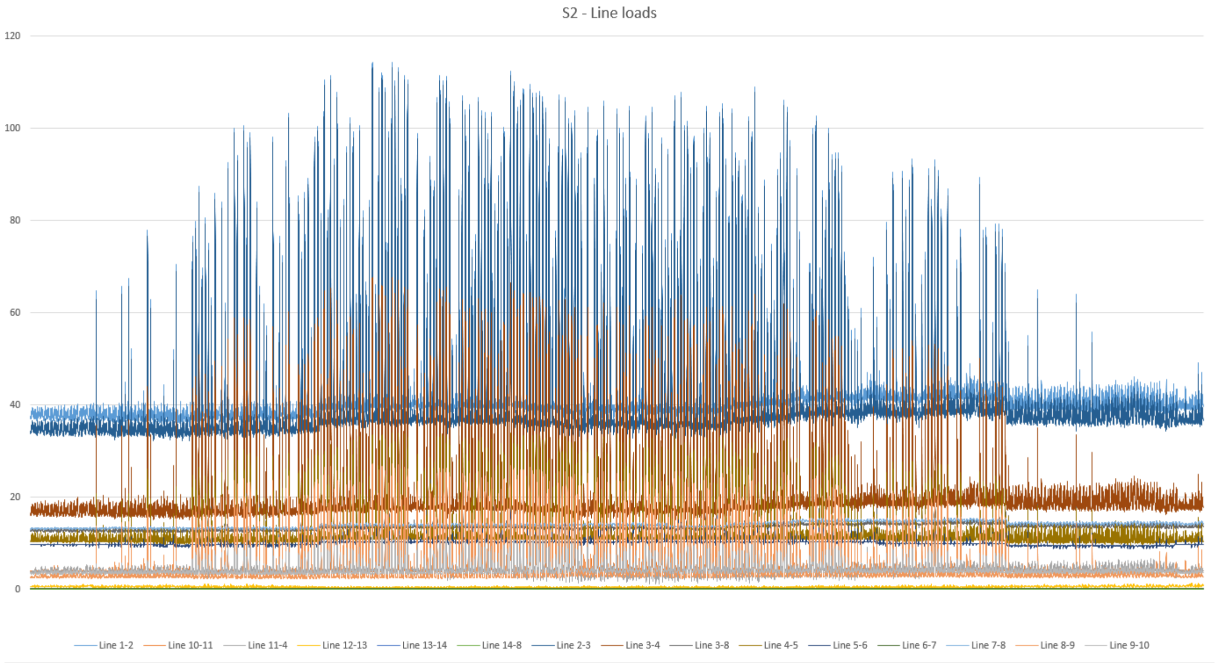


Source: Authors’ own material.

The analysis leads to the following conclusions:

- for each scenario, the maximum load occurs for Lines 1–2 (Figure 10);
- loads on individual lines differ due to the location of RES generation units and receiving units as well as due to their profiles;
- comparison of different scenarios shows that the more RES generation, the higher the value of the maximum load during the year (for specific 15-minute values);
- the dates in a given scenario are different for the analysed lines (the maximum values occur at different times for different places in the network). This is due to specific RES locations and loads in the network topology and their work profiles.

Figure 10. Annual load characteristics of all lines in the analysed network



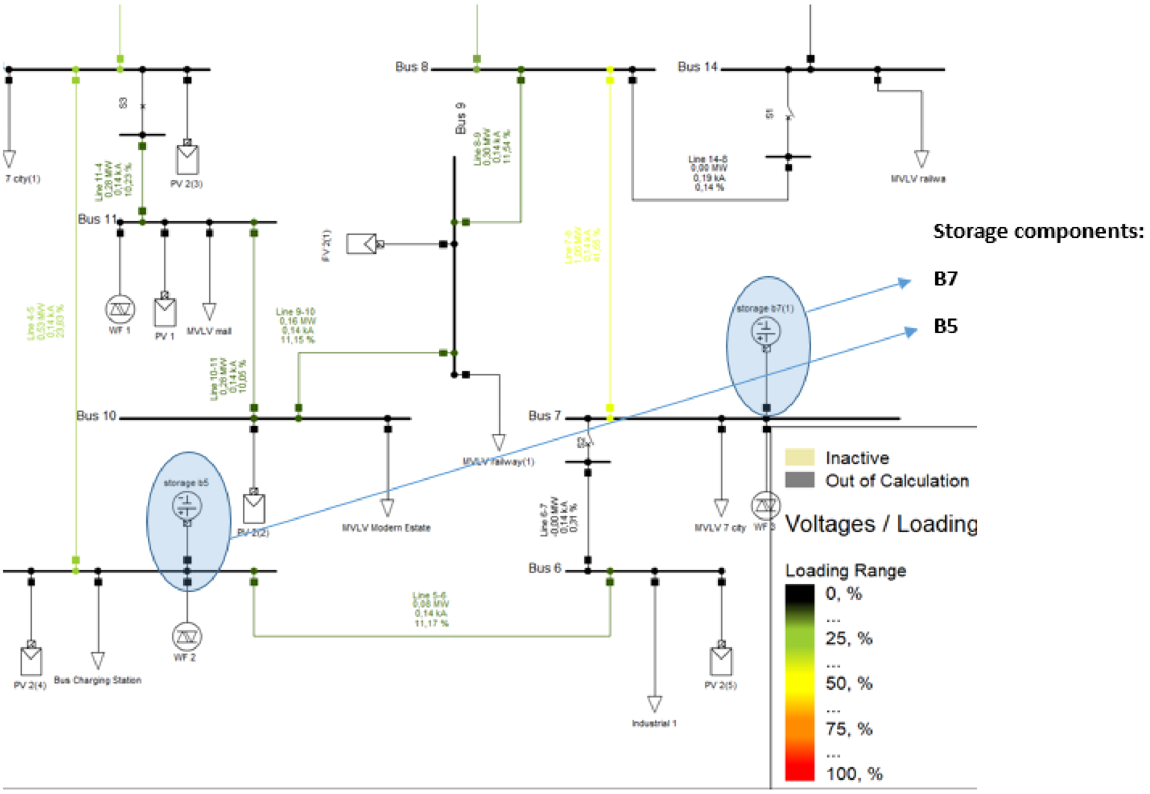
Source: Authors’ own material.

4. Analyses in PowerFactory (digSilent) – Test Case 2 – Analysing the impact of self – consumption and storage on grid congestions

As a result of this analysis, profiles were collected for the most significant variables, i.e.:

- load (%) of each line, including the most critical Line 1–2,
- active power (MW) of working storage facilities,
- state of charge (SoC) (%) – charge level for each of the modeled storage facilities (Figure 11).

Figure 11. Locations of storage components in the CIGRE network



Source: Authors' own material.

Three additional scenarios were performed within the analysis (Table 3).

Table 3. Scenarios of variants of storage operation

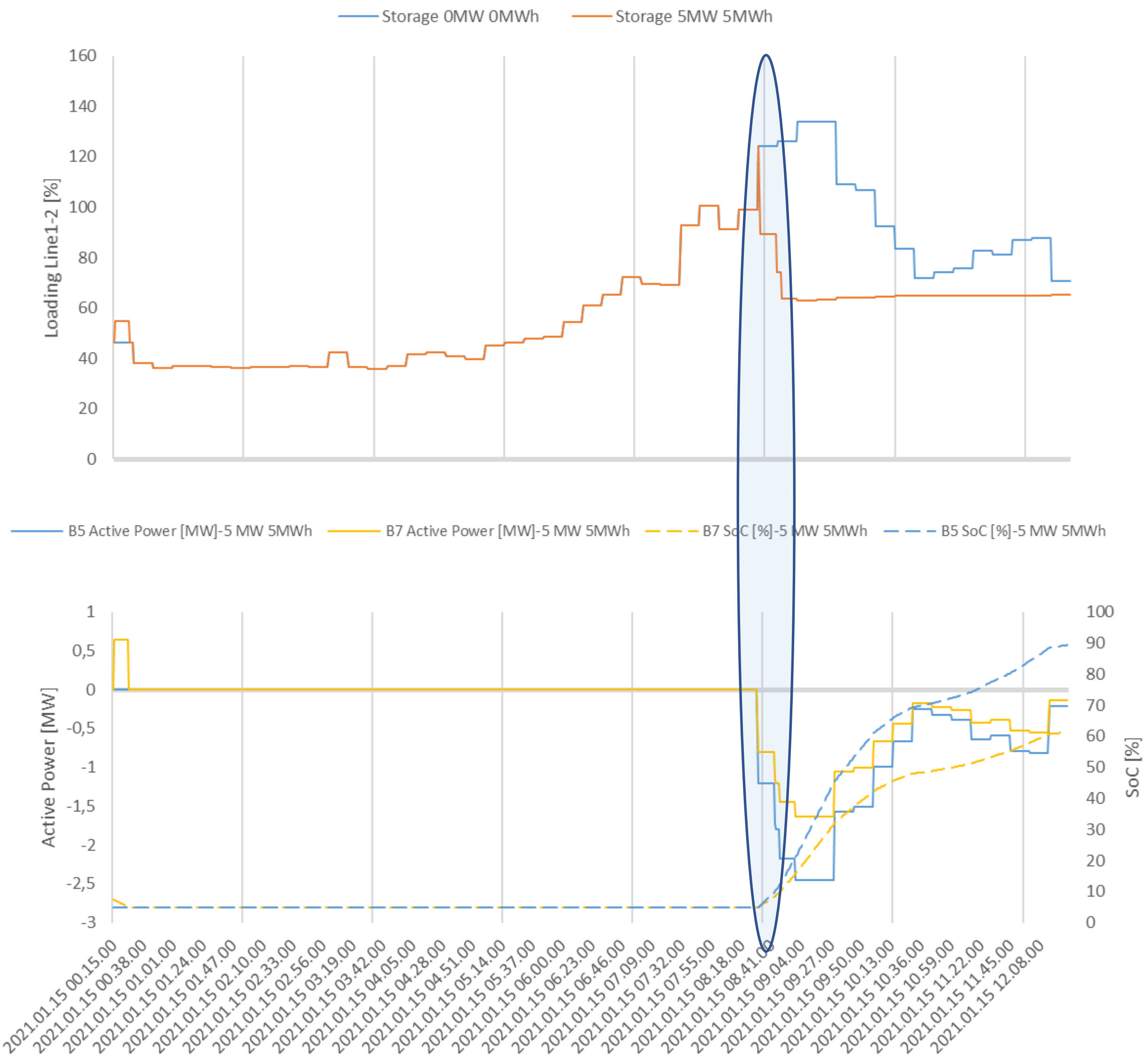
	Number of storage facilities	Power (kW)	Capacity (kWh)
Scenario 0 (reference)[2]	0	0	0
Scenario 1	2	5000	5000
Scenario 2	2	5000	10 000
Scenario 3	2	10 000	10 000

Source: Authors' own material.

---

[2] Scenario 0 is a reference scenario and is the same as the s25 scenario used earlier. All warehouse simulation results compared and related to the reference scenario. These lists enable showing the differences in the options under consideration.

Scenario 1

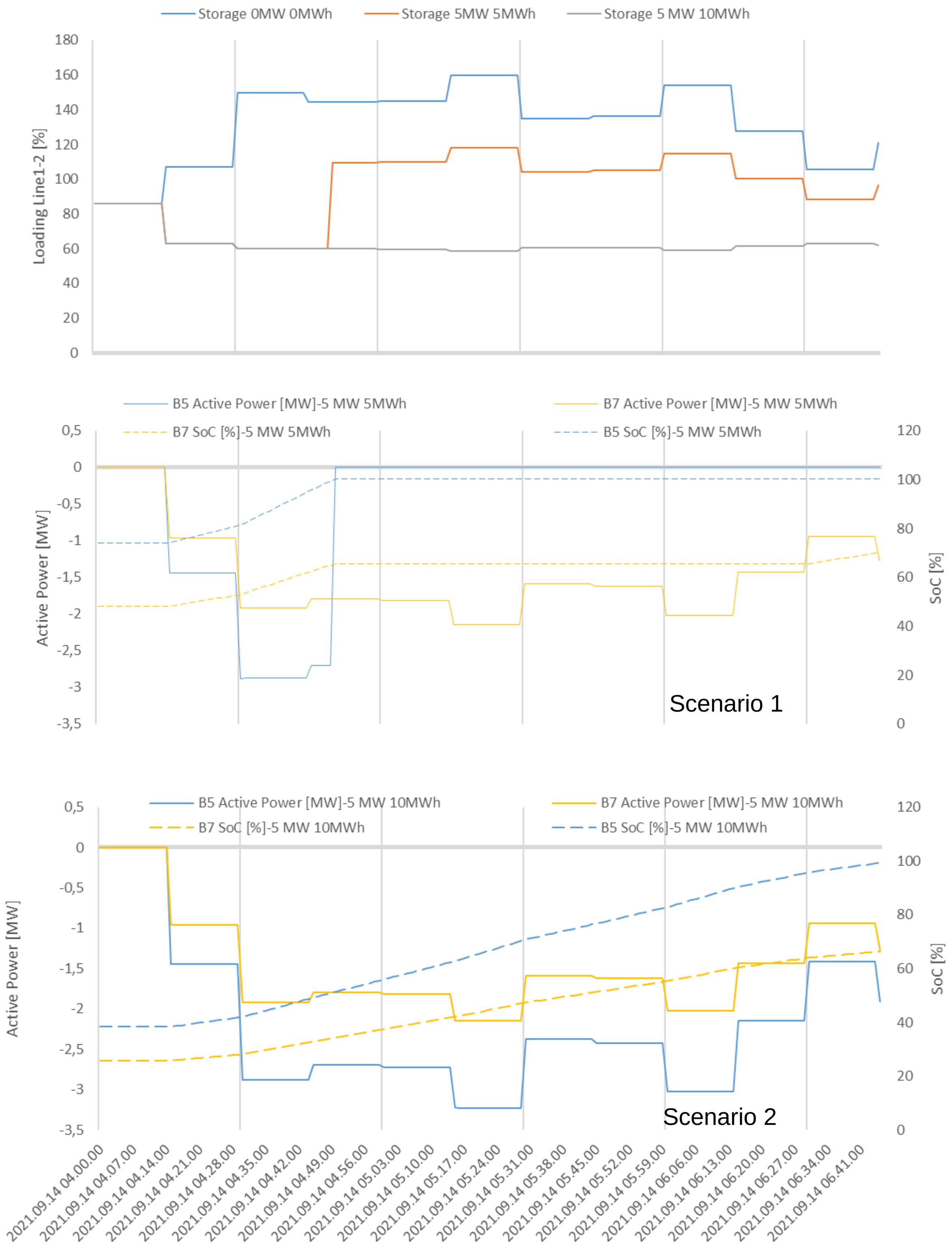


Source: Authors’ own material.

Exceeding the 100% load level by the busiest line is a signal for the battery management system to start operation. Then the battery level (dashed line) increases sharply with a charging power of 1.5 to 2.5 MW.

It is obvious that in line with the decreasing load on Lines 1–2, the battery management system adjusts the charging power of the battery by gradually reducing the active power – a clear stepped characteristic.

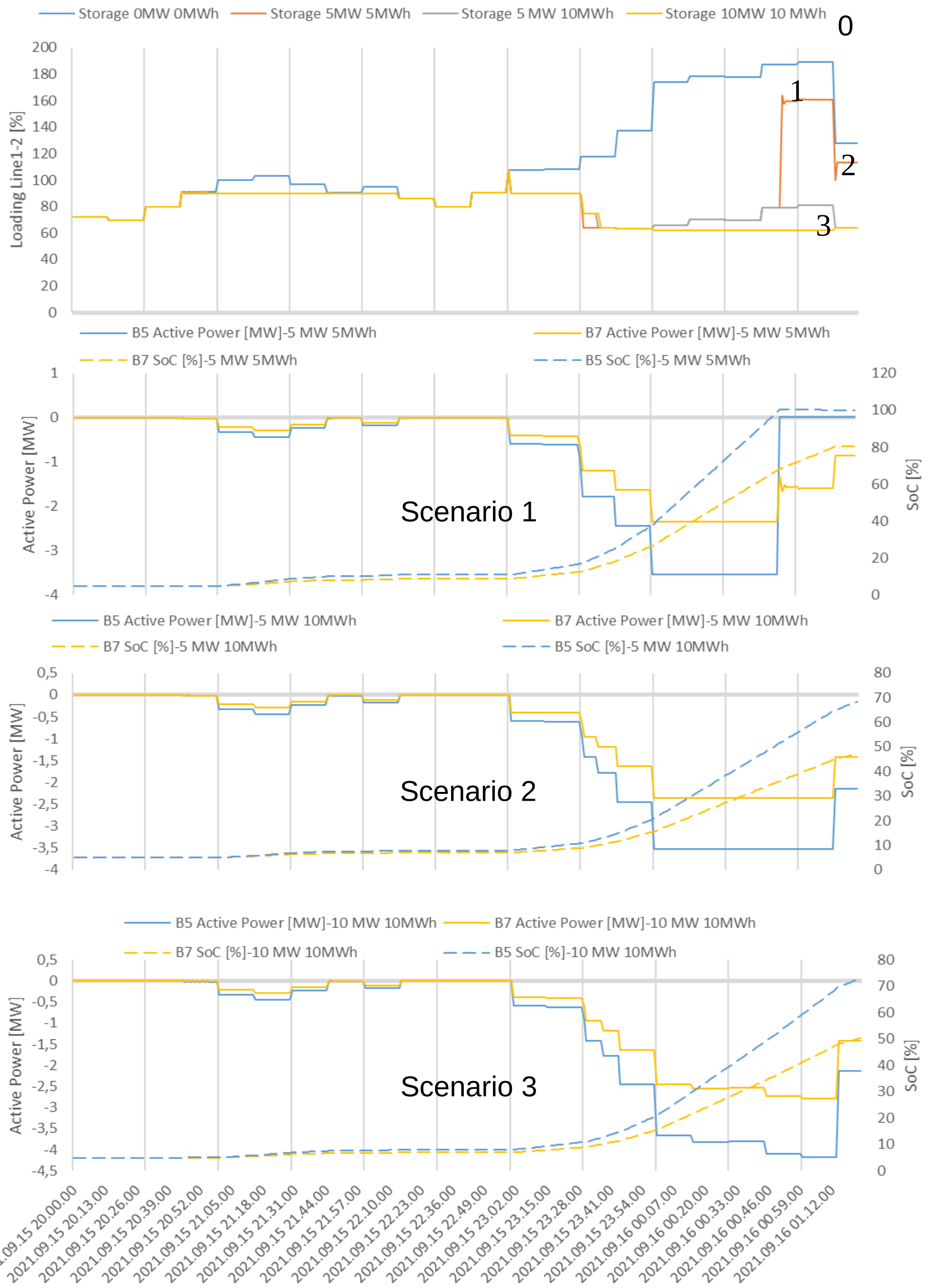
Scenario 2



Source: Authors’ own material.

The diagrams allow for the comparison of results of scenario 2 (5 MW, 10 MWh) with scenario 1 (5 MW, 5 MWh). The first graph shows the effect of the increased battery capacity reducing the load on the line over a long period of time (gray graph vs orange graph). While the B5 warehouse from scenario 1 reached 100% of the charge level (SoC – blue dashed line), the loading power of this magazine dropped sharply. From that moment on, only one warehouse continues to work. Doubled storage capacity reduced SoC levels (%) and allowed both storage facilities to work longer.

Scenario 3



Source: Authors’ own material.

Longer warehouse operation results in the same charge level as in Scenario 1. Doubling the power of the warehouse brings the least results. The reduction of the line load (%) is due to the increase in warehouse parameters:

- active power (MW),
- capacity (MWh).

Conclusions

- Simulated storage facilities allowed to relieve the critical line, and consequently the entire network.
- The use of energy storage allows for increased grid flexibility and greater network “capacity” for new distributed sources.
- Energy storage integrated into the DSO grid has a significant potential to increase the flexibility and resilience of the power grid. The growing amount of energy produced from RES must be mitigated through controllable and programmable energy storage systems – without this, unstable and unpredictable energy sources can be a source of accumulation of power significantly exceeding the transmission capacity of distribution networks.

5. Targets of the DRES2Market project

The presentation and text are based on the work carried out as part of the European Commission’s project in the H2020 Programme: DRES2Market: Technical, business, and regulatory approaches to enhance renewable energy capabilities to take part actively in the electricity and ancillary services markets. Grant number: 952851.

The aim of the DRES2Market research project is to develop a comprehensive and economically beneficial approach to facilitate the integration of distributed generation based on renewable energy sources – RES in the power system and to enable the provision of balancing and backup services according to market criteria by these sources. The project activities are in line with the European Union projects aimed at building a sustainable energy system and a low-carbon economy, at the same time they are part of the global trend of reducing energy dependence on fossil fuels. The DRES2Market project consortium consists of fifteen partners from five European countries: Austria, Spain, Greece, France, Poland and Norway actively participating in the development of RES technologies, from research institutions, academia and distribution companies.

References

Analysis of RES sources connected with the network of ENEA Operator Sp. z o.o.

Bartoszewicz-Burczy, H. (2022). *Barriers for Large Integration of PV and Onshore Wind Energy in the Distribution Network on the Selected European Union Electricity Markets*, https://czasopisma.uksw.edu.pl/index.php/seb/article/view/9721 (access: 3.03.2022).

Barriers for large integration of renewable energies in electricity and ancillary services markets. Deliverable D2.3. 2021. Technical, business, and regulatory approaches to enhance renewable energy capabilities to take part actively in the electricity and ancillary services markets. Horizon 2020-LC – SC3 – 2020 – RES-IA-CSA. July, 2021.

Directive 2018/2001/EU of the European Parliament, and of the Council of 11th of December, 2018, on promotion of the use of energy from renewable sources. Directive 2019/944 of the European Parliament and of the Council of 5th of June, 2019, on common rules for the internal market for electricity and amending Directive 2012/27/EU.

ENEA (2022). *Report of the Management Board on the activities of ENEA S.A. and the ENEA Capital Group in 2021*.

European Commission (2018). *A Clean Planet for All: a European Long-Term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy*, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN (access: 3.03.2022).

European Commission – DG Energy (2018). *Study on Energy Prices, Costs and Subsidies and their Impact on Industry and Households. Final Report*. DOI: 10.2833/825966.

European Commission (2022). *European Green Deal*, https://ec.europa.eu/ clima/eu-action/european-green-deal_en (access: 3.03.2022).

Federacja Konsumentów (2016). *zostać prosumentem. Raport Federacji Konsumentów (How to become a prosumer. Consumers' Federation Report)*, http://www.federacja-konsumentow.org.pl/n,159,1307,91,1,raport-federacji-konsumentow. Html (access: 3.03.2022).

Hirschbichler, F., Low, R., Presch, D. (2021). *European Barriers in Retail Energy Markets Project: Austria Country Handbook*. Luxembourg: Publications Office of the European Union. DOI: 10.2833/214989.

OECD, IEA (2011). *Deploying Renewables, Best and Future Policy Practice*. Paris: International Energy Agency.

Ropuszyńska-Surma, E., Węglarz, M. (2017). *Bariery rozwoju rozproszonej energetyki odnawialnej w świetle badań ankietowych (The barriers to the development of the distributed renewable energy in the light of survey)*. DOI: 10.15199/48.2017.04.23.

Sæle, H., Cherry, T.L. (2017). *Attitudes and perceptions about becoming a prosumer: results from a survey among Norwegian Residential customers – 2016*, https:// sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2448126/2017-00078.pdf (access: 3.03.2022).

Xue Yan, C., Lindkvist, M., Temeljotov-Salaj, A. (2021). Barriers and potential solutions to the diffusion of solar photovoltaics from the public–private–people partnership perspective. Case study of Norway, *Renewable and Sustainable Energy Reviews*, 137, 110636, DOI: 10.1016/j.rser.2020.110636.

Krzysztof Zagrajek

Warsaw University of Technology

Chapter XI

Electric Vehicles as Mobile Energy Storage Facilities. A Proposal of New Energy Services

Abstract

This chapter presents basic assumptions regarding the creation of energy services markets, which will include electric vehicles. The use of electric vehicles is important because from the point of view of the power system they should be treated as mobile energy storage facilities. They can be used by power grid operators as resources to increase grid flexibility or to improve reliability and quality parameters of electricity supplied to consumers. From the point of view of final customers, they can be an additional source of electricity during unplanned and planned interruptions in its supply. The chapter discusses examples of concepts of use of electric vehicles, it focuses on the analysis of legal conditions that would enable the creation of such a market for energy services. It presents the main assumptions of the concept of author's designed programme of services implementing the vehicle-everything technology (V2X) in the Polish energy market conditions.

Keywords: electric vehicles; V2X technology; energy market; smart-grid; energy transition

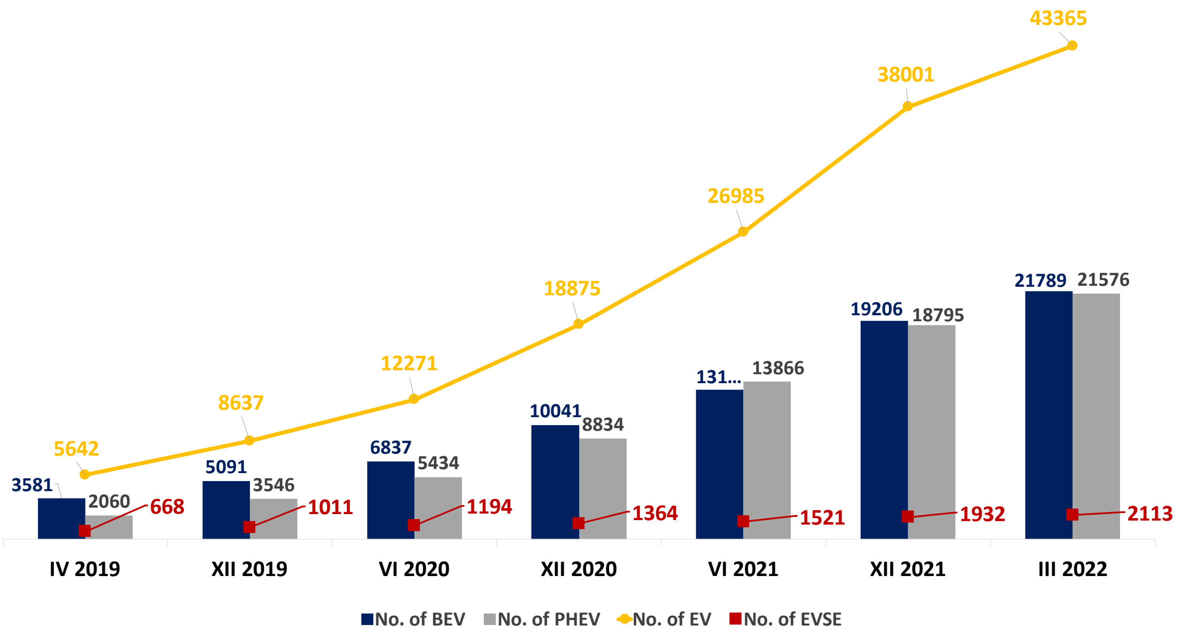
List of abbreviations and designations

BEV	battery electric vehicle driven by the energy stored in batteries
EV	electric vehicle
EVSE	electric vehicle supply equipment – vehicle charging infrastructure (most often understood as charging stations)
PHEV	plug-in hybrid electric vehicle – hybrid electric vehicle with plug-in rechargeable system
V2X	vehicle-to-everything – technology of transferring energy stored in the battery of an electric vehicle to many types of reception (houses, power grid, industrial facilities)
V2G	vehicle-to-grid – technology of transferring energy stored in the battery of an electric vehicle to the power system

Introdution

The increasing electrification of public and private transport within the European Union (EU) should prompt reflection on exploiting the full potential of electric vehicles [Hedegaard et al., 2012]. It should be stressed that the continued fight to reduce carbon dioxide emissions in the transport sector [Marrero et al., 2021] and the recent proposal by EU legislative bodies to ban the sales of internal combustion vehicles from 2035 will undoubtedly result in a significant increase in the number of electric vehicles on the road [Popp, 2022]. Currently, the number of these vehicles, especially in Poland, is not large. According to the data of the Polish Alternative Fuels Association (PSPA), in May 2022, the number of electric vehicles was 46,676, of which 22,476 were BEVs and 24,200 were PHEVs [PSPA, 2022]. This would account for about 0.2% of all passenger vehicles moving in Poland [GUS, 2021]. At this point, it should be emphasised that accurate statistics on the number of EVs in Poland can be kept only since the beginning of the second quarter of 2019. This is due to the launch by PSPA of a cycle of monthly reports of the so-called Electromobility Counter [PSPA, 2019]. In addition to the number of electric vehicles, PSPA also runs statistics on the number of public charging points and stations. Figure 1 shows the progress of changes in the area of Polish electromobility from April 2019 to March 2022.

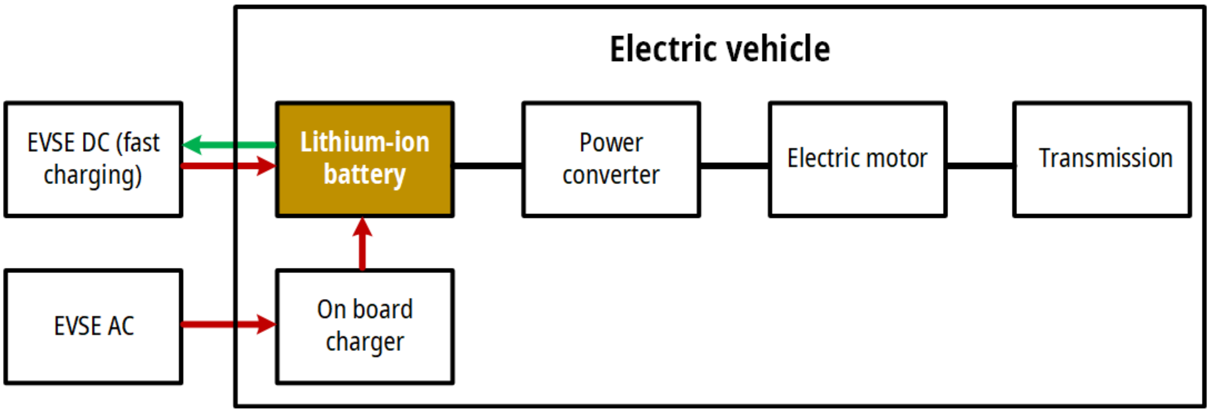
Figure 1. Number of EVs and public charging stations in 2019–2022



Source: Author’s own material based on PSPA, 2019.

However, the question arises as to what it means to use the full potential of electric vehicles. It seems that from the point of view of the power system, they will only act as an additional demand for electricity, due to the need to charge them [Gilleran, Bonnema et al., 2021]. However, an electric vehicle should be interpreted as an electric energy warehouse but remaining in constant motion. Therefore, it is possible to propose for them the term mobile energy warehouse [Zagrajek, Paska, Sosnowski, Gobosz, Wróblewski, 2021]. The role of storage is played by EV batteries, which in normal operation are used to drive the electric motor. The fact that an electric vehicle should be treated as an electricity storage system is also evidenced by its definition in Directive 2014/94 of the EUROPEAN Parliament of 22 October 2014 on the development of alternative fuels infrastructure [Directive 2014/94]. According to its provisions, an electric vehicle means a motor vehicle equipped with a powertrain containing at least one non-peripheral electric machine as energy converter with an electric rechargeable energy storage system, which can be recharged externally [Directive 2014/94]. The fact that an electric vehicle should be treated as an energy storage system also means that a two-way flow of energy between the vehicle battery and the electric vehicle charging infrastructure (EVSE) is possible, which must have such functionality. Figure 2 shows a block diagram of the electric vehicle with marked directions of electricity flow between the EVSE and the EV vehicle battery.

Figure 2. Electric vehicle block diagram



Source: Author’s own material based on Huang, 2022; Mitsubishi Electric, 2022.

The technology that enables the bi-directional flow of electricity between the EV’s battery and any point in the power system is called Vehicle-to-Everything (V2X) [Thompson, Perez, 2020]. Most often, however, two types of this technology are mentioned – the most popular Vehicle-to-grid (V2G) or Vehicle-to-home (V2H) [Liu et al., 2013]. The technical requirements for energy transmission and communication between the vehicle and the charging station (acting as an intermediary in the transmission of energy) are described in ISO 15118-20:2022 [ISO15118, 2022].

In the scientific literature, however, the problems of integrating electric vehicles with the power grid are most often discussed. One of the most frequently presented aspects in the context of V2G or V2X technology is a possible implementation of system services such as frequency and voltage regulation [Loisel, Pasaoglu, Thiel, 2014; Rao, 2021]. Importantly, the above-mentioned aspects are analysed not only in the technological, but also in the economic layer. Business models of system service aggregators using V2G technology are also analysed [Brandt et al., 2017; Krueger, Cruden, 2018; Peng, Zou, Lian, Li, 2017]. Many publications also attempted to price such services [Zheng, Yu, Shao, Jain, 2020; Li et al., 2020]. An extremely important aspect in the context of the development of V2X technology is the analysis of whether electric vehicles can be used to provide system services at the level of the distribution network, i.e. flexibility services. Some publications [Rundqi et al., 2020; Schuller, Flath, Gottwalt, 2015] presented the possibilities of using EV in demand reduction or energy storage processes. Taking into account the above aspects, it should be considered whether in Polish conditions it is possible to create a modern market for energy services based on the use of electric vehicles as mobile energy storage facilities while involving ordinary EV users in these processes. This article presents the basic assumptions that will allow to create a general framework for the functioning of the V2X services market, while maintaining compliance with European Union and national law.

1. Legal framework to create energy services using electric vehicles

An extremely important aspect during the implementation of V2X or related technologies is to adapt to the applicable law in the area of electrical power engineering and electromobility. Generally, the existing rules in these areas can be divided into two groups: Acts of European Law and National Legal Acts. Among the former, two directives of the EU Parliament should be distinguished, which outline the framework for later adopted implementing acts of the member states. The first of these is the aforementioned Directive of the EU Parliament of 22 October 2014 on the development of alternative fuels infrastructure. Main definitions are found there in the field of electromobility, such as the previously mentioned definition of an electric vehicle. In addition, it contains concepts such as [Directive 2014/94]:

- "'recharging point' means an interface that is capable of charging one electric vehicle at a time or exchanging a battery of one electric vehicle at a time"(Article 2(3)),
- "'normal power recharging point' means a recharging point that allows for a transfer of electricity to an electric vehicle with a power less than or equal to 22 kW, excluding devices with a power less than or equal to 3,7 kW, which are installed in private households or the primary purpose of which is not recharging electric vehicles, and which are not accessible to the public" (Article 2(4)),
- "'high power recharging point' means a recharging point that allows for a transfer of electricity to an electric vehicle with a power of more than 22 kW." (Article 2(5)).

As can be seen from the above definitions, certain regulations in the area of electromobility have been presented, which apply to charging electric vehicles. However, as regards V2X technology, only a brief mention can be found in the recitals (28) to this directive and the following passage is found: "In the long term, this may also enable electric vehicles to feed power from the batteries back into the grid at times of high general electricity demand." Besides these, there are no regulations regarding the two-way transmission of electricity between the vehicle and the power grid.

Another European legal act to be examined is EU Parliament Directive 2019/944 of 5 June 2019 on common rules for the internal market in electricity [Directive 2019/944]. It contains a number of provisions on electricity storage, including in particular attention to the provisions of Article 36, which prohibit Distribution System Operators (DSOs) from having storage facilities, except for those that contribute to the stable and safe operation of the power system [Directive 2019/944]. The Directive also contains provisions on the ownership of charging points for electric vehicles. In accordance with Article 33(2) of the Directive, "Distribution system operators shall not own, develop, manage or operate recharging points for electric vehicles, except where distribution system operators own private recharging points solely for their own use." [Directive 2019/944]. This notation is critical for the implementation of V2G technology. It seems that the DSOs have the best knowledge in the field of electricity balancing, and it is worth mentioning that the processes of transferring electricity to the network from the vehicle can affect the stable operation of the power system on a large scale. It should also be mentioned that DSOs may obtain appropriate derogations from the above conditions (Article 33(3)), however, it should be remembered that the use of electric vehicles for the purpose of regulating the operating parameters of the power system is part of the basket of flexibility services, and these should be provided to DSOs by the so-called third parties

[Directive 2019/944]. Thus, there is some doubt as to who should be the operator of V2X/G services in a given area and what relations between the DSO and such an operator should exist.

European legislation is reflected in national legal acts. This article presents selected issues from two acts: the Act of 10 April 1997 (as amended later) Energy Law and the Act of 11 January 2018 (as amended later) on electromobility and alternative fuels. It is worth mentioning that both of these acts are regularly amended to comply with the provisions of the previously discussed directives. The law on electromobility and alternative fuels introduces identical definitions of charging points (power divisions) as in the case of the EP Directive [Electromobility Law]. Nevertheless, the Polish law introduces another important definition, namely charging stations. Unlike a charging point, a charging station is “construction facility comprising a normal power recharging point or a high-power recharging point associated with a construction facility, or a free-standing construction facility with at least one normal-power recharging point or a high-power recharging point installed – equipped with software enabling the provision of charging services, including a parking station and an installation leading from the charging point to the electricity connection” [Law on electromobility]. Distinguishing these concepts is extremely important, not only because of the specific goals to be achieved in the promotion of electromobility in Poland, but also resulting from the introduction of the role of the Operator of Public Charging Stations (OOSŁ) [Law on electromobility]. As in the case of European legislation, the principles of equal treatment are introduced. Moreover, in accordance with the Polish regulations, there is a distinction between the so-called Charging Service Provider to provide charging services in public charging stations [Law on Electromobility]. Article 7 of the Act on Electromobility and Alternative Fuels introduces a provision strongly limiting the possibility of providing V2X/G services in public places, as it cannot make the provision of charging services conditional on the prior conclusion by the operator of an electric vehicle or hybrid vehicle of a contract in writing, in paper or electronic form [Law on electromobility]. In the case of V2X/G services, it is necessary for the service provider to be sure that after the call to discharge the vehicle will be able to perform the service. It should be mentioned that in Polish legal regulations we will not find a definition of a two-way charging point, i.e. one that would enable the transfer of electricity from the vehicle to the grid. It is worth mentioning, however, that in the draft amendments to the Energy Law in January 2020, such a definition was, but at further stages of work it was deleted.

The Act Energy Law is constantly being amended in order to comply with the framework for the development of internal electricity markets of member states imposed in Directive 944/2019. The amendment of 2021 brought the expected changes in the field of energy storage [Act Energy Law]. The definitions of energy storage and storage facilities are clarified and a number of orderly regulations have been introduced in the field of connecting storage facilities to the power grid and settling and tariffing electricity from them. In the context of the V2X/G technology, there is one phrase that may cause some doubts. Namely, in accordance with Article 43g(1): "The electricity system operator shall keep, in an electronic form, a register of electricity storage facilities connected to his network, forming part of it or included in the generating unit or final customer installation connected to his network," and in accordance with Article 43g(3): "Electricity storage facilities with a total installed capacity of more than 50 kW shall be subject to the entry in the register referred to in paragraph 1" [Energy Law Act]. From a technical point of view, an electric vehicle, in particular providing services for the provision of electricity for the needs of the customer or the network, connected to the charging station (irrelevant to the location of the station) is an energy storage connected to the final customer's installation. His installed power can be determined by the maximum charging or discharging power. The question arises whether such a mobile energy storage should also be subject to the obligation to enter in the register. At this point, it is necessary to return to the considerations from the introduction to this chapter, when an electric vehicle is defined as a mobile energy storage. When the V2X/G technology is to be implemented, the priority is to separate stationary and mobile energy storage. The need for changes in the existing legal acts was mentioned in the publication [Zagrajek et al., 2021]. On the basis of the considerations discussed in it, changes in Polish legislation are proposed. They are presented in Table 1.

Table 1. Proposed changes in Polish legislation to implement the V2X/G technology

Missing legal aspect	Proposal
Failure to include mobile energy storage in the definition of installation of energy storage facilities	Inclusion and recognition of an electric vehicle as a mobile energy storage installation
No definition of a bidirectional charging point	Introduction of the amendment to the Act on electromobility and alternative fuels as soon as possible
No market for the V2X services	Establishing a legal framework for the emergence of a V2X services market
TSOs are solely responsible for the purchase of system services	Both TSOs and DSOs should be able to purchase system services in-house – introduction of flexibility services
No adjustment for EV users who want to use V2X	Establishing a legal framework for the efficient discharging of electric vehicles, e.g. priority access to selected bi-directional charging points.
No division of roles between DSOs and V2X Service Operators	Introduction of roles and responsibilities for entities
Lack of regulations regarding the participation of the Energy Regulatory Office (ERO) in the creation of the V2X Programme	Active cooperation between the government, the Energy Regulatory Office and relevant entities

Source: Author's own material based on Zagrajek et al., 2021.

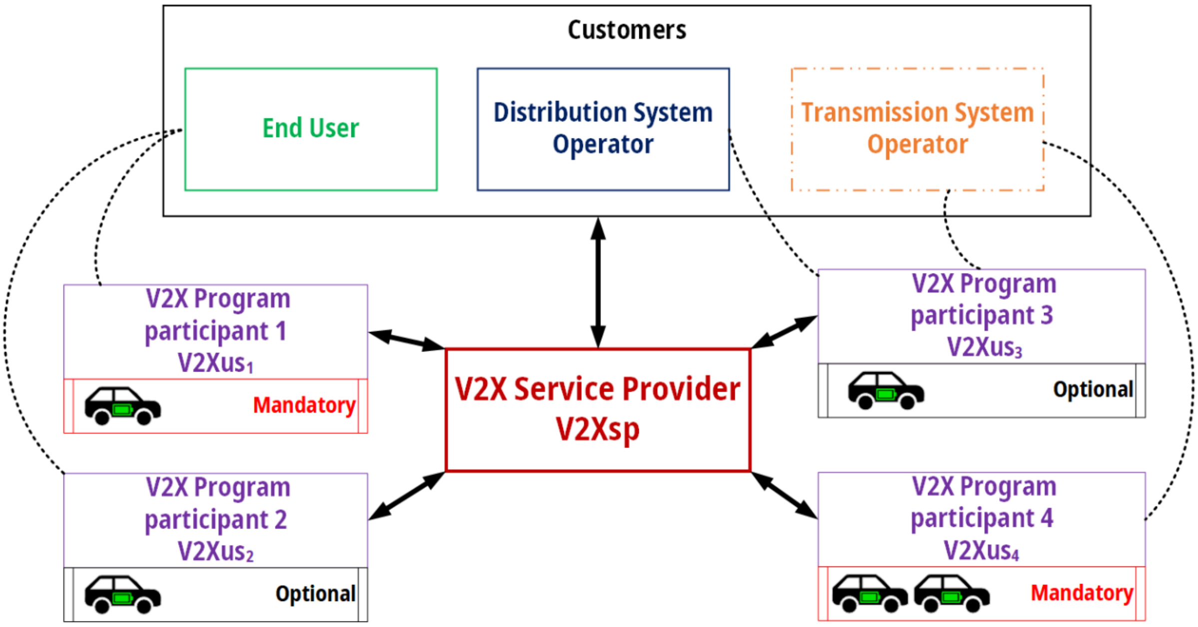
2. Concept of an energy service programme using electric vehicles

The publications [Zagrajek et al., 2021] and [Zagrajek, 2021] addressed the basic issues related to the launch of an energy service programme using electric vehicles – then called the V2G Programme and V2G Services. The V2X technology includes more ways to discharge vehicles than the V2G technology, so the definitions contained in the publications may be extended [Zagrajek et al., 2021; Zagrajek, 2021], to make them more universal. Thus, the V2X Programme is “a mechanism consisting in the use of electric vehicles to increase the flexibility resources of the power system, including improving the operating parameters of the power grid and/or improving the security of electricity supply to the final customer.” The V2X service is “a defined activity, taken by a service provider using an electric vehicle, aimed at improving the operating parameters of the power system or providing the functionality of a mobile electricity storage to the end user.” Focus should be placed on the second part of the proposed V2X service definition. One of the objectives of the introduction of the V2X Programme is to ensure that the final customer’s demand can be met during planned and unplanned interruptions in energy supply. Therefore, it is necessary to divide services into those that can be contracted in advance (scheduled) and those whose contracting process must begin immediately after the occurrence of a failure in the power system (intervention). The entity that is to manage the processes of contracting V2X services should be an energy company independent of the DSO called the V2X Service Provider (V2Xsp). On the side of service providers and recipients, the following players should be distinguished:

- in the group of service providers: users of electric vehicles, providing services in many modes, making their remuneration dependent on being on standby and providing services, or only on responding to the current needs reported by V2Xsp;
- in the group of service recipients: final customers who would like to be secured by electric vehicles during periods of electricity supply disruption and DSOs who could contract flexibility services to improve the operating parameters of the distribution network.

Figure 3 shows the basic relations between the most important players in the proposed concept of the V2X Programme.

Figure 3. Relations between V2X Program participants



Source: Author's own material.

In order to understand the process of contracting and pricing V2X services, it is important to reduce all considerations to one analysed parameter – electricity [Zagrajek et al., 2021]. From the point of view of the power system, any service involving EV (emergency or planned power supply, frequency and voltage regulation, or even forced EV charging) is related to the flow of electricity from or to the battery. What should not forget is also the random behaviour of the participants of the programme. One of the key parameters is to take into account the probabilities of the V2X service provided both from the point of view of the service provider and the recipient, as the failure to take them into account may result in the contracting of too few vehicles [Zagrajek, 2021]. Equations (1) and (2) describe these phenomena.

$$e_{V2X+,n} = C_n \cdot \left(SOC_{t,n} - (SOC_{f,n}(1 + REZ_n)\right) \cdot \eta_d \qquad (1)$$

$$E'_{V2X,T} = \mathrm{P_{uEV}}(\mathrm{A}) \cdot \sum_{n=1}^{N_{uEV}^{EST}} e_{V2X+,n} \qquad (2)$$

where:

C_n – battery capacity of the electric vehicle, expressed in kWh;

$SOC_{t,n}$ – the battery level of the V2X electric vehicle at the start of the charging or discharging process, expressed in %;

$SOC_{f,n}$ – the battery level of the electric vehicle required for the next journey, expressed in %;

REZ_n – battery level reserve of the electric vehicle, with which the route can be extended, e.g. to avoid traffic congestion, expressed in %;
η_d – efficiency of the discharge process, expressed in %;
$E'_{V2X,T}$ – the expected value of electricity transmitted from or to the electric vehicle within the V2X service, accounting for the reserve resulting from the probability of performing this service;
$\mathrm{P}_{\mathrm{uEV}}(\mathrm{A})$ – probability of performing the V2X service on the part of the V2X Programme Participant;
N_{uEV}^{EST} – the number of V2X electric vehicles that will be needed to perform the service, considering the need to send more inquiries and requests resulting from the probability $\mathrm{P}_{\mathrm{uEV}}(\mathrm{A})$.

Bearing in mind these considerations, it is possible to propose a model of settlement for service providers and recipients, which will be based on dependencies related to reliability indicators of power systems. It is due to the fact that the amount of electricity supplied by electric vehicles, in particular during power outages, will be correlated with these indicators, both in terms of the undelivered volume of energy from the system, as well as in the economic dimension, i.e. how much the customer is able to pay for ensuring the continuity of electricity supply. It should also be emphasised that in many publications [Huang et al., 2022; Li et al., 2020; Ma, Houghton, Cruden, Infield, 2012], rates for V2X services are determined based on electricity prices in a given region. Analysing the legal environment and the possibility for consumers to use the principle of choosing an energy seller (TPA – third party access), it seems unreasonable to compare reference rates for users of electric vehicles for discharging their vehicles to the market price of energy. Instead, it is proposed that the reference rate, which will be increased depending on the time of day and traffic, should be the price for charging vehicles at public charging stations in a given area.

Conclusions

The chapter presents issues related to the possibility of creating a market for energy services based on the use of electricity from EV vehicles. During the implementation of such a service programme, it is necessary to observe the applicable legal acts and proposals for their amendments extremely carefully. The key factor affecting an easy process of creating the V2X services market model from the participants' point of view is cooperation between government authorities, the regulator and energy companies in order to ensure a competitive method of securing the continuity of electricity supply. It should be remembered, however, that at this point the V2X technology should be treated as a product still in the R&D phase, while with the saturation of the passenger vehicle fleet in Poland with electric vehicles, this technology may become a leader in the field of interventional protection of end users, in particular in areas of a self-balancing nature. The role of scientists and entrepreneurs is to familiarise users of electric vehicles with their energy potential and to constantly monitor and analyse the data obtained on the movement of users and the charging schemes implemented.

References

Act of 10 April 1997 Energy Law (Journal of Laws of 1997, No. 54, item 348, as amended later).

Act of 11 January 2018 on electromobility and alternative fuels (Journal of Laws of 2018, item 317, as amended later).

Brandt, T., Wagner, S., Neumann, D. (2017). Evaluating a business model for vehicle-grid integration: Evidence from Germany, *Transportation Research Part D*, 50, pp. 488–504.

Directive 2014/94 of the European Parliament of 22 October 2014 on the deployment of alternative fuels infrastructure.

Directive 2019/944 the European Parliament of 5 June 2019 on common rules for the internal market for electricity.

Gilleran, M., Bonnema, E. et al. (2021). Impact of electric vehicle charging on the power demand of retail buildings, *Advances in Applied Energy*, 4, 100062.

GUS (2021). *Transport – results of operations in 2020*, https://stat.gov.pl/obszary-tematyczne/transport-i-lacznosc/transport/transport-wyniki-dzialalnosci-w-2020-roku,9,20.html (access: 15.06.2022).

Hedegaard, K., Ravn, H., Juul, N., Meibom, P. (2012). Effects of electric vehicles on power systems in Northern Europe, *Energy*, 48, 356–368.

Huang, S., Liu, W., Zhang, J., Liu, C., Sun, H., Liao, Q. (2022). Vehicle-to-grid workplace discharging economics as a function of driving distance and type of electric vehicle, Sustainable Energy, *Grids and Networks*, 31, 100779.

ISO 15118-20:2022 (2022). *Road vehicles – Vehicle to grid communication interface – Part 20: 2nd generation network layer and application layer requirements*.

Krueger, H., Cruden, A. (2018). Modular strategy for aggregator control and data exchange in large scale Vehicle-to-Grid (V2G) applications, *Energy Procedia*, 151, pp.7–11.

Li, X., Tan, Y.; Liu, X., Liao, Q., Sun, B., Cao, G., Li, C., Yang, X., Wang, Z. (2020). A cost-benefit analysis of V2G electric vehicles supporting peak shaving in Shanghai, *Electric Power System Research*, 179, 106058.

Liu, C., Chau, K.T., Wu, D., Gao, S. (2013). Opportunities and Challenges of Vehicle-to-Home, Vehicle-to-Vehicle, and Vehicle-to-Grid Technologies, *Proceedings of the IEEE*, 101(11), pp. 2409–2427.

Loisel, R., Pasaoglu, G., Thiel, C. (2014). Large-scale deployment of electric vehicles in Germany by 2030: An analysis of grid-to-vehicle and vehicle-to-grid concepts, *Energy Policy*, 65, pp. 432–443.

Ma, Y., Houghton, T., Cruden A., Infield, D. (2012). Modeling the Benefits of Vehicle-to-Grid Technology to a Power System, *IEEE Transactions on Power Systems*, 27 (2), pp. 1012–1020.

Marrero, A.S., Marrero, G.A., González, R.M., Rodríguez-López, J. (2021). Convergence in road transport CO_2 emissions in Europe, *Energy Economics*, 99, 105322.

Mitsubishi Electric (2022). *Automotive applications*, https://www.mitsubishielectric.com/semiconductors/application/automobile/ (access: 15.06.2022).

Peng, C., Zou, J., Lian, L., Li, L. (2017). An optimal dispatching strategy for V2G aggregator participating in supplementary frequency regulation considering EV driving demand and aggregator's benefits, *Applied Energy*, 190, pp. 591–599.

PSPA (2019). *Uruchomiono polski licznik elektromobilności([Polish electromobility meter has been launched)*, https://pspa.com.pl/2019/informacja/uruchomiono-polski-licznik-elektromobilnosci/ (access: 15.06.2022).

PSPA (2022). *Licznik Elektromobilności: Polska musi się przygotować na planowany zakaz rejestracji samochodów spalinowych (Electromobility counter: Poland must prepare for the planned ban on the registration of combustion cars)*, https://pspa.com.pl/2022/informacja/licznik-elektromobilnosci-polska-musi-sie-przygotowac-na-planowany-zakaz-rejestracji-samochodow-spalinowych/ (access: 15.06.2022).

Popp, D. (2022). *Fit for 55: MEPs back objective of zero emissions for cars and vans in 2035*, https://www.europarl.europa.eu/news/en/press-room/20220603IPR32129/fit-for-55-meps-back-objective-of-zero-emissions-for-cars-and-vans-in-2035 (access: 15.06.2022).

Rao, Y., Yang, J. et al. (2021). A frequency control strategy for multimicrogrids with V2G based on the improved robust model predictive control, *Energy*, 222, 119963.

Rundqi, D., Xiang, Y., Huo, D., Liu, Y., Huang, Y., Huang, C., Liu, J. (2020). Exploring flexibility of electric vehicle aggregators as energy reserve, *Electric Power System Research*, 184, 106305.

Schuller, A., Flath, C.M., Gottwalt, S. (2015). Quantifying load flexibility of electric vehicles for renewable energy integration, *Applied Energy*, 151, pp. 335–344.

Thompson, A., Perez, Y. (2020). Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications, *Energy Policy*, 137, 111136.

Zagrajek, K. (2021). A Survey Data Approach for Determining the Probability Values of Vehicle-to-Grid Service Provision, *Energies*, 14 (21), 7270.

Zagrajek, K., Paska, J., Sosnowski, Ł., Gobosz, K., Wróblewski, K. (2021). Framework for the Introduction of Vehicle-to-Grid Technology into the Polish Electricity Market, *Energies*, 14, 3673.

Zheng, Y., Yu, H., Shao, Z., Jian, L. (2020). Day-ahead bidding strategy for electric vehicle aggregator enabling multiple agent modes in uncertain electricity markets, *Applied Energy*, 280, 115977.

Notes on the Authors

HANNA BARTOSIEWICZ-BURCZY – PhD, assistant professor at the Energy Economics Laboratory, Institute of Power Engineering in Warsaw; conducts R&D work on energy economics, energy efficiency, economic aspects of development of renewable energy and new technologies as well as energy sector security.

ALEKSANDRA GAWLIKOWSKA-FYK – PHD, specialist in the European Union energy policy and regulations, in particular in the areas of internal electric power market, energy security and low-emission transition. For five years, the head of the "Energy" project and then the "International Economic Relations and Energy Policy" programme at the Polish Institute of International Affairs, one of the most recognised analytical teams in Central Europe. Previously, for many years, working on the issues of the national sector and regional electric power market markets at the Energy Regulatory Office. Doctor of Economic Sciences, Master of Administration. Author of many publications on energy, combining political and economic perspectives. Regular commentator on energy and international issues in the media.

HONORATA NYGA-ŁUKASZEWSKA – PhD, graduate of the Warsaw School of Economics. Doctor of Economics, assistant professor at the Collegium of World Economy of the Warsaw School of Economics. Her professional career is associated with the Ministry of Foreign Affairs of the Republic of Poland. Member of the Polish delegation to the UNFCCC. Graduate of the U.S. government scholarship programme and many trainings, e.g. at the International Energy Agency. Author of publications in the field of international economics, including in particular international energy markets and energy security.

EWA MATACZYŃSKA – PhD, degree in economics in the Institute of Economic Sciences of the Polish Academy of Sciences in Warsaw. Master of Mathematics and Programming Techniques of Electronic Digital Machines. Over 25 years of experience in the electricity sector. Currently, the most important activities focus on topics related to involvement in scientific and professional work as an expert at the Ignacy Łukasiewicz Institute of Energy Policy; Chief Specialist for International Relations and Regulations in the Distribution Services Department of PGE Dystrybucja S.A.; Vice-Chairperson of the WG1 (Reliable, economic and efficient smart grid system) ETIP SNET working group; member of the Technology Committee and the E.DSO Policy Committee for smart grids, vice-chairperson of the Active System Management working team at E.DSO for smart grids, member of the DF (distributed flexibility) expert group in the EU DSO Entity, expert in the DSF (demand side flexibility) advisory group set up by ACER to work on the development of guidelines for flexibility regulation (Flexibility Network Code), member of the working group on the use of stationary energy storage in Europe Batteries. Author of numerous publications in the field of the broadly understood energy market, with particular emphasis on energy communities, new technologies, grid flexibility, hydrogen. Currently, the leading theme in professional and scientific work is the directions of new regulations at the level of European Union regarding flexibility services (the process of creating a new network code).

DARIUSZ MICHALSKI – ATH professor at the Department of Economic Sciences of the University of Technology and Humanities in Bielsko-Biała. Expert in management control and risk management, with particular focus on the corporate performance on the energy market, supported by extensive business experience and theoretical knowledge of the power sector. Author and co-author of books on management control and risk management and over 100 publications devoted to enterprises of the real sphere and the energy market, especially finance and risk management in the power industry.

DOROTA NIEDZIÓŁKA – PhD in Economics, SGH professor. Head of the Department of Economic Geography, Dean of the Master's Degree at the Warsaw School of Economics. Energy market expert. Author of over 100 publications on the determinants of operation of energy markets, location of elements of technical infrastructure as well as energy security.

JÓZEF PASKA – professor, the title of MSc Eng. at the Faculty of Electrical Engineering of the Warsaw University of Technology in 1974 (specialisation – power plants and power management); doctoral degree in 1982 (doctoral dissertation entitled *Reliability models of electrical systems supplying own needs and power output of power plants*), habilitated doctor degree in 2002 (habilitation monograph entitled *Assessment of the reliability of the generation subsystem of the power system*), academic title of professor on 21 December 2007. In the years 2002–2005 and 2005–2008, Deputy Dean of the Faculty; and in the years 2009–2020, head of the Department of Power Plant and Power Economy. Member of the programme councils of the magazines "Rynek Energii" and "Energetyka". In the years 2003–2006, member of the Committee on Energy Problems at the Presidium of the Polish Academy of Sciences; in the term 2011–2015, member of the Presidium of the Committee on Energy Problems at the Faculty of Technical Sciences of the Polish Academy of Sciences; in the term 2015–2018, member of the Committee of Energy Problems at the Presidium of the Polish Academy of Sciences; and in the term 2019–2022, member of the Committee on Energy Problems at the Presidium of the Polish Academy of Sciences; in the term 2016–2020, member of the Committee of Electrical Engineering of the Polish Academy of Sciences. From December 2013 till May 2022, Chairman of the SEP Nuclear Energy Committee. In the period July 2017 – June 2019, Chairman of the Scientific and Technical Council for Innovation of the Energa Group. In the years 2020–2025, member of the Scientific Council of the Distributed Energy Competence Network (SKER). His scientific interests concern electricity generation technologies, including distributed generation and the use of renewable energy resources, power management and power economics, reliability of the power system and security of electricity supply. Author of over 330 articles and papers as well as 14 monographs and academic textbook; member of the Association of Polish Electricians, the Polish Society of Theoretical and Applied Electrical Engineering, the Polish Nucleonic Society, the World Scientific and Engineering Academy and Society and the International Council on Large Electric Systems (CIGRE).

FILIP SCHRAUBE – technical specialist in the Department of Innovative Initiatives at Enea Operator sp. z o.o. in Poznań; works on the implementation of pilot and R&D projects in the field of electricity distribution. The main topics implemented by the Department: the quality of electricity, modern measurements in the low-voltage network and smart meters of remote reading system, the use of virtual reality to support the process of electrical technician training, the use of drones for line inspection and property passporting, energy storage in the DSO network (H2, LTO, VRLA, EDLC, LIC, LFP), etc.

KATARZYNA STALA-SZLUGAJ – D. Sc., Eng., working for the Mineral and Energy Economic Research Institute, Polish Academy of Sciences in Krakow, Division of Fossil Fuels and Energy Market Research. Author or co-author of many scientific publications and statutory reports as well as research and development work in the field of the domestic and international fuel and energy markets, done for business entities in the field of mining and energy.

TOMASZ P. WIŚNIEWSKI – research and didactic worker of the Institute of International Economic Policy at the Collegium of World Economy, Warsaw School of Economics. Many years of national and international analytical and managerial experience, gained in enterprises and financial institutions of the private sector as well as offices and institutions of public sector. His research work focuses especially on the issues of development economics, welfare economics and happiness economics as well as investment and energy economics.

PAWEŁ WRÓBEL – expert in the European Union regulations specialising in energy and climate policy. A founder and head of the consulting company Gate Brussels. Currently, manages the BalticWind.EU platform and also cooperates with Porozumienie Branżowe na Rzecz Efektywności Energetycznej (Sectoral Agreement for Energy Efficiency), (POBE) and the RE-Source Poland Foundation, which promotes the model of corporate power purchase agreements (CPPA). In the years 2015–2018, Director of the Polish Electricity Committee in Brussels, representing the interests of the power sector; in the years 2010–2015, working in the cabinets of the Commissioners for the Budget of the European Union as well as in the Directorate of the European Commission for the Budget. Participated in the work and negotiations on many EU regulations creating a legal framework for the modernisation of the energy sector. Author of many analyses and reports in the field of energy transition.

KRZYSZTOF ZAGRAJEK – engineer and master engineer in the field of electrical engineering in 2017 and 2018, respectively. His master's thesis entitled *The development of electromobility in public transport on the example of the Warsaw urban agglomeration* awarded in the Tauron Dystrybucja competition for the best degree thesis in the academic year 2017/2018. In 2018, worked in the Polish Power Grids in the Department of Certification and Capacity Market Auction. As of 2019, assistant professor at the Institute of Electrical Power Engineering of the Warsaw University of Technology. His scientific interests concern the integration of electric vehicles with the power system, in particular as part of the Vehicle-to-Everything technology as well as work related to the implementation of the power market in Poland. Author of several research publications and scientific-industrial studies on modern approach to power systems.