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Monika Papież, Sławomir Śmiech

Editorial

Energy Transition in the Context of Society, Environment, and Economy

The need to reduce greenhouse gas emissions is essential for ensuring a balanced ecosystem and reducing negative effects of the climate crisis. The energy transition aimed at reducing greenhouse gas emissions is becoming a necessity, but also a challenge of the modern world. Although they did not bring any significant breakthrough, the Kyoto conferences in 1997 and the Paris Agreement ratified in 2016 both emphasised the concern of numerous countries about the climate and set the course for economic and social changes.

By shaping their energy and climate policies, the European Union's Member States are moving towards a low-emission or even a zero-emission economy, i.e. towards the green economy. This aspiration requires the undertaking of major initiatives. The European Union has set climate and energy policy targets to be achieved by 2020, as well as targets for the following decades up to 2030 and 2050. These primarily relate to the development of renewable energy sources (RES) and taking action towards the decarbonisation of countries, thus introducing changes in the construction of the electricity system in all the Member States. Hence, the transformation of the electricity sector is one of their greatest challenges. In the European Union, energy transformation is reflected in a number of initiatives, which include the commitment of the countries which has been expressed in the Europe 2020 strategy and now in the *Fit for 55* package.

The most significant policy instrument of the EU is the introduction of the CO2 emissions trading scheme. In the first three phases, the need to purchase emissions was extended mostly to electricity generating companies, and the greatest progress was achieved in these sectors (Papież et al., 2021). Emissions reductions in individual countries are derived from a number of specific circumstances, such as the fossil fuels resources (Papież et al., 2018) or conditions for wind or solar power (Papież et al., 2019). As part of the *Fit for 55* package, it is planned to extend the trading of emissions from households and individual transport. The pressure to reduce greenhouse gas emissions is becoming a major political, economic, technological, and social challenge for the countries within the European Union.

Poland has also joined the group of countries which are undertaking initiatives supporting the implementation of the climate neutrality concept. One of them is the resolution on the "Energy Policy of Poland until 2040" plan, approved by the Council of Ministers on 2nd February, 2021. This document specifies Poland's strategy for energy transition related to the energy sector, as well as for meeting

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economic needs that stem from the weakening of the economy due to the COVID-19 pandemic.

In Poland, emission reductions will consist in the further substitution of coal in the energy mix. The launch of nuclear power plants is planned within the next two decades, but temporary reductions in emissions will be a result of replacing coal with natural gas. At the same time, it is extremely important to take into account the regionalisation of the natural gas market, which is conditioned by the gas transmission infrastructure.

The issue of the existence of long-term equilibrium between the European and the American markets is addressed by Katarzyna Bech-Wysocka in her article titled "Understanding the Dynamics of the Prices of Natural Gas as an Important Step in Energy Transition". The VECM model constructed in the author's study proves the existence of long-term relations between the American and the European markets, which indicates significant links despite the lack of common infrastructure. Furthermore, the study shows that shocks from the European market transmit to the USA.

The social impact of the energy transition can be felt by poorer groups of society. In Poland, for example, changing energy sources means switching from cheap coal to more expensive gas. Therefore, if the change of sources is not combined with an improvement in the energy efficiency of buildings, households bear higher costs, which can result in an increase in the extent and depth of energy poverty (Karpinska & Śmiech, 2021). The issues of measuring energy poverty are taken up by Lilia Karpinska in the article titled "Faces of Poverty: Who Are the Energy Poor in Poland?" This study reveals a difference in the scope of energy poverty, which results from the use of alternative poverty measures. It also provides the profiles of energy-poor households, which potentially allows a more effective planning of social policies to cushion the negative social consequences of energy transition.

Another issue related to energy transition is the creation of a common electricity market in the European Union's countries. Energy integration is necessary, because it creates the conditions for building solutions which support energy security and the reliability of the electricity system (including supply) throughout Europe. In crisis situations involving interruptions in energy supply, a common energy market will make it possible to import electricity from other countries. An example of such an action includes the failure of the Polish power plant in Bełchatów (17th May, 2021), in which 10 out of 11 power units were switched off as well as, in order to avoid blackout, energy was imported to Poland mainly from Germany and Sweden. Magdalena Sikorska addresses the issue of creating an integrated electricity market in her study titled "The Integration of the Polish Electricity Market in the Period 2015–2021". Using a qualitative method, the author presents the changes taking place in the energy policy of the European Union and Poland with regard to the creation of a common electricity market. In particular, she analyses the balance of actual cross-border synchronous and asynchronous flows between Poland and the neighbouring countries. The author concludes that the degree of integration of the Polish energy sector with the European energy market increases with the introduction of new electricity market regulations in the European Union. These results can be important for policymakers, as they indicate that the European Union's energy policy influences the degree of integration of the energy sector, including the Polish one.

"The Development of Biogas Production in the Context of Energy Transition: The Case of Poland", which is an article by Paulina Szterlik, can be a voice in the discussion on what the new energy system in Poland should look like in the next 20 years. The author focuses on the question whether the energy system in Poland should be highly concentrated or dispersed, or whether Poland should choose an in-between solution. Using heuristic techniques of data analysis and the SWOT analysis, the author examines the chances for further development of biogas production, which is one of the types of RES, despite the current changes in Polish programmes. The author concludes that biogas production can be beneficial to local economic growth, environmental awareness, and social welfare. She also indicates that there is a strong need to break down barriers to a further development of biogas production. Biogas production can help meet national and international targets for a just energy transition, developing low-carbon economies and coping with modern economic trends. It also highlights the importance of biogas in the energy transition in Poland while taking into account the "Energy Policy of Poland until 2040" plan.

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Katarzyna Bech-Wysocka

Understanding the Dynamics of the Prices of Natural Gas as an Important Step in Energy Transition

Abstract

Objectives: The natural gas seems to be an attractive supplement to the renewable energy sources in energy transition towards low carbon emissions. Given its flexibility to transmit and store, the natural gas offers a diversity of the renewables. Understanding the formation of natural gas prices is crucial for evaluating the costs of energy transition, in particular the return to investment into natural gas infrastructure.

Research Design & Methods: In order to study the natural gas prices dynamics in Poland, I developed a Vector Error Correction model (VECM) for a joint determination with prices in the USA and in Europe. The VECM setup made it possible to analyse the interactions among non-stationary prices as well as investigate how disturbances specific to the discussed markets pass on within the system.

Findings: By exploring impulse response functions and forecast error variance decompositions, I demonstrate that the European natural gas prices are not affected by shocks in the American gas market, as they are determined solely by the shocks specific to the European natural gas market. Additionally, the natural gas prices in Poland are highly correlated with, and responsive to, other European countries' prices. The results go in line with the hypothesis of the existence of a common, integrated European natural gas market.

Implications / Recommendations: In the context of energy transition, the return to investment within natural gas infrastructure can only be forecast given the predicted prices. The appropriate proportion of alternative energy sources in the energy mix can be achieved only after examining this dynamics and the differences in prices of alternative energy commodities. Hence, the feasibility of predicting natural gas prices should always be considered at the early stages of any energy transition policy.

Contribution / Value Added: The results add to the discussion on the role of natural gas in energy transition. They reveal how gas prices on the main markets have fluctuated over the recent years as well as they link the prices in Poland to natural gas prices abroad. The findings fill the gap in the literature, which so far has been focused mainly in the American market.

Keywords: natural gas market; natural gas prices; energy transition; VECM

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Introduction

The world is going green. The new Climate Law agreed in the EU Parliament sets the target to reduce carbon emissions by at least 55% by 2030 when compared with the 1990 levels. It also commits Europe to become the first climate neutral continent by 2050. The American President Joe Biden also recommends to reach net zero carbon emissions by 2050. Such ambitious climate protection plans require the core energy transition in the form of moving away from coal to ‚greener' energy sources. This is especially encouraged in countries where carbon pricing is either implemented or scheduled for implementation, including emissions trading systems and carbon taxes.

An important question in energy transition is how to complement unstable supply of energy from renewables in a flexible way by the use of energy supplies from traditional sources. The natural gas, which provides energy for all kinds of purposes (residential, commercial, industrial, power generation uses, vehicle fuel) seems to be an attractive choice, as natural gas electric plants are very flexible and at the same time the CO2 emissions from natural gas are lower than from other fossil fuels. The huge advantage is also the ease of storing and transmitting natural gas between powerplants and countries, provided that the appropriate infrastructure is in place. Hence, natural gas offers the possibility to balance the variability of the renewable energy sources. Natural gas is also the cleanest of fossil fuels. It has been proven that switching from coal to natural gas reduces carbon dioxide and methane emissions by 30%–50%, depending on the production purpose (heat vs. electricity) (IEA, 2020). In terms of pricing, the combination of the recently low natural gas prices has given it an additional economic advantage. An interesting fact is that even though switching away from coal has become a hot topic recently, switching to natural gas has got a much longer history in Europe, especially in the residential sector. As the IEA (2020) report shows, residential gas usage in the UK overtook the coal use already in the mid-1970s. Hence, the role of gas in energy transition is irreplaceable.

Searching for the alternative to coal energy sources is particularly important, especially in view of recent events in the EU. The Polish brown coal mine (Turów) near the border with the Czech Republic has been ordered to cease activity by the European Court of Justice. The Turów mine delivers coal to the near power plant, which on average provides 7% of the total country electricity production. As the mine was forced to immediately stop extracting coal due to environmental issues, it has raised the concern about whether the other energy sources are sufficient to cover the loss. It is suggested that because of favourable weather conditions, the gap should be filled by solar and wind plants. However, the question with regard to the best long-term solution remains open. Perhaps switching to natural gas to a larger extent might provide a quick win not only for the environment, but also for the neighbourly relations. One can imagine that similar cases of suing the worst polluters might occur in the future, which is why securing the appropriate energy source is crucial.

This article discusses the role of natural gas in the energy transition and provides an overview of the European gas market. It reveals how the gas prices on the main markets have fluctuated over the recent years and tries to link the prices in Poland to natural gas prices abroad. The contribution of this paper is twofold. First, I show that the natural gas prices in Europe are not affected by shocks in the American gas market. Second, I confirm that there is a strong integration of the natural gas prices in Europe.

Similarly to coal market, the global natural gas market is geographically segmented into several localised markets, which is due to transportation costs and heterogeneous institutions (Papież & Śmiech, 2015). The role of natural gas in energy transition has recently been widely discussed in the literature, for instance by Najm and Matsumoto (2020), who deliberate on the substitution of natural gas with renewable energy sources in the global energy mix. Gillessen et al. (2019) emphasise the role of natural gas infrastructure, while Blazquez et al. (2020) highlight the role of technology and consumer preferences towards zero carbon emissions.

My main interest has been to understand how natural gas prices on distinct markets are interrelated. Obviously, the literature on the dynamics of natural gas prices is relatively rich, but the focus is in the US market, where prices are entirely determined by market forces from the mid-1990s (Joskow, 2013), providing the longest time-series to analyse. Research shows that demand shocks seem more important in explaining the dynamics of natural gas prices than supply shocks do (Arora & Lieskovsky, 2014; Hou & Nguyen, 2018; Hailemariam & Smyth, 2019). The dynamics of the European natural gas market is relatively unexplored when compared to the US market. The main question posed in the literature is whether natural gas prices in the European market are driven by changes in crude oil or US natural gas prices, or maybe by the fundamentals specific to the European natural gas market. One conclusion is that the co-movement of European and North American natural gas prices is driven by crude oil prices rather than gas-to-gas arbitrage (Bastianin et al., 2018; Brown & Yucel, 2009). The other part of the literature focuses more on natural gas prices determinants on individual markets. For instance, Erdos (2012) applies the Vector Error Correction Model (VECM) in order to show that natural gas prices traded in the UK remain in a long-term equilibrium with crude oil prices, but also react to deviations from a cointegrating relationship between the US natural gas prices and WTI prices. Hulshof et al. (2016) find out that daily spot prices at the Dutch gas hub are over the short-term horizon only mildly affected by changes in oil prices, but that they react to the level of natural gas inventories, temperature, and the production of wind electricity. Nick and Thoenes (2014) use a structural Vector Autoagression (VAR) approach in order to examine how gas prices in Germany are impacted by gas supply disruptions, weather conditions, storage activity, and LNG imports.

Typically, the commodity prices (including natural gas) are non-stationary and cointegrated on different markets. Therefore, one of flexible ways of dealing with such time-series is the aforementioned Vector Error Correction Model (VECM). Certainly, such an approach is not new in the natural-gas-related literature and has been applied, for instance, by Schultz and Swieringa (2013), or Ramberg and Parsons (2012), among others. I apply the VECM specification in order to determine the relationship between the European and the American natural gas prices, as well as their impact on the Polish prices.

The paper is structured as follows. In the subsequent section, I summarise the structure and provide some main statistics with regard to the European natural gas market. The third section describes in detail the data utilised in this study. In the fourth section, I present the model and the findings. The methodological and policy implications conclude the study.

The European gas market

In the recent years, the growing popularity of renewable energy sources such as solar, wind, or geothermal power has been observable globally. Over the past decade, renewable energy consumption has grown globally at the average annual rate of 13.7%. However, the energy supply from these green sources depends heavily on the geographical location and different weather conditions. Not all of the countries have access to the seacoast – which would allow for the production of tidal energy – as well as not all of them are able to invest in geothermal plants. Additionally, the power produced by the renewables is difficult to store. For instance, during the summer time, Norway produces the energy in the hydropower plants in amounts far beyond the country's consumption needs, and sells the surplus abroad. In winter, when rivers are frozen, the country is forced to buy energy from abroad, often at a higher price. With all these drawbacks of renewables, another source of energy is needed to replace coal and provide ‚quick wins' for lowering emissions and decreasing the levels of air pollution. Even recently, with the COVID-19 crisis – which resulted in global energy demand drop of approximately 30% at one point (the first estimates by the International Renewable Energy Agency) – the interest of investors in sustainable and resilient energy sources did not decrease.

Since 2010, natural gas prices have been on a downward trend. As a consequence, the global gas consumption has been continuously growing at the rate of 1.8% per year (IGU, 2018), reaching a record of growth of 2.3% in 2019 (IGU, 2020). However, the recent post-COVID-19 figures show a drastically different picture. According to the International Energy Agency, gas demand in 2020 fell by 2.5% and it was the largest ever recorded drop in gas consumption since the development of the gas industry in the second half of the 20th century. In comparison, gas demand fell only by 2% in 2009 because of the global financial crisis. Clearly, gas demand is impacted by lockdowns (lower electricity use) and the uncertainty of pandemic persistence (IGU, 2020). Nevertheless, the full recovery of demand to pre-COVID-19 levels is predicted within the next two years. Obviously, the natural gas infrastructure investment is critical for obtaining such growth levels. On the other hand, the pandemic's impact on the natural gas supply was rather limited, and preliminary estimates show that natural gas production was relatively stable (IGU, 2020). For the future, the IEA predicts the average natural gas demand growth of 1.5% per annum from 2019 to 2025. The earlier (pre-COVID-19) forecast for the same period mentioned 1.8% of average annual growth. Additionally, the experts suggest that the share of natural gas will reach 25% of global energy demand in 2040, overtaking oil (IGU, 2020).

The European natural gas market went through a series of regulatory and technological reforms in the last thirty years. From state-owned monopolies with bilateral long-term contracts, it moved towards a competitive and integrated market. The reforms have regulated all parts of the gas market: up-stream (production), mid-stream (transport), and down-stream (local distribution) (Chyong, 2019).

The European natural gas consumption has constantly been growing since 2014, driven by the economic growth and the need of energy transition by means of switching away from coal. We have observed a stable, constant natural gas consumption growth at the rate of around 2% per year till 2019. The leaders in 2018 included the Netherlands (growth of 10% y/y), Italy (6% y/y), and Germany (6% y/y). All these countries plan to eliminate coal from their energy production by the 2030s. With the COVID-19 crisis, gas demand in Europe suddenly declined by 7% y/y over the first five months of 2020 (IGU, 2020). After the stagnation at the beginning of 2020, the latest data from the fourth quarter of 2020 shows a consumption increase of 1.3% (European Commission, 2020).

The European gas production grew by 1.9% in 2018, mainly because of Norway on the North Sea (IGU, 2018). However, the production across the rest of Europe declined. For example, the Dutch government decided to limit gas production on its territory due to the earthquake risk. The figures of 2019 reveal the decline of the European gas production by 6.9% (IGU, 2020). The latest figures show the decrease of 15% in the fourth quarter of 2020, compared to the fourth quarter of 2019 (European Commission, 2020). The European gas reserves in the Netherlands, the UK, Germany, France, and Italy are in decline. Apart from Norway, there is no potential for supply expansion within the EU (Correljé, 2016).

A critical aspect of the European gas market is its heavy dependence on imports, either via pipelines or by means of LNG. The growing European consumption is mainly supplied by the Russian gas production growth via the Nord Stream pipeline. Other large exporters of gas to Europe include Norway and Algeria. Pre-COVID-19 figures have shown 11% growth in trade via pipelines from Russia and Norway. Generally, in 2019, the net imports increased by 6% (IGU, 2020). However, the latest data from the fourth quarter of 2020 reveals the 9% year-to-year decrease in net imports. Additionally, the recent LNG imports fell by 27% year-to-year (European Commission, 2020).

The Polish gas consumption has reached 20.4 billion cubic meters in 2019 and has constantly been growing since 2005. Around 30% of this amount is produced locally, with the remaining volume imported mainly from Russia and Norway. Interestingly, the biggest supplier of imported LNG to Poland is Qatar (European Commission, 2020). As for the energy transition, the main problem is that Poland is still heavily dependent on coal, which accounts for 48% of local energy production. The Polish energy plan states that the last black coal mine will be closed no later than in 2049, but international critics have called for the energy transition much sooner.

Bearing in mind the need for the reduction of carbon and greenhouse gases emissions, a well-planned gas infrastructure must be provided. As these assets require time to be developed, the industry and policymakers in newly developing natural gas markets should pay attention to network infrastructure developments. The largest recent gas-related investments in Europe include: Europe's Nord Stream pipeline (completed in 2012), which increased the transmission capacity from Russia to Europe via Germany; the Trans-Anatolian pipeline (TANAP; completed in 2018), which connects Azerbaijan with Europe via Turkey; and the Trans-Adriatic pipeline (completed in 2020) providing the supply to Italy via Greece. On the other hand, the growing number of LNG terminals around Europe ensures the diversification of energy supply (Correljé, 2016). Generally, the existing gas infrastructure is capable of meeting the EU's decarbonisation goals.

Gas prices

Over the recent decades, the natural gas prices increased globally due to a bigger than expected demand and an increase in oil prices, as a large number of long-term gas contracts are indexed in oil prices (Chyong, 2019). Worldwide, a similar increase of oil and coal prices was also observed. It is worth noting that natural gas is still much more expensive than coal; the premium of gas to coal is around 40% globally, and even higher in Europe. Recently, gas prices have started to decrease, reaching in Europe the negative growth rate of -38% in 2019 (IGU, 2020).

Theoretically, the perfect competition in the European gas market ensures that natural gas prices in different European countries only vary only by transaction costs, such as the cost of transporting gas from one place to another, or non-trade barriers (Chyong, 2019). My aim is to examine the relationship between the European and the American natural gas prices. I am particularly interested in evaluating the impact of prices abroad on the natural gas prices in Poland. Understanding the formation of natural gas prices is important especially in the process of energy sector transformation. In order to evaluate the costs of energy transition in Poland, the ability to forecast future natural gas prices is crucial, even in the planning phase, when a typical cost-benefit analysis is employed. Investing in the natural gas infrastructure, e.g. building gas power plants and pipelines, must take into account the dynamics of natural gas prices, especially in comparison with the renewable energy, which, after initial investment, is practically costless. Another important aspect is that if policymakers are aware of the response of the natural gas prices in the Polish market to shocks in other gas markets (especially within the EU), they can react relatively quickly and, if possible, adjust the energy mix towards cheaper sources if natural gas prices are predicted to increase.

To understand the natural gas price dynamics, we use the time-series of daily observations on the natural gas prices (closing prices) in the main European (the United Kingdom, the Netherlands, Denmark, and Italy), American, and Polish gas markets. All series are with different time horizons. When necessary, I limit observations to a common time frame, which is from April 13th, 2015, to April 12th, 2021 (the shortest series is from

Poland, while the longest one is from the USA). For presentation purposes, the weekly and monthly averages of prices have been calculated, and I have constructed the appropriate growth rates. The data comes from the Thomson Reuters Eikon. All data has been transformed to a common unit of measurement, i.e. EUR/MWh.

Figure 1 shows the average monthly values of the natural gas prices on the main markets from April 2015. Clearly, the natural gas prices are strongly correlated, which is particularly visible in the European market. While the European prices are similar in magnitude, the US prices are the lowest.

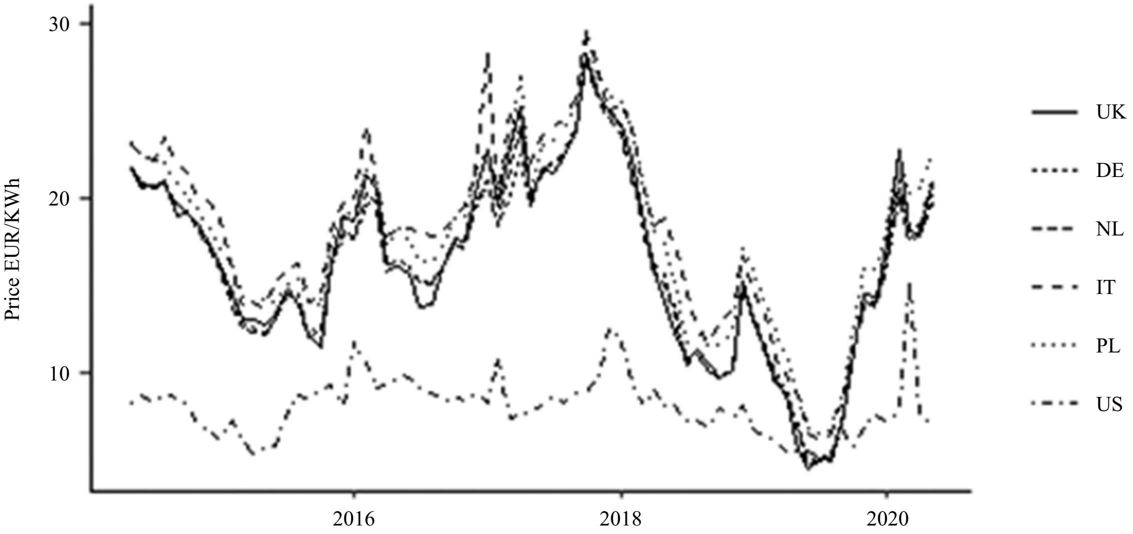


Figure 1. Natural gas prices (monthly average values)

Source: own elaboration.

Moreover, Figure 2 shows the monthly growth rates for each market separately. Here, I focus on the common time horizon from April 2015. The US prices seem to fluctuate much more than the European prices do, especially towards the end of the sample. This reflects different structures of the American and the European natural gas markets. The growth rates in European countries look very similar to one another. This is a clear sign of the existence of a common, integrated European gas market.

Table 1 shows the average weekly growth rates of natural gas prices on the main markets. I focus on the common horizon from April 2015. The average values are additionally split into pre- and post-COVID-19 periods with the aim of better understanding the recent dynamics and taking into account the global crisis and its impact on energy markets. It will be interesting to investigate whether the behaviour of natural gas prices will reverse soon and follow the pre-COVID-19 pattern, or whether the crisis will have the long-lasting impact on the energy market.

I observe the negative dynamics of natural gas prices in the recent years. Even though I recognise negative growth rates from 2015 to 2020, an interesting feature is observed during the COVID-19 crisis. The natural gas prices increased at the weekly average of around 0.85% in the UK and 0.7% in continental Europe, and 0.2% in the USA. This is rather unexpected, as the global demand for energy in general decreased over that period.

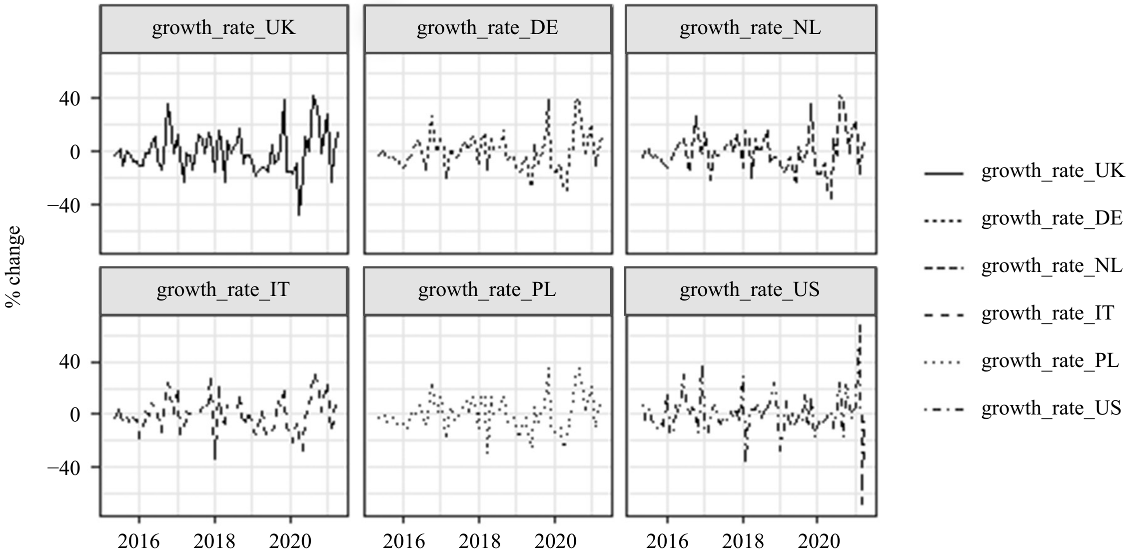


Figure 2. Monthly growth rates of natural gas prices

Source: own elaboration.

Table 1. Average weekly growth rates of natural gas prices

	the United Kingdom	Denmark	the Netherlands	Italy	Poland	the USA
Full sample	−0.031	−0.032	−0.041	−0.037	−0.026	−0.049
Pre-COVID-19	−0.287	−0.226	−0.262	−0.242	−0.266	−0.107
Post-COVID-19	0.904	0.676	0.768	0.712	0.849	0.162

Note: The Table presents the mean for weekly log changes (x100). The pre-COVID-19 period is from April 2015 to December 2019, while the post-COVID-19 period is from January 2020 to April 2021.

Source: own elaboration.

Table 2. Descriptive statistics for weekly natural gas prices

	Mean	SD	Min.	Max.	Skew.	Kurt.	JB	ADF		ADF-GLS	
								lev.	diff.	lev.	diff.
UK	16.323	5.529	3.499	44.924	0.230	4.453	30.79	−0.833	−15.873	−1.226	−3.163
DE	16.157	5.051	−3.930	30.360	−0.110	2.816	1.094	−0.646	−12.411	−1.231	−3.710
NL	16.071	5.260	3.630	41.880	0.173	4.169	19.694	−0.800	−15.865	−1.133	−3.414
IT	18.004	5.391	5.216	41.380	0.138	3.764	8.753	−0.917	−17.292	−1.009	−3.179
PL	17.758	5.221	5.663	46.535	0.329	5.150	66.962	−0.772	−16.537	−1.155	−3.097
US	8.046	2.265	4.678	35.222	5.673	66.956	55.903	−1.575	−18.337	−2.581	−7.262

Note: JB and ADF refer to the values of the Jarque-Bera normality and the Augmented Dickey Fuller tests. ADF-GLS stands for Elliott, Rothenberg, and Stock's (1996) test for a unit root. The critical values for these tests for the 1%, 5%, and 10% significance levels are –3.44, –2.87, and –2.57 (ADF); 4.61, 5.99, and 9.21 (JB), and –2.57, –1.94, and –1.62 (ADF-GLS).

Source: own elaboration.

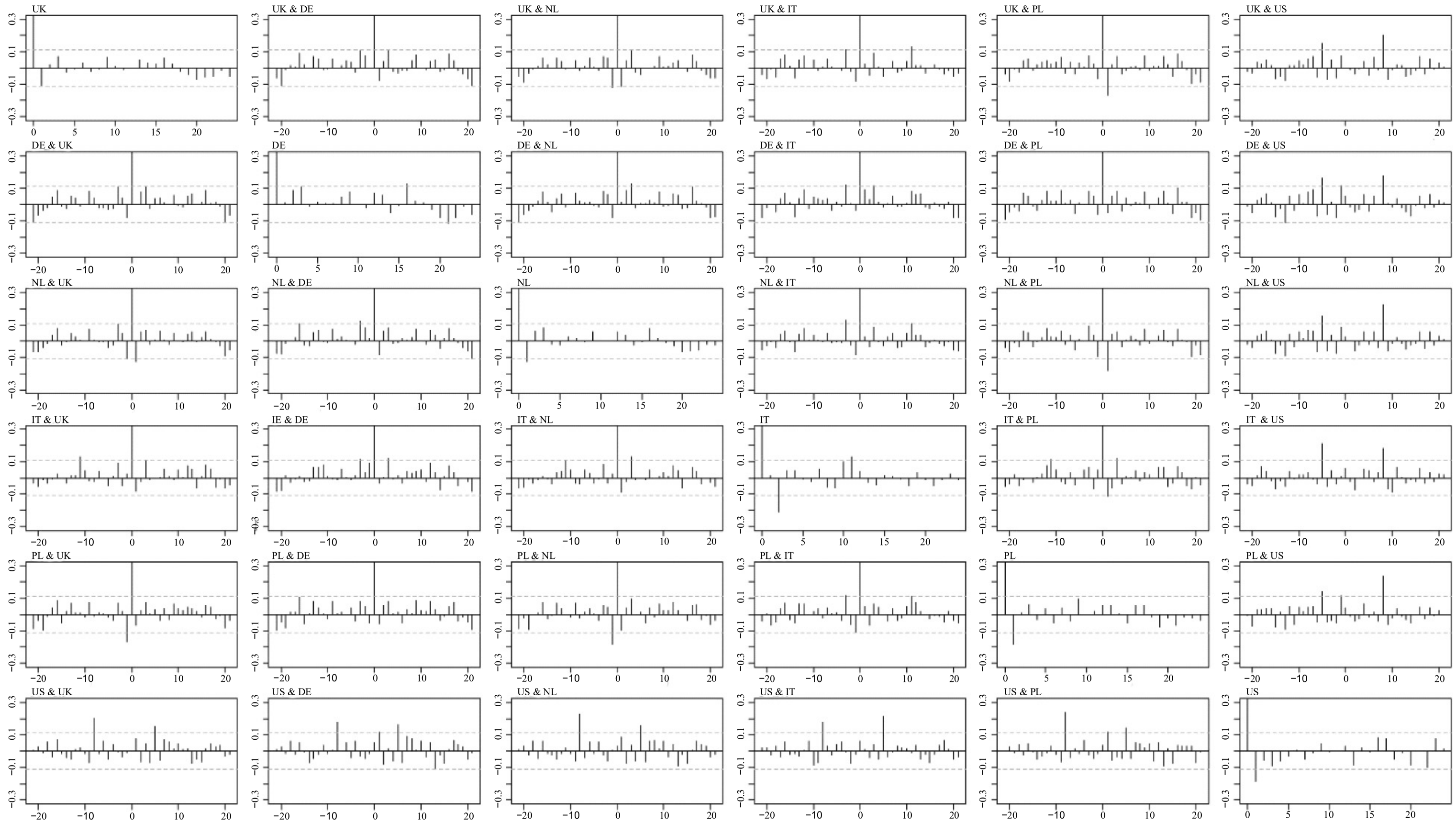


Figure 3. Cross correlations for weekly growth rates of natural gas prices

Source: own elaboration.

The descriptive statistics of the series are presented in Table 2. They confirm that the dynamics of the American natural gas prices is different from that of the European prices, which behave similarly country-by-country. In particular, the American natural gas prices are much lower than the European ones, with a smaller standard deviation, but one that is skewed and leptokurtic. Not surprisingly, the results of the ADF tests in all series indicate a unit root behaviour in levels, but not in the first differences. Hence, as is typically the case with commodity prices, natural gas prices are I(1). As the demand for natural gas tends to increase and this tendency is likely to be auxiliary, I additionally perform the ADF-GLS test for a unit root, which has higher power than the standard ADF test when dealing with a time series that is close to being integrated. The conclusions from both ADF tests are the same with the exception of the case of the USA, where the null hypothesis of non-stationarity for levels is rejected in the ADF-GLS test.

Given what is presented on graphs and in tables, the next step is to examine the dynamic relationships between the series by means of looking at cross correlograms presented in Figure 3. The panels show how natural gas prices react to their own lags (on the main diagonal) and to changes in prices on different markets. The main observation is that most of the growth rates are correlated only contemporaneously and do not react to past changes.

The model and its implications

I analyse the dynamics of prices in the natural gas market by considering the Vector Error Correction Model for a vector, denoting the natural logarithm of weekly average values of prices on these markets. As presented above, the natural gas prices in European countries have similar characteristics and dynamics. I have chosen the Netherlands as the representative country. The Netherlands has been relying on natural gas for generations and has one of the lowest share of renewables in its total energy use in Europe. As the country’s largest gas field is slowly closing down, the Dutch economy is just at the beginning of the energy transition, which makes it particularly interesting to investigate in this study. I avoid fitting the model with all series, because given the sample size, the number of parameters to estimate in the system would be alarmingly large.

I start by analysing the standard VAR model with a lag length p, i.e.:

$$y_t = A_0 + A_1 y_{t-1} + \cdots + A_p y_{t-p} + \varepsilon_t, \varepsilon_t \sim N(0,\Sigma), \quad (1)$$

where y_t is the 3 × 1 vector of endogenous variables, A_0 is the 3 × 1 vector of constant terms, A_jf or = 1,2,...p are 3 × 3 matrices of coefficients, and ε_t is the 3 × 1 vector of residuals.

As presented in Table 3, the lag length $p = 2$ is chosen as optimal, based on the AIC and FPE criteria.

Table 3. VAR lag order selection criteria

Lag	AIC	HQ	SC	FPE
1	−15.955	−15.897	−15.810	1.177
2	−15.982	−15.880	−15.727	1.145
3	−15.972	−15.826	−15.608	1.157
4	−15.971	−15.781	−15.497	1.159
5	−15.947	−15.714	−15.365	1.186

Note: AIC: Akaike information criterion; HQ: Hannan-Quinn information criterion; SC: Schwarz information criterion; FPE: Final prediction error. The presented values of FPE are multiplied by 10^7.

Source: own elaboration.

As all series are non-stationary, instead of fitting the standard VAR model, I perform the Johansen cointegration test to verify whether there exists a cointegrating relationship between natural gas prices on different markets. As the natural gas prices are cointegrated, the VECM specification is fitted as

$$\Delta y_t = B_0 + \Pi y_{t-1} + B_q y_{t-q} + \cdots + \\ + B_q \Delta y_{t-q} + \varepsilon_t, \varepsilon_t \sim N(0,\Sigma), \qquad (2)$$

where Πy_{t-1} is the error correction term, which captures the effect of how the growth rate of a variable in y changes, if one of the variables departs from its equilibrium value. The matrix is assumed to have rank r, which indicates the number of cointegrating relationships between the variables. Note that the coefficient matrix can be expressed as $\Pi = \alpha\beta'$ where β' is referred to as the cointegration matrix and α as the loading matrix. β contains the information on the long-run relationships between variables, and – on the speed at which the dependent variable converges back to the equilibrium. Note that $q = p - 1 = 1$, as one lag is 'lost' for differencing.

The results of the Johansen test are shown in Table 4, including both trace and maximal eigenvalue test.

The first null hypothesis of no cointegration (H_0:$r = 0$) as well as the second one (H_0:$r \leq 1$) are rejected in both tests. There is no evidence for rejecting the final null hypothesis (H_0:$r \leq 2$), leading to the conclusion that the rank of the cointegrating matrix is 2, which means that two cointegrating relations have emerged. To ensure that the VECM is correctly specified, I have run a set of diagnostic tests. Failing to satisfy the normality of error assumption is not a problem given the sample size, and, more importantly, the specification passes the errors autocorrelation test.

Note that I have experimented with 'larger' specifications, i.e. with lag lengths $p = 3$ and $p = 4$, which translates into additional $(t - 2)$and $(t - 3)$ terms in the VECM specification. However, the results are qualitatively the same as in the more parsimonious version of the model. As a robustness analysis, I additionally present the estimates of the enlarged model, but my main focus continues to be the original specification.

Estimates. The estimated coefficients of the VECM model are presented in Table 5. The estimated cointegrating vectors are shown in Table 6.

The negative and statistically significant value of the error correction coefficient indicates the existence of a long-run causality between the natural gas prices. I observe this in equations for the Dutch and the Polish prices. In other words, the changes in natural gas prices in the Netherlands and in Poland can be explained by natural gas prices in Europe as a whole. Additionally, these parameters indicate the rate of convergence to the equilibrium. The corresponding estimates for the US market are insignificant in the smaller model, but significant when more lags are added to the specification.

The individual lag coefficients in Table 5 are interpreted as a short-term causality, i.e. short-term impact on the natural gas prices. I observe that the US natural gas prices do not depend on the European prices, but only on their own lags. For the European market, I observe the interdependence of prices, i.e. both Polish and Dutch natural gas prices depend on their past realisations.

Table 4. The results of the Johansen cointegration test

Null hypothesis	Trace statistic	5% critical value	Max-Eigen statistic	5% critical value
$r = 0$	95.19	42.44	58.47	25.54
$r \leq 1$	36.72	25.32	33.00	18.96
$r \leq 2$	3.72	12.25	3.72	12.25

Source: own elaboration.

Table 5. VECM estimates

	$\Delta ln(NL_t)$			
	Estimate	**SD**	**Estimate**	**SD**
Error correction terms				
ECT1	0.447***	0.116	0.404***	0.128
ECT2	−0.529***	0.134	−0.488***	0.147
Deterministic				
constant	0.222***	0.068	0.185**	0.073
Lagged differences				
$\Delta ln(NL_{t-1})$	0.431***	0.146	0.445***	0.146
$\Delta ln(PL_{t-1})$	−0.673***	0.152	−0.684***	0.153
$\Delta ln(US_{t-1})$	0.019	0.040	0.015	0.040
$\Delta ln(NL_{t-2})$			0.501***	0.157
$\Delta ln(PL_{t-2})$			−0.551***	0.170
$\Delta ln(US_{t-2})$			−0.024	0.041
	$\Delta ln(PL_t)$			
Error correction terms				
ECT1	0.688***	0.111	0.669***	0.122
ECT2	−0.805***	0.129	−0.788***	0.141
Deterministic				
constant	0.357***	0.065	0.334***	0.069
Lagged differences				
$\Delta ln(NL_{t-1})$	0.730***	0.139	0.734***	0.140
$\Delta ln(PL_{t-1})$	−0.996***	0.146	−1.003***	0.146
$\Delta ln(US_{t-1})$	0.005	0.038	0.003	0.038
$\Delta ln(NL_{t-2})$			0.708***	0.150
$\Delta ln(PL_{t-2})$			−0.830***	0.162
$\Delta ln(US_{t-2})$			−0.023	0.039
	$\Delta ln(US_t)$			
Error correction terms				
ECT1	0.276*	0.165	0.514***	0.180
ECT2	−0.212	0.191	−0.477**	0.207
Deterministic				
constant	0.329***	0.096	0.442***	0.103
Lagged differences				
$\Delta ln(NL_{t-1})$	−0.075	0.207	−0.109	0.206
$\Delta ln(PL_{t-1})$	0.240	0.217	0.272	0.215
$\Delta ln(US_{t-1})$	−0.313***	0.056	−0.325***	0.056
$\Delta ln(NL_{t-2})$			−0.192	0.222
$\Delta ln(PL_{t-2})$			0.135	0.239
$\Delta ln(US_{t-2})$			−0.241***	0.058

Note: * denotes 10% significance; ** denotes 5% significance; *** denotes 1% significance.
Source: own elaboration.

Table 6: VECM normalised cointegrating vectors

	$ln(NL_t)$	**$ln(PL_t)$**	**$ln(US_t)$**
*r*1	1.000	0.000	−2.527
*r*2	0.000	1.000	−2.125

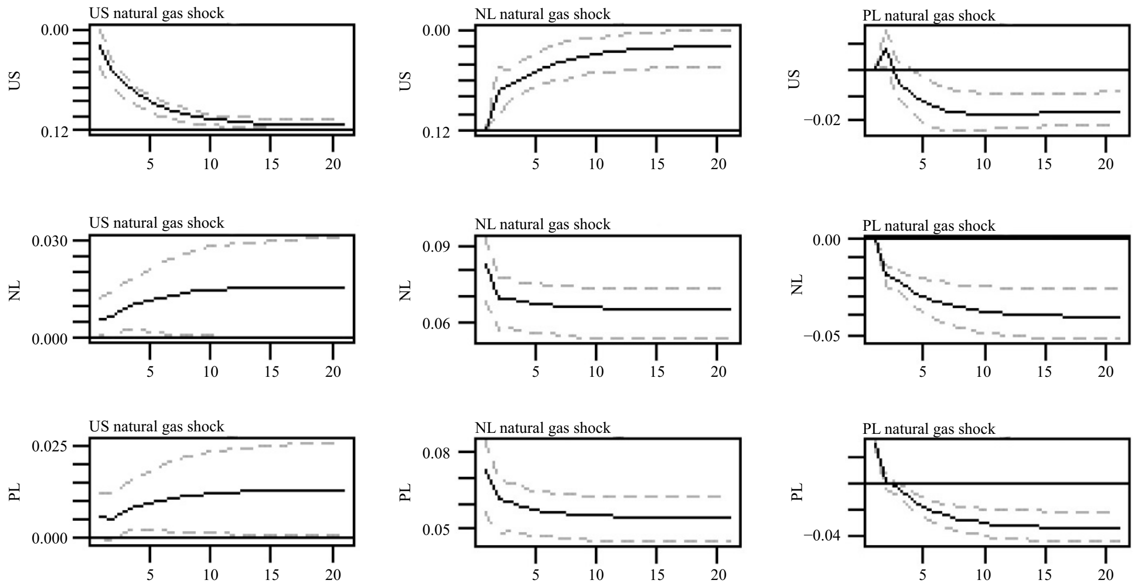
Note: The Table presents the cointegrating vectors for VECM with lag.

Source: own elaboration.

Impulse response functions. In order to investigate the effect of innovations in all variables in the system on the natural gas prices, the impulse response analysis is performed. The impulse responses to one standard deviation innovations are presented in Figure 4. Note that the situation in which the impulse responses do not necessarily approach zero is common in cointegrated models, because the variables are not stationary.

The top row illustrates the response of natural gas prices in the USA. The top left panel shows that in response to their own shock, the American prices initially jump by around 12% and then revert to the pre-shock level relatively quickly, and five months after the shock they are back in equilibrium. The middle panel illustrates that the shock in the Netherlands leads to an initial increase in the American natural gas prices by 1.5%, which accelerates to 2.5% after three months. Finally, the reaction to a shock in Poland is initially insignificant, but after a month the US natural gas prices start to decrease to approximately –1.5%.

The middle row of Figure 4 focuses on the responses of the natural gas prices in the Netherlands. Firstly, it seems that prices in the Netherlands are not significantly affected by shocks to natural gas prices in the USA. Secondly, the country's own shock leads to an immediate increase in natural gas prices of approximately 8%. After the initial jump, the prices start to drop, but even after five months they are still over 6% above the level observed before the occurrence of the shock. Thirdly, the innovation in the Polish market leads



Note: The solid lines represent the impulse response functions to three structural shocks. The dashed lines denote the upper and lower 75% bootstrapped confidence bounds.

Figure 4. Impulse responses in VECM

Source: own elaboration.

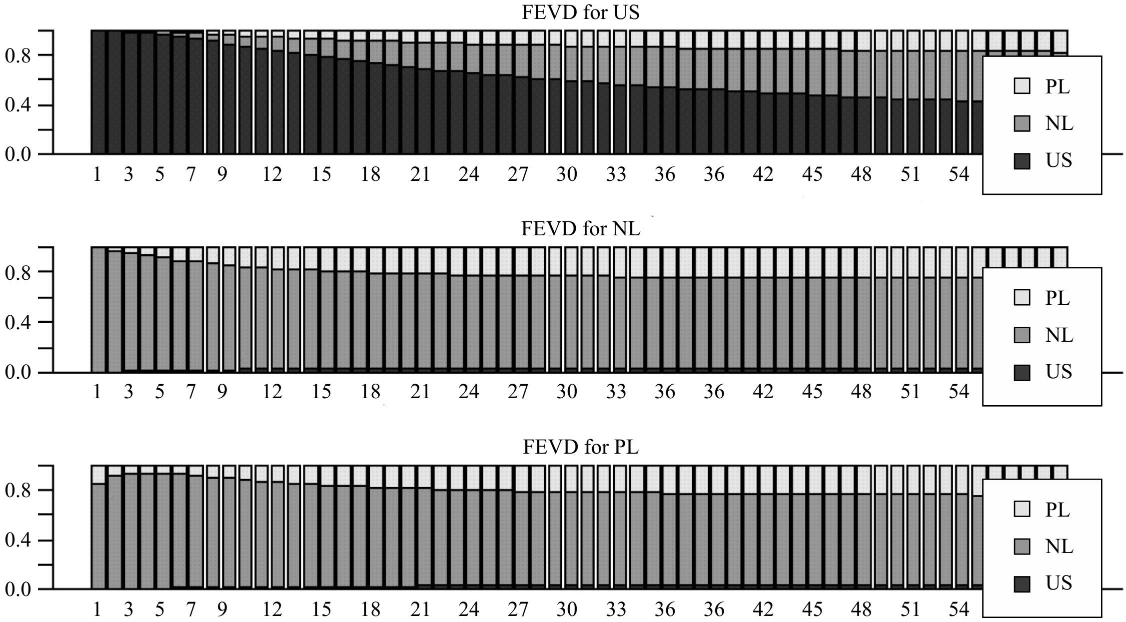
to a decrease in the Dutch natural gas prices of approximately 4% after 10 weeks, and prices do not return to their equilibrium level.

The reaction of natural gas prices in the Polish market to three structural shocks is presented in the bottom panels of Figure 4. They show that the reaction of Polish prices to a shock in the USA is insignificant. In the reaction to shocks in the European (Dutch) natural gas market, the Polish prices initially increase by around 7%, and start to fall gradually. The prices never come back to their equilibrium level and even after 20 weeks they are almost 6% higher than originally. In fact, no matter how long the horizon is considered, the prices remain well above the original level. Finally, the reaction of natural gas prices in the Polish market to the shock in Poland is an initial jump of prices by about 3%, with its relatively quick reversion to equilibrium, which lasts 2–3 weeks. Then, I observe a gradual decrease in prices, resulting in approximately 3% drop in the long run. Again, the prices do not return to their original level.

The analysis of all impulse-response functions leads to two main conclusions. First, Dutch and Polish natural gas prices exhibit similar behaviour. In the long run, they both increase after the occurrence of an innovation in the European gas market and decrease in response to the shock in the Polish market. However, they do not react to changes in the USA. Second, the US prices seem to behave differently. The reaction to shocks in Europe is significant, but smaller in magnitude. What is more, the response to a shock in the US gas market is only short-lasting, as the prices quickly come back to the original levels.

Forecast error variance decomposition. In order rto compare the contribution of the variables to the change in natural gas prices, the forecast error variance decomposition is shown in Figure 5.

In the short run, the American natural gas prices are almost entirely determined by idiosyncratic


FEVD for US

FEVD for NL

FEVD for PL

Figure 5. Forecast error variance decomposition

Source: own elaboration.

shocks. However, for further horizons, there is a visible increase of the European shocks' contribution, which rises to about 60% (40% due to the Netherlands and 20% because of the Polish shocks).

The figures for the Dutch and the Polish prices look very similarly. The natural gas prices in both markets are predominantly (around 80%) driven by shocks specific to the Dutch natural gas market. The contribution of shocks in the Polish market increases with horizon in order to stabilise at around 20% after three months. The impact of the US prices is negligible.

In general, the FEVD analysis leads to two conclusions. First, it confirms that developments in the US gas market do not affect European natural gas prices. Second, it shows that natural gas prices in the USA are linked to natural gas prices in Europe on medium and long horizons. These conclusions are consistent with the observations from the impulse-response functions.

Concluding remarks and policy implications

In this study, I have investigated the dynamics of the natural gas prices in Europe (the Netherlands and Poland) and in the USA over the period of 2015–2020. I have applied the Vector Error Correction Model, which is appropriate for investigating the dynamic interactions among non-stationary variables such as commodity prices, including natural gas are non-stationary. As my main interest is to understand the formation of the natural gas prices in Poland, the key results are twofold. First, the natural gas prices in Europe are not affected by shocks in the American gas market, but they are determined by shocks specific to the European natural gas market. Second, the natural gas prices in Poland are highly correlated and responsive to the Dutch prices. Having experimented with the remaining European countries in the sample (the United Kingdom, Denmark, and Italy), one can draw similar conclusions, which are in line with the assumption of the single, integrated European gas market.

This work matches other studies which discuss the single market hypothesis for natural gas, e.g. the recent research by Chiappini et al. (2019). With longer time-series, studies are able to show that there exists a very strong integration among most of the European gas markets and that this integration has increased in recent years. Moreover, parallel to the findings herein, research states that there is no perfect integration between the European market and the American one.

In a broader context, understanding the dynamics of natural gas prices is essential in energy transition. The return to investment in natural gas infrastructure can only be forecast based on the predicted prices. When the investment is planned, several factors should be considered. With regard to the costs, there is, for example, the initial investment into a gas plant or a pipeline, as well as future operating costs, including the expenditure on the natural gas. With regard to the benefits, apart from the reduction of emissions, there is, for example, a monetary gain from reducing the carbon taxes burden. Without the knowledge on the dynamics of natural gas prices, these two aspects cannot be compared. Therefore, only after examining the dynamics and the differences in the prices of alternative energy commodities, can the appropriate proportion of alternative energy sources in the energy mix be achieved.

Clearly, this work's approach to studying the integration of natural gas prices is not without limitations. One of the possible directions for future research in the field is to improve the quality of the estimates by employing a longer time series of natural gas prices. Also, it might be interesting to conduct the analysis similar to that of Chiappini et al. (2019), allowing for structural breaks, especially if one is interested in the impact of the COVID-19 pandemic. Additionally, the specification of the model could (and perhaps should) be enriched in such a way as to control for other important determinants of the natural gas prices, such as the price of renewable energy sources or some indicators of the infrastructure developments, such as LNG terminals. I shall leave it all for future research.

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Lilia Karpinska

Faces of Poverty: Who Are the Energy Poor in Poland?

Abstract

Objective: The author's goal is to portray energy poor households in Poland based on several well-recognised and original indicators and some clustering techniques. In this study, I check whether the target population is identified correctly and I show possible directions in which the state energy poverty policy might evolve in this regard.

Research Design & Methods: The ten-percent energy poverty measure, the ability-to-keep-home-warm, and the hidden-energy-poverty measures are used to examine the profiles of the energy poor. My source of data is the energy consumption module of the Household Budget Survey collected by the Polish statistical office in 2018. The statistical techniques include multiple linear regression, lasso regression, partitioning around medoids procedure, and hierarchical clustering, among other things.

Findings: All indicators produce different rates of energy poverty, but they are consistent in describing the energy poor groups. Two similar clusters are obtained. The first group is composed mostly of retired single women occupying blocks of flats. The second group is represented mainly by working men living in families with children in stand-alone houses in remote areas.

Implications / Recommendations: Although politicians might choose an energy poverty measure which gives the convenient level of energy poverty incidence, the profile of the target population does not change much. The above implies that regardless of the approach to estimating energy poverty, the profiles obtained in this study should be considered as a target population for policy actions.

Contribution / Value Added: Energy poverty in Poland is often linked to low-stack emissions coming from the residential sector. The owners of single-family houses are the main target of many state programmes aimed at improving the air quality in the country as well as fighting energy poverty. In this study, I show that there are at least two target groups. The results are robust with regard to energy-poverty measuring.

Keywords: energy poverty, profiles, hidden energy poverty, energy poverty ratio, subjective indicator, Poland

Article classification: research article

JEL classification: C1, D1, D6, I3, Q4

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Introduction

The discussion on the energy poverty metrics comes to the point at which a choice of a single energy poverty measure becomes needless (Deller, 2018). First of all, this is because countries differ in terms of socio-economic grounds and consequences of energy poverty. Secondly, energy poverty data collection is limited. Thirdly, the phenomenon of energy poverty is too complex to be captured through one measure. Researchers agree that all measures are equally important, as they reflect various aspects of energy poverty (Sareen et al., 2020).

Energy poverty can be defined as a condition in which households or individuals suffer from an insufficient level of essential energy services (EPOV, 2021a). The EU Commission recommends that member-states develop their approach to tackle energy poverty (EU Commission Recommendation 2020/1563). The existing energy poverty indicators are quite numerous. There are supporting indicators, such as demographic factors, energy prices, supply choice, heating system, etc. (Rademaekers et al., 2016). Another category is subjective indicators, such as the ability-to-keep-home-warm or the leaking-roofs-damp-rot. There are also expenditure-based indicators, such as the Low Income High Cost (UK Government, 2021), etc. According to some, classification indicators are primary, e.g. the share of energy expenditures, or secondary, e.g. the number of rooms per person (EPOV, 2021b). The above-mentioned list of indicators is non-exhaustive.

In this study, I shift the focus away from the energy poverty metrics towards considering the profiles of the energy poor instead. The goal is to describe the portrait of the energy poor and examine sources of energy that each group uses for heating their homes. I would like to prove that regardless of the metrics, similar groups of the energy poor can be identified. In order to test this hypothesis, I select three measures of energy poverty.

The first measure is the hidden energy poverty indicator. This indicator builds on the premise that people save on energy costs when facing budget constraints and having cheap energy sources, such as coal, firewood, biomass, and others (Karpinska & Śmiech, 2020a). Here I estimate the energy costs required to meet the energy needs of a household. If the required energy costs are too high to push a household into income poverty, then this household experiences hidden energy poverty. Energy poverty is invisible, because the share of energy costs in the total budget is low (Karpinska & Śmiech, 2020b). This phenomenon received the attention of authors from different countries (Meyer et al., 2018; Papada & Kaliampakos, 2020; Betto et al., 2020). The problem is acute among the poor population (Brunner et al., 2012).

The second measure is the self-reported energy poverty indicator. These measures have become very popular in comparative studies due to their simplicity and suitability for replication (Karpinska & Śmiech, 2020c; Thomson & Snell, 2013; Bouzarovski & Tirado-Herrero, 2017). At least three self-reported energy poverty indicators are worth mentioning here. The first one is the answer to the question on the ability to keep homes warm, also frequently used in dynamic assessments of energy poverty (Karpinska & Śmiech, 2021a; Chaton & Lacroix, 2018). The second one is the question on the arrears on utility bills. The third one is the assessment of buildings' technical condition; the question is about problems with a dwelling such as a leaking roof, damp walls/floors/foundation, rot in window frames, or floor. The questions come from the 2021 EU Survey on Income and Living Conditions (EU-SILC), which is the primary source of micro-level data for the energy poverty research in Europe.

The third measure is the ten-percent energy poverty ratio. This ratio was introduced by Boardman (1991). According to this indicator, energy poverty occurs when more than 10% of households' income is spent on energy needs. In the UK, 10% represented the double median threshold at that time, and as such it is proved to be improper to measure energy poverty (Schuessler, 2014). After years of discussions, the ten-percent energy poverty ratio has been replaced by the Low Income High Cost indicator (Hills, 2012), which is the official measure of energy poverty in the UK and as such is contested by some researchers (Middlemiss, 2017; Moore, 2011). Yet, the ten-percent energy poverty ratio attracts a lot of attention and is often computed (Miazga & Owczarek, 2015). This measure of energy poverty is considered in the Polish social policy planning and is claimed by the governmental representative Piotr Naimski (2021) to be a good indicator of energy poverty in Europe.

The comparative analysis of energy poverty profiles has been rarely considered in the literature (Belaïd, 2018; Primc et al., 2019; Sanchez-Guevara et al., 2020). I contribute to the limited literature on energy poverty groups in Poland (Lis et al., 2016) and argue that – contrary to the results provided by Fizaine and Kahouli (2018) – the selection of an indicator in this case does not impact the profile of the energy poor groups.

The study is divided into several sections. In the introduction, I explain the concept of energy poverty, set the hypothesis, state my contribution, and review the literature. The next section is dedicated to data and methods. In the section on the results, I discuss the outcomes of the study. In the last section, I summarise the main points.

Data and methods

I obtain cross-sectional data for this analysis from the Polish statistical office. My database consists of the Household Budget Survey (HBS) and the recent energy consumption module (EGD[1]) of the HBS. The module is collected once in three years and is available for the year 2018 at the latest. My sample contains information on 4081 households, which represents 11.3% of all observations from the HBS. The sample is considered as a representative minimum.

In order to count energy poor households, I use three indicators. The first one is the original approach to reveal hidden energy poverty developed by Karpinska and Śmiech (2020a). The second one is a subjective assessment of a household's ability to keep the home warm. The third one is a ten-percent energy poverty ratio that points at high – i.e. more than 10% – energy expenditures in households' income.

The hidden energy poverty indicator requires the estimation of energy costs[2]. The energy costs are regressed against household type, building characteristics, living conditions, income level, etc. In total, 12 variables are utilised; the variables' description is provided in Table 1. In order to account for the composition of a household, I modify the disposable income according to the OECD equivalisation scale, where coefficients 1, 0.5, and 0.3 are applied to the first adult, the next adult, and a child under 14 years old respectively.

For the subjective energy poverty indicator, the respondents need to answer the question: "In your opinion, does your house/flat provide thermal comfort (is it warm enough in winter, adequately cool in summer)?" Figure 1 shows the distribution of income and energy costs.

I perform the analysis in two stages. First, I calculate the energy poverty rate in three cases, such as hidden energy poverty, subjective energy poverty, and energy poverty ratio. The study relies on hidden energy poverty estimations published in a recent report (Karpinska & Śmiech, 2021b). The multiple linear regression is calculated using the ordinary least squares method. The formula is as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \ldots + \underline{\beta_n} \underline{\mathrm{x}_n} + \varepsilon, \qquad (1)$$

where y is a response variable, β_0 is a constant term, $\underline{\beta_n}$ are coefficients for variables x, ε is an error

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[1] The survey on energy consumption in households [Pol. *Ankieta o zużyciu paliw i energii w gospodarstwach domowych*].

[2] In the ten-percent energy poverty indicator, I use actual and not modelled energy costs.

Table 1. The description of variables

Variable	Category
Type of building	Blocks of flats Single-family Other
Year of construction	before 1946 in 1946–1960 in 1961–1980 in 1981–1995 in 1996–2011 after 2011
The total usable floor area of the apartment	up to 50 m^2 50–100 m^2 100–200 m^2 above 200 m^2
Number of rooms	1 room 2 rooms 3 rooms 4 rooms more than 4 rooms
Subjective evaluation of the building (whether it has appropriate technical and sanitary conditions, namely efficient wastewater, water, electricity, gas, and heating installations; good condition of the roof, walls, floors, windows)	yes no
Thermal comfort of the building	yes no
Subjective perception of a household's financial condition	good rather good neither good nor bad rather bad bad
Urban and rural areas	densely populated intermediate thinly populated
Household type	with dependent children without dependent children one-person household other
Voivodeship	
Insulation in buildings	yes, entirely yes, partially no don't know

Source: own elaboration.

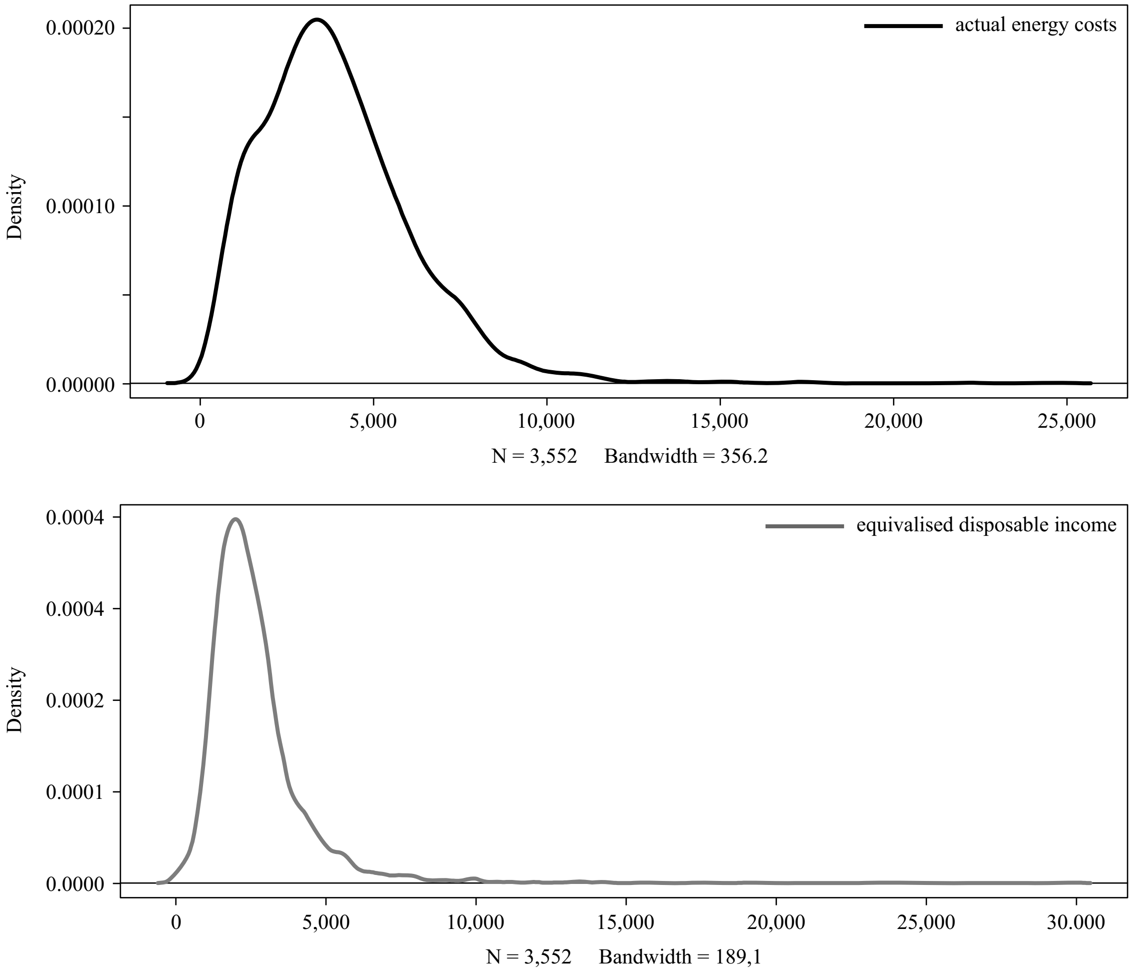

Figure 1. The distribution of annual energy costs and monthly equivalised household disposable income

Source: own elaboration.

term, and *n* is the number of variables. Following the lasso procedure, I check the robustness of the results. The shrinkage makes it possible to retain only the most informative variables as well as it solves the problem of possible correlations between them (Tibshirani, 1996). I apply the most regularised version to ensure the accuracy and predictability of the model.

Second, I group the energy poor population into clusters. The groups are obtained in partitioning around medoids procedure and hierarchical clustering. Both methods belong to unsupervised machine learning algorithms that are widely explored in energy poverty studies (Belaid, 2018). The first one creates an algorithm for finding the most representative object, i.e. a medoid, and for assigning each observation to the closest medoid. In the second method, the similarity between observations is measured in terms of distance, which in my case is Ward's minimum variance distance.

All computations are done in R.

Results

According to my estimations, the rate of energy poverty oscillates between 13.17% and 33.3%, and depends on the metrics I use. Figure 2 presents the results. The lowest rate is reported by households themselves. When answering the question on the thermal comfort of buildings, 13.17% of the households recognise that houses are not comfortable in terms of the temperature inside. Quite similar results are obtained for hidden energy poverty; 17.2% of households are classified as energy poor by the original measure[3]. The ten-percent ratio yields the highest rate of energy poverty (33.3%). It is worth noting that the ten-percent ratio captures only high-energy expenditures and ignores the energy-saving aspect of energy poverty.

Tables 2 and 3 illustrate the coverage of different energy poverty measures. The similarity of classifications measured by the adjusted Rand index shows a very high level of disagreement. It is worth noting that households classified by all three measures as energy poor constitute only 10.58% of all households, whereas the non-energy-poor account for 7.31% of observations. This finding confirms that the measures I choose capture different aspects of energy poverty. Politicians might be tempted to opt for the measure that shows low numbers in the case of pro-governmental forces, and *vice versa* (Karpinska, 2018). The hidden-energy-poverty overlaps with the ten-percent measures to a much greater extent (54.92%) than the subjective-energy-poverty indicator with either of the measures considered in the study.

The profiles of the energy poor are presented in Figures 3, 4, and 5. I identify two groups, the respective PAM and hierarchical results are shown in Figures A1, A2, and A3. Despite striking differences in classifications between different measures of energy poverty, the profiles of energy poor households are almost the same. It can be easily noticed that one group consists of mostly elderly people inhabiting thinly populated areas. The retired or inactive people in the group occupy small two-room flats of about 50–100 square meters in old blocks constructed before 1961 or single-family houses of the same size and age in almost equal proportions. Buildings are, for

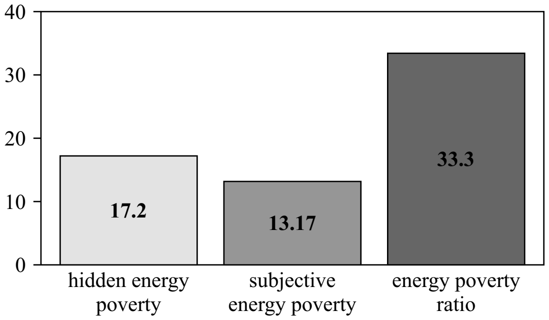

Figure 2. Energy poverty prevalence in Poland, 2018 (in %)

Source: own elaboration.

Table 2. The adjusted Rand index estimates

	Ten-percent measure	**Subjective energy poverty**
Hidden energy poverty	0.21	0.05
Subjective energy poverty	0.008	

Note: The closer the adjusted Rand index is to 1, the greater similarity between classifications is found.

Source: own elaboration.

Table 3. The overlap between different energy poverty measures (in %)

	Ten-percent measure – yes		**Ten-percent measure – no**	
Hidden energy poverty	yes	no	yes	no
Subjective energy poverty – yes	10.58	17.93	3.37	54.92
Subjective energy poverty – no	2.16	2.61	1.06	7.31

Source: own elaboration.

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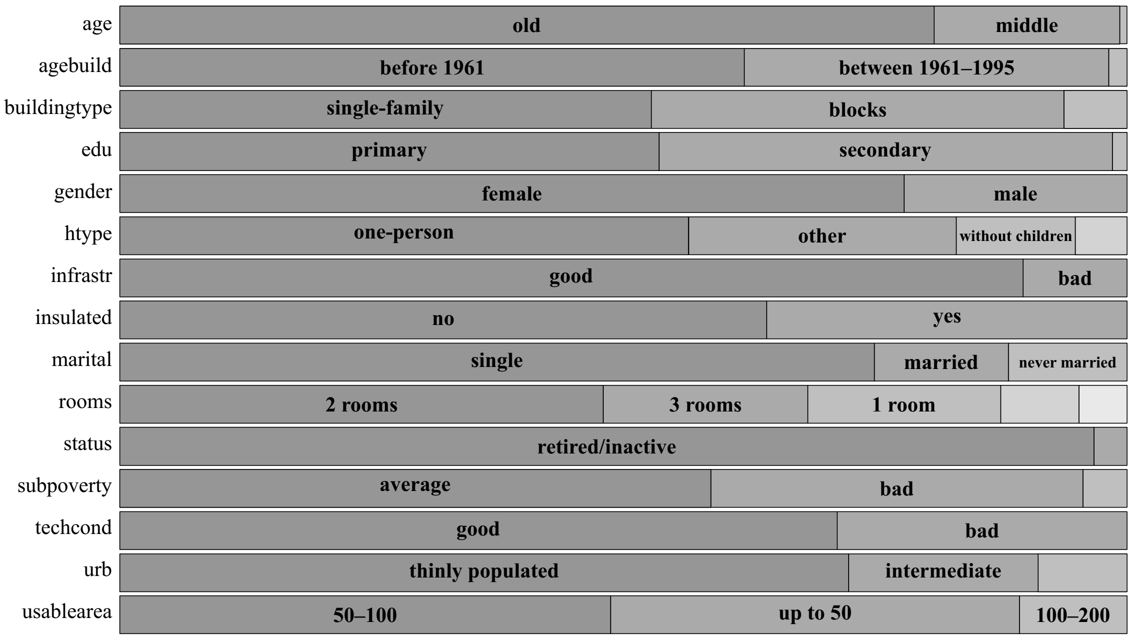
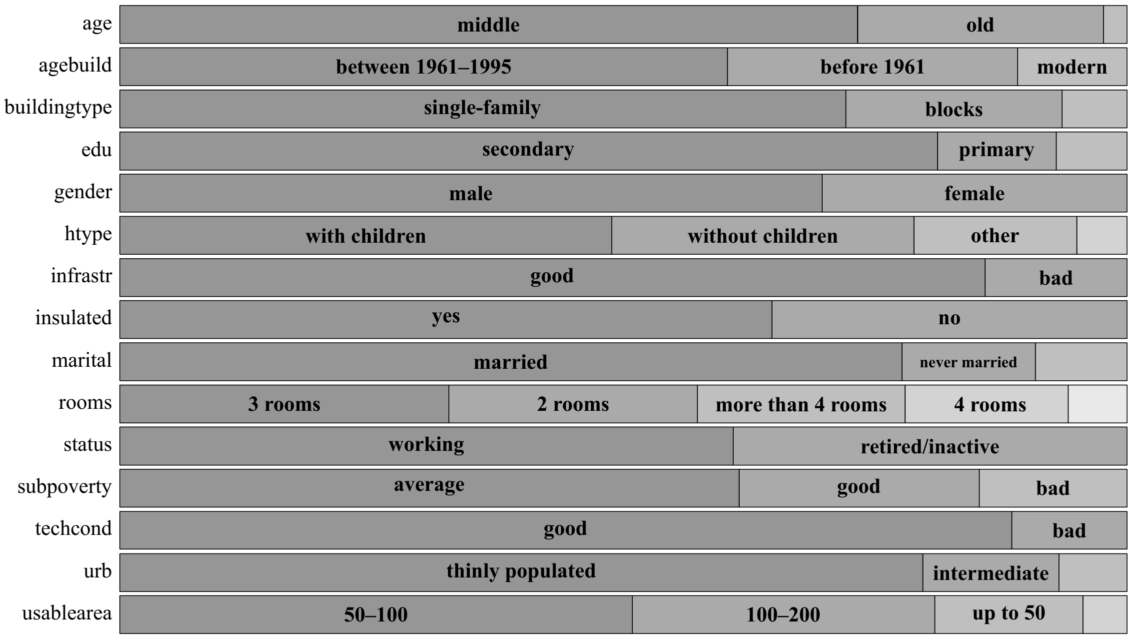
[3] The regression results are available upon request.



Frequency of categorical levels in df::GroupOne



Frequency of categorical levels in df::GroupTwo

Figure 3. Profiles of the energy poor – hidden energy poverty

Source: own elaboration.

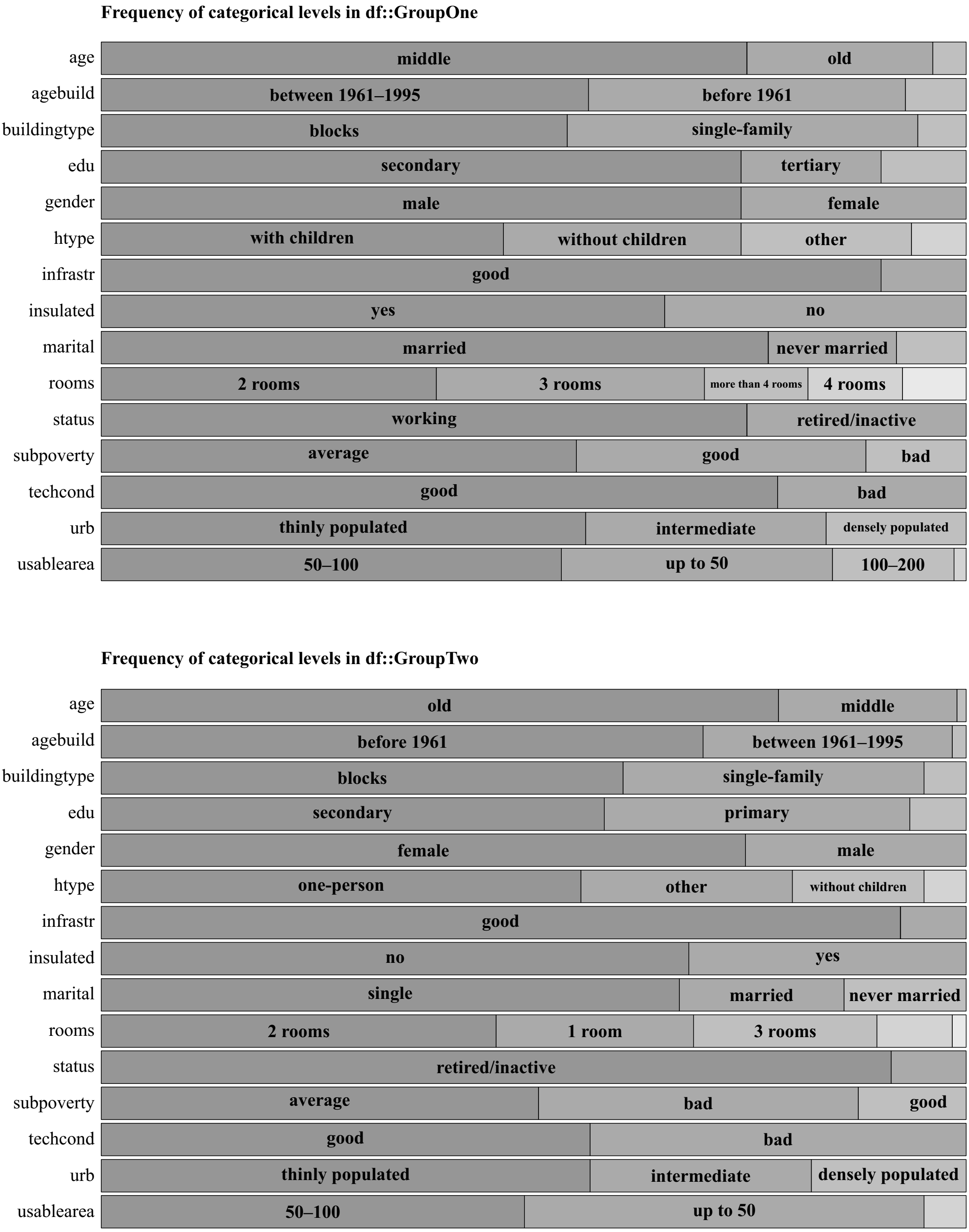


Figure 4. Profiles of the energy poor – subjective energy poverty

Source: own elaboration.

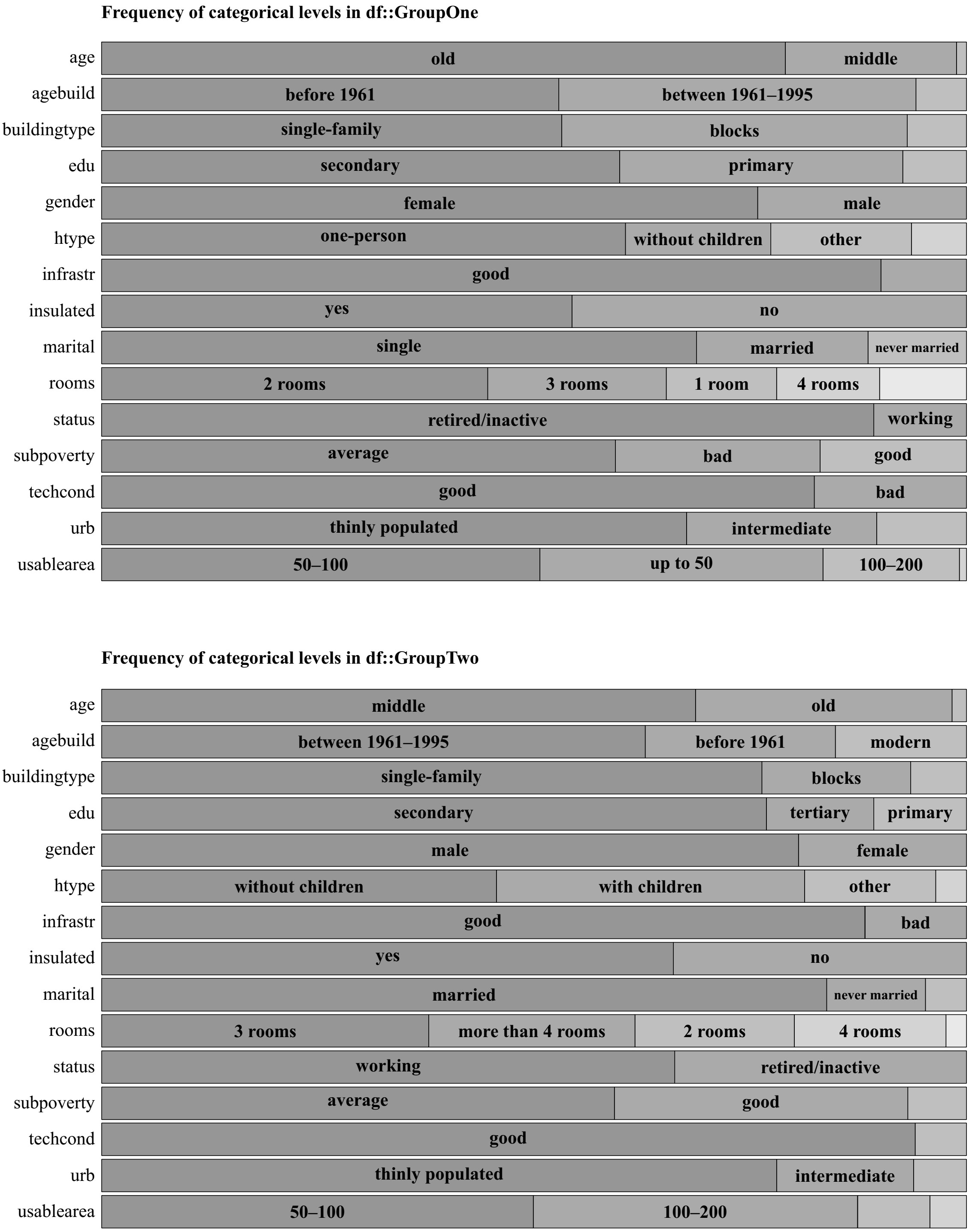


Figure 5. Profiles of the energy poor – ten-percent energy poverty ratio

Source: own elaboration.

the most part, not insulated. This group is mostly represented by single women reporting average ability to make ends meet, i.e. subjective poverty. The highest level of education in the group is primary or secondary. The level of urbanisation is predominantly low. The infrastructure, such as shops and access roads, is good in both groups.

The other group consists of households with or without children, living in single-family buildings and sometimes blocks of flats in case of subjective energy poverty. According to the subjective energy poverty indicator, blocks of flats dominate in this group. The buildings are built between 1961 and 1995, and the respondents state that they are in good technical condition, i.e. they have appropriate technical and sanitary conditions (efficient wastewater, water, electricity, gas, and heating installations) as well as their roofs, walls, floors, windows, etc. are in a good shape. Heads of households consist of married middle-aged men who are active on the labour market. The heads of households indicate average ability to cope with financial difficulties in this group. The level of education achieved by the heads of households is a bit higher than in the first group, i.e. the obtained education is predominantly secondary. The usable area is around 50–100, sometimes 100–200 square meters, which might be difficult to heat. The buildings are mostly insulated. It is interesting to mention that subjective indicators – such as poverty, technical conditions of houses, etc. – reported by households are not bad in both groups. A subjective assessment most probably indicates a relative position of a household compared to other households in the neighbourhood.

Both groups have common traits. One characteristic feature which is worth mentioning is that the usable area of buildings or flats is too big for these households, particularly in the case of single-family households or households without children. Primary sources of energy used for heating purposes in both groups per different indicators are represented in Figures 6, 7, and 8. Unsurprisingly, in all groups – regardless of the type of buildings – coal is the major source of heating. The next preferred source of heating is district heating, which is especially relevant to blocks of flats and firewood. The other sources play a marginal role in households' energy consumption. Solid fuels used by the energy poor for heating their premises inevitably deteriorate the air quality in the country. Yet, the low price of coal and firewood determines the choice of energy for people experiencing budget constraints.

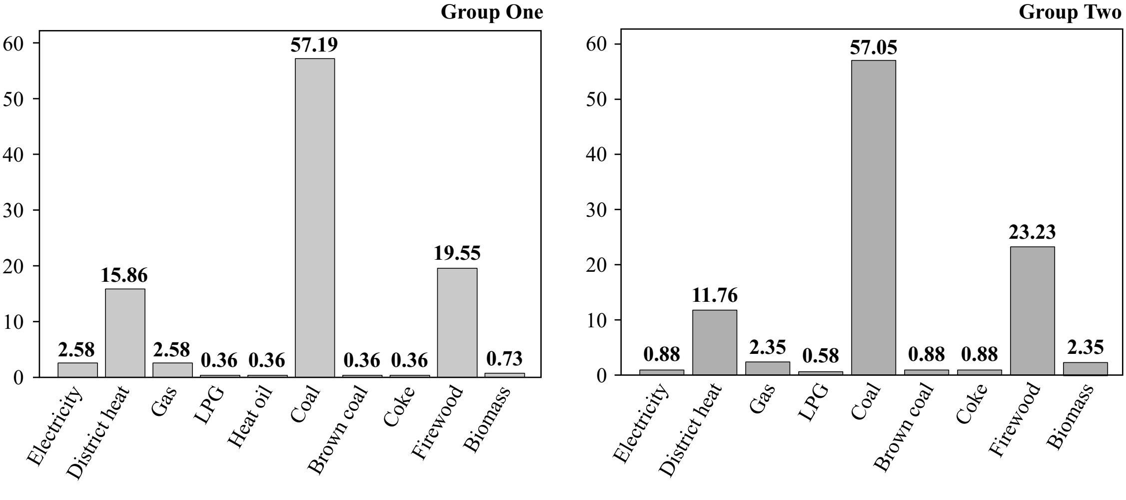


Figure 6. Primary source of heating homes – hidden energy poverty (in %)

Source: own elaboration.

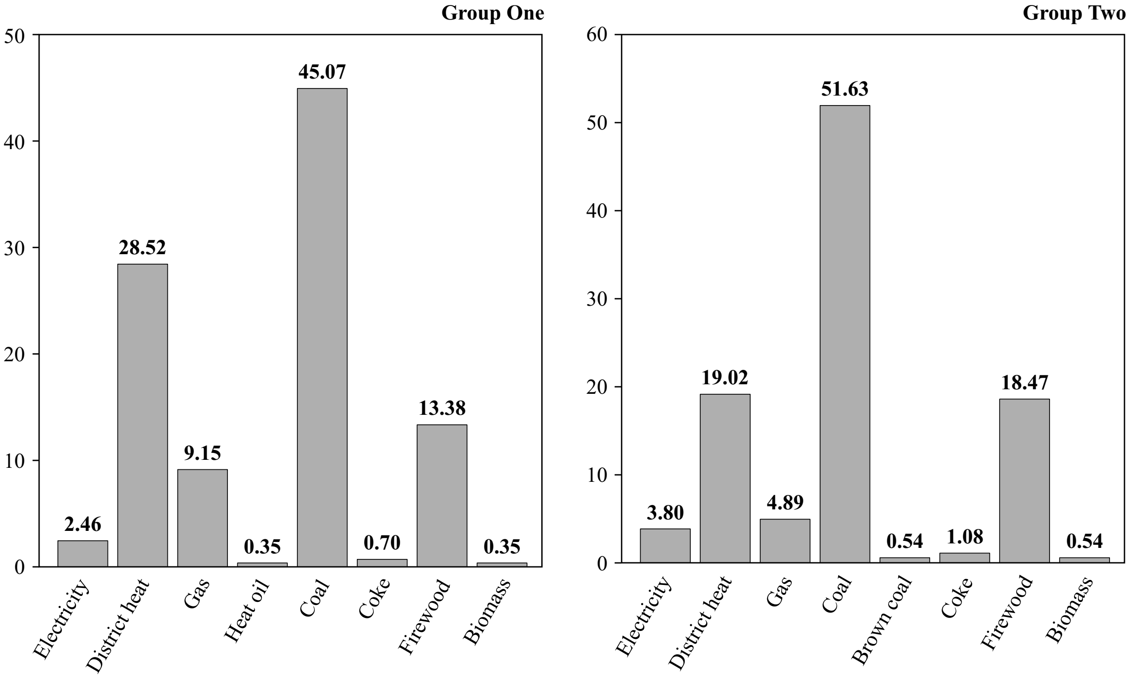


Figure 7. Primary source of heating homes – subjective energy poverty (in %)

Source: own elaboration.

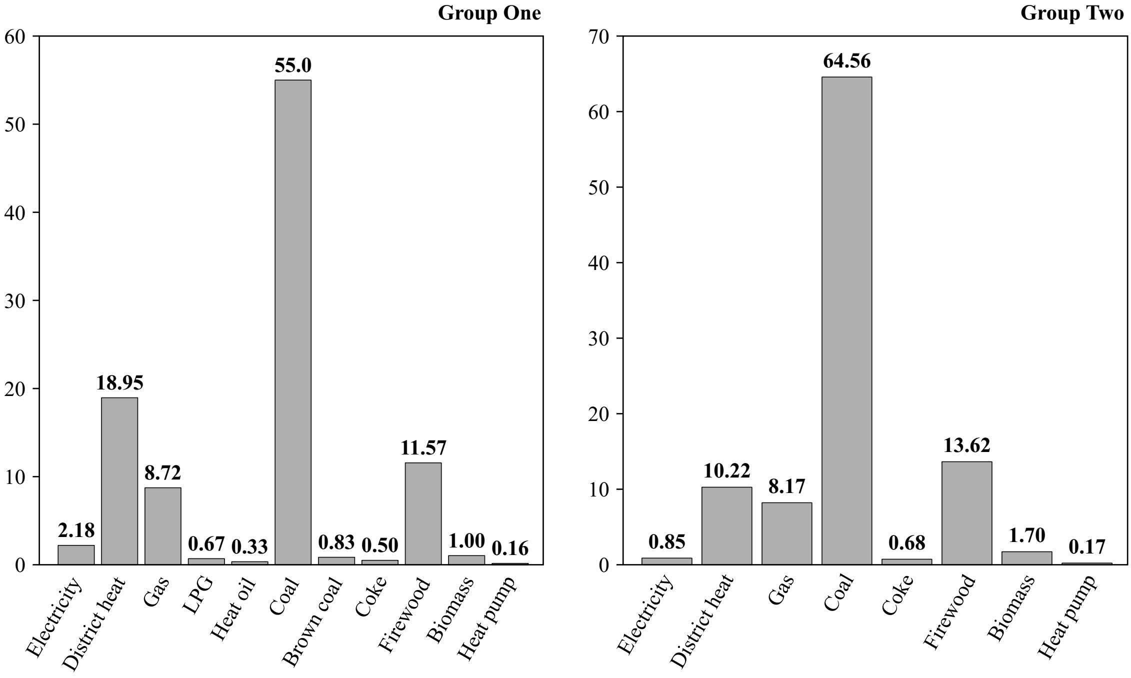


Figure 8. Primary source of heating homes – ten-percent energy poverty ratio

Source: own elaboration.

Concluding remarks

In this study, I describe the portrait of the energy poor households in Poland based on the EGD and the HBS statistics from 2018. Three measures of energy poverty that capture different aspects of this phenomenon are utilised, i.e. hidden energy poverty, subjective energy poverty, and ten-percent energy poverty ratio. I claim that despite the low overlap between these measures, the profile of the energy poor remains the same. The latter fact provides grounds for a clear policy targeting. I believe that the problem of energy poverty metrics yielding inconsistent rates can be overcome by focusing on the beneficiaries of the energy poverty policies.

According to my estimations, energy poverty in Poland affects up to 33.3% of people per ten-percent energy poverty ratio, up to 17.2% per the previously described original hidden energy poverty indicators, and up to 13.17% per subjective energy poverty indicator. Only 10.58% of Poles are classified as energy poor by all three measures. Actual energy expenditures are used to compute the ten-percent energy poverty ratio. To obtain the hidden energy poverty rate, I model energy expenditures accounting for households' needs and buildings' parameters. The prevalence of energy poverty provides little understanding of the target group. Moreover, different political reasons might stand behind the choice of the energy poverty indicator. Tuning the results provides a better or worse picture of energy poverty in Poland. In this study, I draw attention to the energy poor themselves, as well as to the mix of energy sources they use to heat their homes.

I discover two groups of the energy poor. The first one consists of retired single women occupying old buildings, mostly blocks of flats. The second group comprises households with and without children, led by men active on the labour market and living in stand-alone houses. In both cases, the occupied property might be difficult to heat. The homes of the energy poor could be found in less urbanised regions usually characterised by a low level of people's general well-being. The images I draw provide clear guidance for policymakers on who the energy poor are and where to find them. The results are robust to different energy poverty metrics, including the original one proposed by Karpinska and Śmiech (2020a), as well as the most popular one, frequently reviewed in the literature.

One of the most important conclusions is that the energy poor rely on dirty solid fuels as a primary source of heating their homes, i.e. coal and firewood. District heating is not that common even in blocks of flats, where the energy poor live. The low price of coal and firewood and a low level of urbanisation of the affected areas make it difficult and unreasonable to conduct a thermal modernisation of these buildings and to offer the energy poor modern energy sources that require significant investments. Given the age and the social status of some groups of the energy poor, the only reasonable solution might be social assistance and subsidies. When discussing energy poverty in Poland, one should bear in mind the link between the air quality and pollutions coming from the residential sector. For the time being, the vast majority of the energy poor rely on dirty fuels.

The study is limited by the data availability, i.e. the EGD module is collected only once in three years. The comparative analysis of the energy poor profiles obtained for all known at the moment measures of energy poverty seems an interesting topic for future research.

Appendix

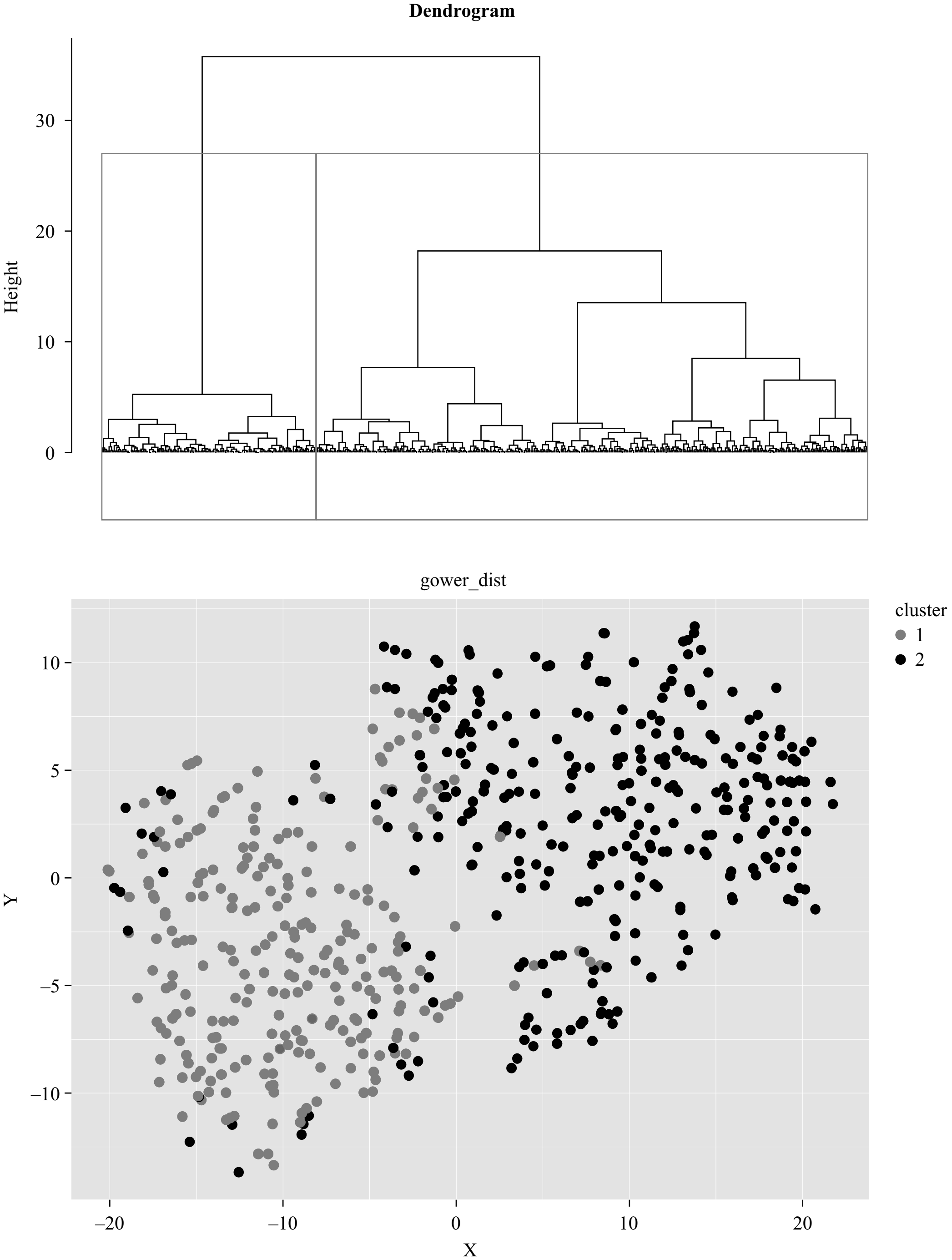


Figure A1. Hierarchical clustering and PAM results – hidden energy poverty

Source: own elaboration.

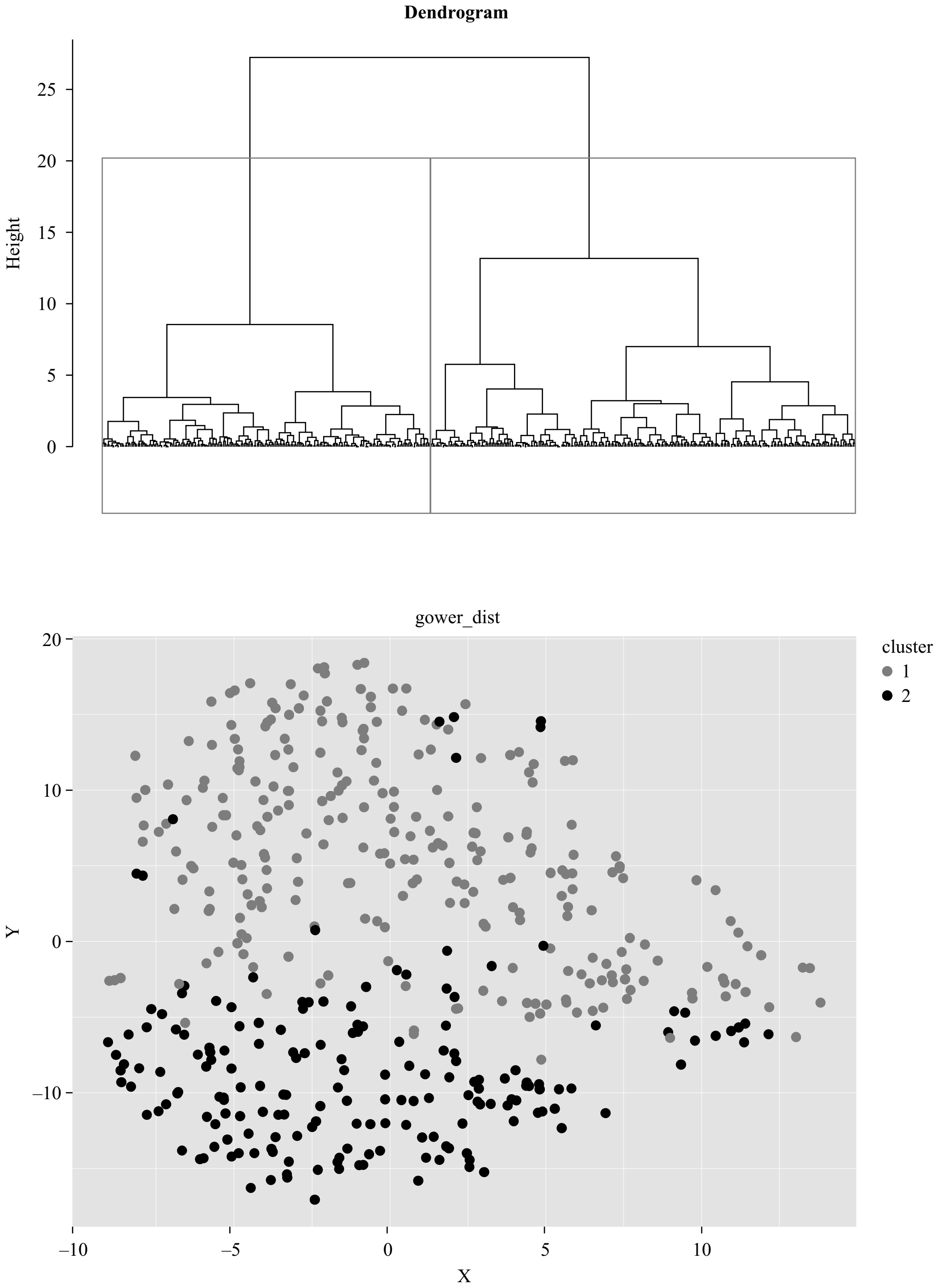


Figure A2. Hierarchical clustering and PAM results – subjective energy poverty

Source: own elaboration.

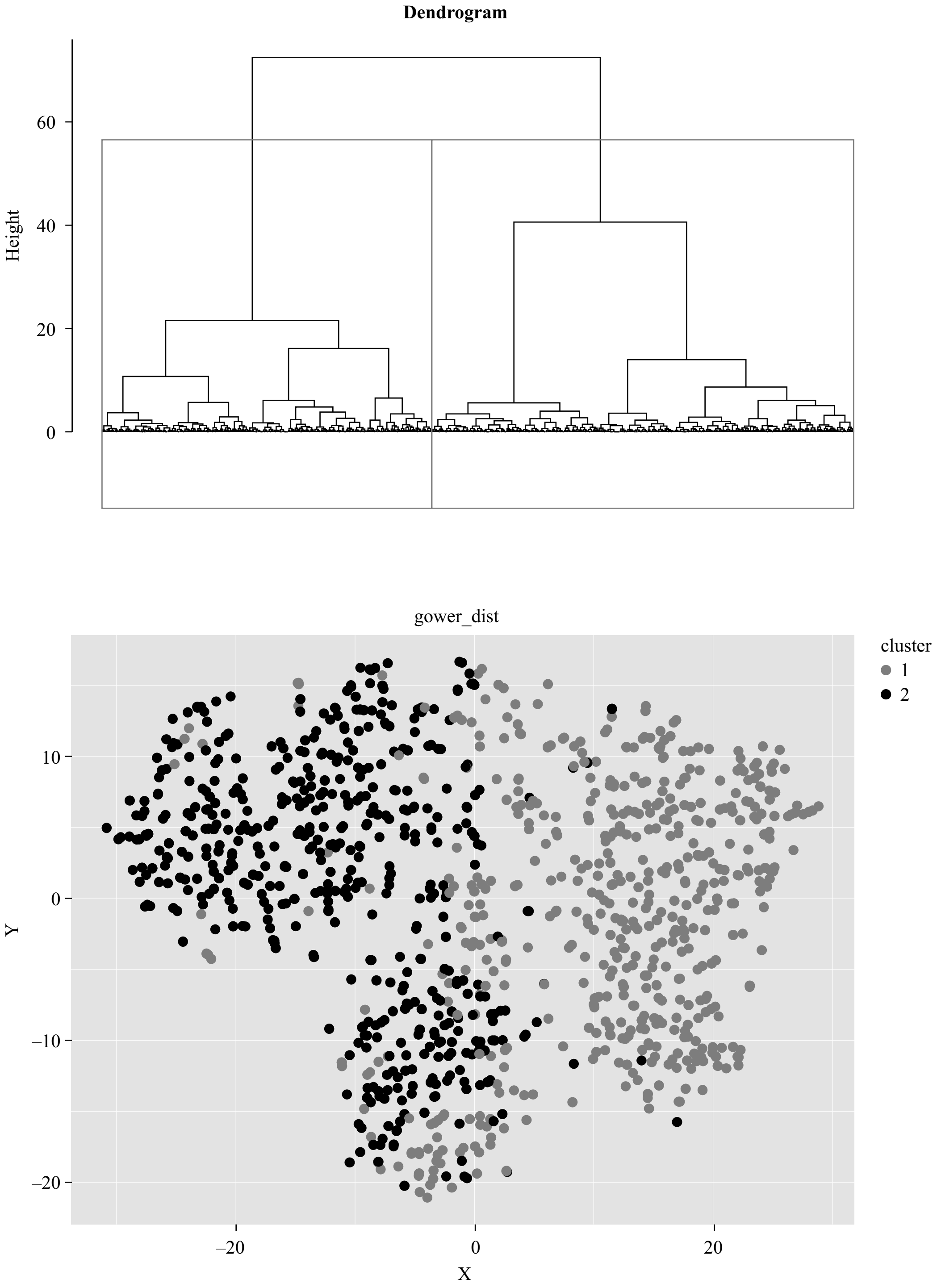


Figure A3. Hierarchical clustering and PAM results – ten-percent energy poverty ratio

Source: own elaboration.

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Magdalena Sikorska

The Integration of the Polish Electricity Market in 2015–2021

Abstract

Objective: Creating a common energy market is a tremendous challenge for the European Union, directly impacting all areas of life. Energy integration is essential, because it creates the conditions to build solutions that support energy security, as well as it facilitates the integration of renewable sources, increases electricity affordability, and improves competition and environmental sustainability. The process of integrating energy markets in the EU's countries and Poland began in the 1990s. This paper aims at describing the integration process of the Polish energy market within the European Union. This study tried to verify the following research hypothesis: The degree of the integration of the Polish energy sector with the European energy market is increasing with the introduction of new energy market regulations in the EU.

Research Design & Methods: This article uses a qualitative method to describe the changes taking place in the EU and in the Polish energy policy with regard to creating a common energy market. Furthermore, the cross-border synchronous and asynchronous flows in Poland are described. In the following part of the paper, quantitative methods are applied to analyse electricity's domestic production and consumption. Additionally, the balance of actual flows with individual countries is analysed. The leading exporters and importers of electricity are also presented, as well as it is shown how the role of the Polish electricity market changed from exporter to importer.

Findings: The study confirmed the hypothesis that the degree of integration of the Polish energy sector with the European energy market increases with the introduction of new energy market regulations in the EU. This is particularly visible from the perspective of possibilities to increase electricity import to Poland after introducing the Third Energy Package in 2007 (including Directive 2009/72/EC). Currently, the main directions of electricity imports to Poland are mainly Germany and Sweden. On the other hand, Poland exports the most electricity to Lithuania, Slovakia, and the Czech Republic. Moreover, since 2016, Poland has become a net importer of electricity (in previous years, it had been a net exporter).

Implications / Recommendations: The results presented in the article may be relevant for policymakers, as they indicate whether the European Union's energy policy affects the degree of integration of the energy sector, especially the Polish market. The results might also interest consumers and the industry, as energy market integration brings many economic, social, and environmental benefits (e.g. lower electricity prices, electricity system reliability). Further research could use more advanced statistical methods to look in more detail at the integration of the Polish energy sector with the European energy market.

Contribution / Value Added: The author tries to present how the changes in the European energy policy influence the integration of the Polish energy sector with the European energy market. The article attempts at supplementing the existing research in this area, as the recent changes in the energy policy had not been covered in the literature, which referred only to selected countries.

Keywords: electricity market integration, European energy policy, internal energy market

Article classification: theoretical/review paper

JEL classification: Q480, Q41

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Introduction

The liberalisation process of electricity markets in Europe is more than two decades old. It is based on four steps (European Union Directives in 1996, 2003, 2009, and 2019) which facilitate member countries to change the architecture of their national electricity markets to achieve market integration (Cambini et al., 2020). In the energy sector, the completion of the European Union's (EU) internal market requires the removal of numerous obstacles and trade barriers, the approximation of tax and pricing policies, measures in respect of norms and standards, and environmental and safety regulations. The objective is to ensure a functioning market with fair market access, a high level of consumer protection, and adequate interconnection and generation capacity (Saez et al., 2019). In addition, a common electricity market in Europe increases the competition and reliability of electricity supply, facilitates the integration of renewable energy sources, and makes electricity more affordable (Pantos et al., 2019).

According to González and Alonso (2021), the integration of European energy markets enables energy to circulate freely throughout the territory of the European Union, without any technical or regulatory obstacles, so that all market players can compete independently where resources are geographically located or delivered. Ioannidis et al. (2019) show that under the hypothesis of no physical limitation during the transfer of electricity among cross-border connections in the EU, a low-cost country would be able to export electricity to countries with a higher cost of production. Thus, ensuring an effective EU's electricity market integration by increasing cross-border exchanges and tackling congestion more efficiently is at the top of the EU's energy policy agenda (Poplavskaya et al., 2020).

The integration of electricity markets is based on the concept of market coupling, i.e. the merging of individual and national markets to render possible the trade of electricity across a large geographical area. The EU's mechanism for day-ahead market coupling in Poland was first joined by the Poland–Sweden connection (SwePol) in 2010 and then by the Poland–Lithuania connection (LitPol) in 2015. In June 2021, the mechanism also covered interconnections with Germany, the Czech Republic, and Slovakia.

The integration of the Polish power grid with the European electricity market allows the import of cheaper electricity. As Jankiewicz (2016) points out, Poland has one of the highest wholesale electricity prices in the European Union. However, increased import of cheaper energy results in reduced operation and revenues of large generating units that determine the country's energy security (Chudy & Mielczarski, 2020). Poland cannot treat imported energy as a necessary part of the transmission infrastructure, without which it would be impossible to maintain the continuity of energy supply (Motowidlak, 2018). However, due to the projected increase in energy demand, the assumptions of the European Union's climate and energy policy, and the significant depletion of the existing generating units, it becomes necessary to improve the transmission capacity of Polish cross-border connections (Majchrzak, 2012).

All EU's member states, including Poland, are involved in creating a common energy market. Most studies on the degree of the integration of the Polish energy sector with the European energy market focus on selected countries such as Sweden (Przygrodzki et al., 2016; Szczepański, 2013), Lithuania (Magor, 2015; Pilżys, 2016), Germany (Molo, 2016; Jankiewicz & Grądzik, 2017), Slovakia (Misik, 2016; Kolcun et al., 2019), or the Czech Republic (Mucha-Kuś & Sołtysik, 2011; Grešlová et al., 2019). However, most of these studies are limited and need updating, as they only refer to selected countries and omit recent regulatory developments. To fill this gap in the literature, this study considers the latest changes in the electricity directives and the development of the internal electricity market in the EU.

Furthermore, this paper aims at describing the integration process of the Polish energy market within the European Union. This study tried to verify the following research hypothesis: The degree of the integration of the Polish energy sector with the European energy market is increasing with the introduction of new energy market regulations in the EU. First, the EU's and the Polish energy policies for creating a common energy market are presented in order for the research objective to be achieved. Then, the shape of cross-border synchronous and asynchronous flows in Poland is shown. Finally, the domestic production and consumption of electricity is analysed, and the exchange of electricity with foreign countries in the period 1990–2020 is indicated. Data has been obtained from the Transmission System Operator in Poland (Pol. *Polskie Sieci Elektroenergetyczne – PSE*). In addition, the balance of actual flows with individual countries between 2015 and 2020 is indicated. The leading exporters and importers of electricity are presented, as well as it is shown how the role of the Polish electricity market changed from an exporter to an importer.

The paper is organised as follows. The following section describes the literature review of research on the degree of the integration of the Polish energy sector into the European energy market. Section Two presents the development of synchronous and asynchronous cross-border interconnections in Poland. Data is then presented in Section Three. While the results are presented in Section Four. The final Section concludes the paper.

Literature review

Research on the degree of the integration of the Polish energy sector with the European energy market is carried out to a limited extent. Most of the studies focus on integration only with selected countries, considering synchronous connections with Germany (Molo, 2016; Jankiewicz & Grądzik, 2017), Slovakia (Misik, 2016; Kolcun et al., 2019), and the Czech Republic (Korab & Owczarek, 2012; Grešlová et al., 2019), as well as asynchronous connections with Sweden (Przygrodzki et al., 2016; Szczepański, 2013) and Lithuania (Magor, 2015; Pilżys, 2016).

Most cases of research into the degree of the integration of the Polish energy sector with the European energy market concern synchronous connections. Molo (2016) indicates that the German energy policy assumes measures to integrate energy markets (including Poland) to ensure efficiency for all EU's member states. The policy assumes an increase in the share of renewable energy sources (RES) in the power grid, and it decreases greenhouse gas emissions. In turn, Jankiewicz and Grądzik (2017) point out that the rapid development of RES as well as differences between infrastructure conditions in Poland and Germany can lead to disruptions of energy systems. Moreover, Kolcun et al. (2019) prove in their study that sustainable economic development in Poland and Slovakia is to be guaranteed by renewable sources. According to the authors, it is necessary to provide adequate tariffs in order to guarantee accelerated investment in RES as well as build and modernise cross-border connections. According to Korab and Owczarek (2012), in turn, the improvement of electricity flows between Germany, Poland, the Czech Republic, and Slovakia is to be ensured by phase shifters, which contribute to the reduction of unplanned compensatory flows (due to, among other things, RES development).

There are also isolated studies on asynchronous interconnections of the Polish power grid. Przygrodzki et al. (2016) indicate that an obstacle to the entire functioning of the cross-border interconnection network for Poland and Sweden is network disturbances that deteriorate the quality of the supplied energy. As Szczepański (2013) points out, this problem is due to the need for technological changes enforced by environmentalists. Modernisation and improvement measures need to be carried out in order to to draw all the benefits from the Poland–Sweden submarine cable line, whose aim is to reduce the adverse effects and costs of damage to the return cables. In the context of research on the integration of the energy market of Poland and Lithuania, Magor (2015) indicates that its development is significant for ensuring the country's energy security. In his research, Pilżys (2016) proved that the cooperation between Poland and Lithuania with regard to the energy market is mainly based on political rather than economic decisions. Therefore, the EU should be involved in the process of building and upgrading the connections, and provide adequate financial support.

The background of the EU and Poland energy market integration policy

The liberalisation of the electricity market is a process that began in the 1990s in the EU's countries and Poland. The legal bases implementing the liberal changes became the EU energy directives implemented into national regulations. These include Directives 96/92/EC, 2003/54/EC, 2009/72/EC, and the currently applicable 2019/944/EC.

The first Directive 96/92/EC on common rules for the internal market in electricity was intended to create a level playing field for generation, transmission, and distribution in each Member State. However, initially, there was only accounting separation, which did not yet create sufficient opportunities for competition.

In 2003, the European Council and Parliament approved of a new legislative package (known as the Second Energy Package), which included the Electricity Directive 2003/54/EC (repealing Directive 96/92/EC), Regulation No. 1228/2003/EC on conditions for access to the network for cross-border exchanges in electricity, Decision No. 1229/2003/EC laying down guidelines for trans-European energy networks, and Decision No. 1230/2003/EC adopting a multiannual programme for action in the field of energy (the 'Intelligent Energy for Europe'programme', 2003–2006). Since then, industrial consumers and Member States have been free to choose their gas and electricity suppliers from a broader range of competitors.

This was followed in 2009 by adopting the EU's third energy package, amending the second package and aimed at further liberalising the internal electricity and gas markets, as well as laying the foundation for the completion of the internal energy market. This package included the following legal instruments: Directive 2009/72/EC (repealing Directive 2003/54/EC) and Directive 2009/73/EC, as well as three Regulations (EC): No. 713/2009, No. 714/2009, and No 715/2009. The third package was intended to introduce additional measures to supplement the existing legislation, to ensure that residential and industrial customers continue to benefit from market liberalisation, to facilitate the entry of new companies into the energy market, and to maintain the security of supply.

Finally, the fourth energy package was adopted in 2019, amending the third package, consisting of Directive 2019/944/EC on electricity (repealing Directive 2009/72/EC) and three Regulations (EC): No. 943/2019, No. 941/2019, and No. 942/2019. The fourth energy package introduced new electricity market rules to meet renewable energy needs and attract investment. One of the objectives of the new package is to achieve an interconnection rate of at least 10% by 2020, meaning that each member state should have interconnections that allow it to export or import the equivalent of at least 10% of its national electricity production. The target for 2030 is set at 15%.

Assumptions arising from the EU directives had to be implemented in Polish regulations. The energy policy of Poland after 1990 was, in terms of fundamental objectives, consistent with the EU's energy policy (Ustawa z dnia 10 kwietnia 1997). However, Poland's accession to the EU in 2004 necessitated an update of the national energy policy. This concerned the practical introduction of market mechanisms to the energy sector and the implementation of further assumptions of Directive 2003/54/EC and Directive 2009/72/EC.

The requirement to update the energy policy on a cyclical basis resulted in several consecutive documents: *Polish Energy Policy until 2025* (Zespół ds. Polityki Energetycznej, 2005), *Polish Energy Policy until 2030* (Ministerstwo Gospodarki, 2009), and *Polish Energy Policy until 2040* (Ministerstwo Klimatu i Środowiska, 2021). They contain goals and assumptions concerning the creation of a common European energy market. Moreover, in order to adjust the Polish law to the EU's assumptions regarding the development of the expected energy market, another amendment to the energy law appeared in 2002, namely the *Act of 24 July 2002 amending the Act – Energy Law*. Then, from 2002 to 2021, this document was amended many times, and the uniform text of the act appeared seven times during that time. In 2013. Poland enacted the so-called *Small Energy Triple Package* to implement the provisions of Directive 2009/72/EC and accelerate the creation of a single European energy and gas market. Then, from 2020 onwards, the work continued with regard to incorporating the requirements of Directive 2019/944/EC into the Polish law. Finally, on 18th June, 2021, the *Act of 20 May 2021* amended the *Energy Law* and certain other acts, incorporating the provisions of the latest Energy Directive.

The shape of cross-border synchronous and asynchronous interconnections in Poland

Nowadays, when the UE policies strongly influence the shape of the electricity sector, cross-border connections play an essential role in shaping the national electricity system. The possibility of importing and exporting electricity depends on the type of cross-border interconnections. In Poland, electricity flows on synchronous and asynchronous interconnections.

Synchronous power systems operate using alternating voltage, which makes power flows challenging to control. In turn, direct current is used for asynchronous interconnections. The use of power inverters enables the conversion of direct current into alternating current with an adjustable frequency. This makes these connections easy to control and allows to control of electricity flows with very high accuracy. PSE has intersystem connections with Germany, Slovakia, Czechia, Sweden, Lithuania, and Ukraine. Table 1 presents detailed information on the operating cross-border interconnections of PSE.

Synchronous interconnections

Synchronous interconnections include three connections, i.e to Germany (Mikulov – Hagenverder and Krajnik – Vierraden), Slovakia (Krosno Iskrzynia – Lemesany), and the Czech Republic (Kopanina – Liskovec, Bujaków – Liskovec, Wielopole – Nosovice and Dobrzeń – Albrechtice). These countries operate synchronously with Poland, which means that their compatibility in terms of frequency and voltage phases at any time. There are two double-track connections of Poland with Germany (400 kV and 220 kV lines) and Slovakia (400 kV line) for synchronous interconnections. In the Czech Republic, there is a single-track connection (two 400 kV lines and two 220 kV lines).

Asynchronous interconnections

Asynchronous interconnections are those that use direct current. These connections are easily controllable, making it possible to control the flows with very high accuracy. Poland has a asynchronous interconnection in the form of the DC cable to Sweden with a maximum capacity of 600 MW. This interconnection is a single circuit for 450 kV lines. Other asynchronous interconnections include the high voltage line between Elk and Alytus in Lithuania, where back-to-back inverters are installed with a maximum capacity of 500 MW and possibly expand to 1000 MW. It is a double circuit connection with a voltage of 400 kV.

Other interconnections

There is also an interconnection with Ukraine (island interconnection) between Zamość and the Dobrotwór power plant in Ukraine, where two 200 MW generators are excluded from the Ukrainian system and operate only for the Polish system. This is a single-track connection with 220 kV. As a rule, one generator is in operation, while the other one has a backup function.

Table 1. The characteristics of operating cross-border connections of the PSE

Country	Operator	Line	Number of tracks	Voltage [kV]	Transmission capacity [MW]
Synchronous interconnections					
Western border					
Germany	50Hertz	Mikułowa – Hagenverder	2	400	1,386
Germany		Krajnik – Vierraden (Line upgraded from 220 to 400 kV)	2	220 (planned 400)	457
Southern border					
Slovakia	SEPS	Krosno Iskrzynia – Lemesany	2	400	831
Southern border					
the Czech Republic	CEPS	Kopanina – Liskovec	1	220	412
the Czech Republic		Bujaków – Liskovec	1	220	412
the Czech Republic		Wielopole – Nosovice	1	400	1206
the Czech Republic		Dobrzeń – Albrechtice	1	400	1206
Asynchronous interconnections					
Nothern border					
Sweden	SvK	Słupsk – Starno	1	450	600
Eastern border					
Lithuania	Litgrid	Ełk – Alytus	2	400	500
Other interconnections					
Ukraine	NEK Ukrenergo	Zamość – Dobrotwór	1	220	251

Source: Polskie Sieci Elektroenergetyczne (2020, pp. 101–102).

Data

First, annual data on domestic electricity production and consumption in 1990–2020 is analysed. Next, the balance of electricity exchange with foreign countries (import–export) is presented based on annual data in 1990–2020. This data comes from the Transmission System Operator in Poland – the PSE. Finally, daily data on the balance of cross-border physical flows for each country from Q1 2015 to Q2 2021 is used. This data is obtained from the *Entsoe Transparency Platform*.

Empirical results

Domestic demand and production of electricity

Figure 1 shows the domestic production and consumption of electricity from 1990–2020. Since the 1990s, the economic and technological development has influenced the demand and the production of electricity in Poland. According to data from the PSE, between 1990 and 2014, the energy demand could be covered in 100% by domestic energy production, as it was higher than consumption by 3.1% during this period.

From 2016 to 2020, domestic electricity demand was consistently higher than domestic production. This difference was getting bigger every year. In

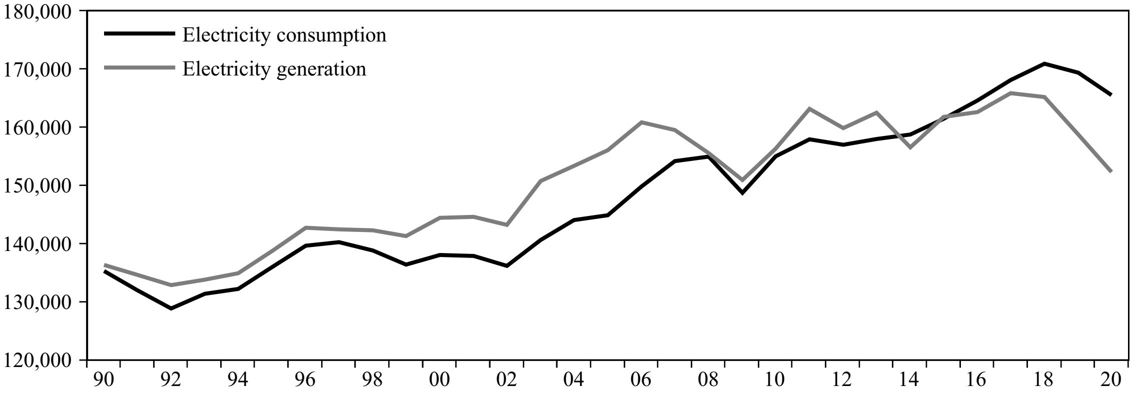

Figure 1. Domestic electricity production and consumption in 1990–2020 [GWh]

Source: Reuters EIKON.

2016, it was 1 999 GWh (+1.23%), then in 2018 it was 5 718 GWh (+3.46%), and in 2020 it was 13,224 GWh (+8.68%). Over the past four years, domestic electricity generation had fallen by 8.16%, from 165,852 GWh in 2017 to 152,308 GWh in 2020. This decrease was mainly due to the rising cost of CO2 emissions and the high cost of fossil fuel extraction. Lower domestic electricity production is being supplemented by higher imports, as rising demand requires it.

However, a slight decrease in domestic energy demand by 3.16% from 170,932 GWh to 165,532 GWh in 2020 was evident from 2018. Nonetheless, this demand is still greater than domestic production by 6.2%. This change was mainly due to energy efficiency improvements to reduce the amount of energy required to provide products and services, as well as the COVID-19 pandemic, which started in the first quarter of 2020.

Balance – import–export

Figure 2 shows the electricity exchange with foreign countries from 1990 to 2020 (physical flows). From 1990 to 2006, the average import volume was about 5 TWh. From 2007 to 2020, there has been a steady increase in demand for energy import (+164%), with an average of 12 TWh. The original assumptions proposed in the first and second energy packages (including Directives 96/92/EC and 2003/54/EC) proved problematic in implementation. It is believed that only the Third Energy Package (including Directive 2009/72/EC) allowed work on a common European electricity market to accelerate. Such changing laws and rules of the internal electricity market enable Poland to purchase cheaper electricity from neighbouring countries.

In contrast, exports are more volatile. From 1990 to 1995, they decreased by about 62%; from 1996 to 2005, they increased by about 204%; and from 2006 to 2010, they decreased again by about 49%. From 2011 to 2014, exports were stable at around 12 TWh, while from 2015 to 2020, there was a substantial decline in exports (49%). With the Third Energy Package liberalising the market and increasing competition, Polish electricity became less profitable to export.

The balance of electricity exchange from 1990 to 2013 and in 2015 shows that Poland was a net exporter of electricity during this period. However, between 2016 and 2020, a systematic increase in net electricity imports is visible (562%). This means that currently Poland mainly imports more electricity rather than exporting it. This is

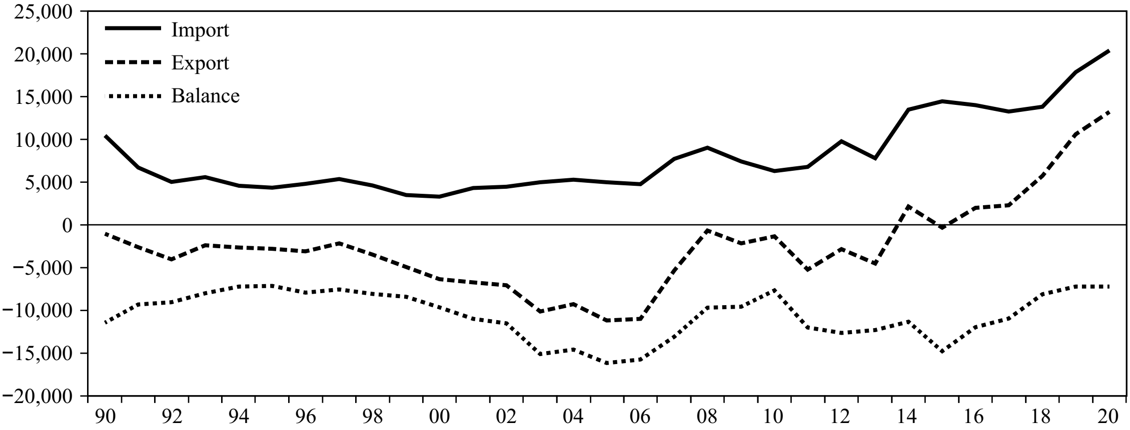

Figure 2. Electricity exchange with foreign countries in 1990–2020 – physical flows [GWh]

Source: Reuters EIKON.

also confirmed by the fact that from 2015 to 2020, electricity exports decreased from over 14 TWh in 2015 to 7 TWh in 2020.

Based on Figure 1 and Figure 2, the share of the balance of electricity exchange with foreign countries in domestic electricity demand can be assessed. From 1990 to 2013 and in 2015, this balance was negative, confirming that Poland was a net exporter of electricity. In contrast, in 2014 and from 2016 to 2020, the share of the balance of electricity exchange in demand was positive and amounted to, respectively: 1.37% in 2014, 1.21% in 2016, 1.36% in 2017, 3.35% in 2018, 6.27% in 2019, and 7.99% in 2020. This situation was mainly due to Poland's ability to purchase cheaper electricity, which in Poland's neighbouring countries usually comes from subsidised RES energy.

Cross-border flows by country

A detailed analysis of cross-border electricity flows was performed for synchronous interconnections (Germany, Slovakia, and the Czech Republic) and asynchronous interconnections (Lithuania, Sweden, and Ukraine). The results shown in Table 2 are based on annual data on the balanced actual flows in individual countries between 2015 and 2020. In turn, Figure 3 shows the results based on daily data on the balance of cross-border physical flows from Q1 2015 to Q2 2021.

In the electricity market, the directions of electricity exchange are determined by the relationship between price offers submitted by market participants for the purchase and the sale of electricity. In addition to the relationship of wholesale prices in Poland and the neighbouring countries, transmission capacity on cross-border power lines also has an impact.

The data in Table 2 shows that the largest importer of electricity to Poland in 2020 was Germany with a volume of 11 235 GWh, which represents approximately 54.98% of total imports. The second importer was Sweden (3 789 GWh), which accounted for less than 18.54% of the total energy imported to Poland. The next countries are Lithuania (2 159 GWh, share: 10.56%), the Czech Republic (1 674 GWh, share: 8.19%), Ukraine (1 484 GWh, share: 7.26%), and Slovakia (92.50 GWh, share: 0.45%).

The data in Table 3 shows that in 2020 Poland exported the most electricity to the Czech Republic with the amount of 3 650 GWh, which accounts for 50.62% of total exports. The second country that received the most electricity from Poland was Slovakia, with 3 154.6 GWh, accounting for 43.75% of total exports. The subsequent countries were Lithuania (380.7 GWh, share: 5.28%), Sweden (12.60 GWh, share: 0.17%), and Germany (12.10 GWh, share: 0.17%).

The data in Table 4 shows that in 2020, Poland net-imported the most electricity from Germany (11 223.1 GWh) and Sweden (3 776.3 GWh), which was 61.46% and 20.68% of total net imports, respectively. This energy came mainly from wind and photovoltaic sources, which is much lower with the current cost of CO2 emission permits. In addition, Lithuania with 1 778 GWh and Ukraine with 1 484 GWh were also net importers

Table 2. Import of actual flows in individual countries between 2015 and 2020 [GWh]

Country	2015	2016	2017	2018	2019	2020
the Czech Republic	208.00	505.20	373.70	632.80	1,022.10	1,674.10
Lithuania	13.80	1,033.50	1,536.70	1,615.20	2,280.40	2,158.70
Germany	10,658.90	8,753.90	7,340.40	7,054.60	10,085.70	11,235.20
Slovakia	0.10	3.10	0.30	28.00	26.80	92.50
Sweden	3,511.70	2,763.60	3,124.90	3,098.40	3,077.20	3,788.90
Ukraine	66.50	957.40	894.80	1,410.0	1,376.80	1,484.10
Total	14,459.00	14,016.70	13,270.80	13,839.20	17,869.00	20,433.50

Source: PSE. Retrieved from: https://www.pse.pl/dane-systemowe (01.10.2021).

Table 3. Export of actual flows in individual countries between 2015 and 2020 [GWh]

Country	2015	2016	2017	2018	2019	2020
the Czech Republic	9,764.70	7,193.20	5,946.30	3,771.60	3,407.60	3,649.70
Lithuania	64.50	440.10	494.30	717.30	384.70	380.70
Germany	17.40	14.90	20.90	20.70	19.70	12.10
Slovakia	4,925.80	4,187.00	4,372.10	3,235.50	3,244.90	3,154.60
Sweden	20.20	175.50	150.50	376.10	188.40	12.60
Ukraine	–	–	–	–	–	–
Total	14,792.60	12,010.70	10,984.10	8,121.20	7,245.30	7,209.70

Source: PSE. Retrieved from: https://www.pse.pl/dane-systemowe (01.10.2021).

Table 4. Balance of actual flows in individual countries between 2015 and 2020 [GWh]

Country	2015	2016	2017	2018	2019	2020
the Czech Republic	−9,556,70	−6,688,00	−5,572,50	−3,138,80	−2,385,50	−1,975,60
Lithuania	−50,70	593,40	1,042,30	897,9	1,895,70	1,778,00
Germany	10,641,50	8,739,00	7,319,50	7,033,90	10,066,00	11,223,10
Slovakia	−4,925,70	−4,183,90	−4,371,80	−3,207,50	−3,218,10	−3,062,10
Sweden	3,491,50	2,588,10	2,974,40	2,722,20	2,888,70	3,776,30
Ukraine	66,5	957,4	894,8	1,410,20	1,376,80	1,484,10

Source: PSE. Retrieved from: https://www.pse.pl/dane-systemowe (01.10.2021).

of electricity for Poland in 2020. These countries accounted for another 9.74% and 8.13% of total net electricity imports to Poland.

In turn, in 2020, Poland remained a net exporter of electricity to Slovakia (3,062.1 GWh), which accounted for 60.78% of total net exports. The second net exporter of electricity in 2020 was the Czech Republic (1,975.6 GWh), which accounted for 39.33%.

Poland ↔ Germany

The data in Table 4 shows that net electricity import from Germany in 2015 amounted to 10,641.50 GWh, which is as much as about 74.94% of all net electricity imports to Poland. In the subsequent three years, this import decreased, while from 2019, it increased again. These fluctuations are mainly due to the unstable operation of renewable sources. Depending on the demand for electricity by German consumers and on electricity production by wind and photovoltaic farms, electricity import to Poland changes. However, in a situation where the production of electricity from renewable sources in Germany is low, energy is exported from Poland to Germany. However, this situation occurs relatively rarely. In 2020, net import amounted to 11,223.10 GWh and was higher by 5.47% when compared to the year 2015.

The data in Table 5 shows a similar trend. The average daily balance of cross-border physical flows was 29,192.72 MW in 2015. In the subsequent three years, the average daily balance decreased, while from 2019 onwards, it increased again. An average variation over the year is observed; it indicates small differences in the daily balance volumes of cross-border physical flows.

Poland ↔ Sweden

The data in Table 4 shows that net electricity import from Sweden in 2015 amounted to 3,491.50 GWh, which is as much as about 24.59% of all net electricity imports to Poland. In the subsequent four years, this import remained at a similar level, averaging 2,793.35 GWh. The reason for this might be network constraints on cross-border connections. The SwePol submarine line was commissioned in 2000 and had a maximum capacity of 600 MW. In 2020, net imports slightly increased, amounting to 3 776.30 GWh, and were higher by 8,16% than in 2015. Due to increased

Table 5. Daily data on the balance of cross-border physical flows for Germany from Q1 2015 to Q2 2021 [MW]

DE				
Year	**Mean**	**Std. Dev.**	**CV**	**Obs.**
2015	29,192.72	7,891.82	27%	365
2016	24,108.92	8,700.68	36%	366
2017	20,139.93	4,598.85	23%	365
2018	19,276.63	6,776.67	35%	365
2019	27,571.02	5,618.11	20%	365
2020	30,658.02	5,755.11	19%	366
2021	25,719.65	9,145.23	36%	181
All	25,202.60	8,077.38	32%	2,373

Source: Entsoe Transparency Platform. Retrieved from: https://transparency.entsoe.eu/transmission-domain/physicalFlow/show (01.10.2021).

Table 6. Daily data on the balance of cross-border physical flows for Sweden from Q1 2015 to Q2 2021 [MW]

SE				
Year	**Mean**	**Std. Dev.**	**CV**	**Obs.**
2015	9,486.90	3,255.56	34%	365
2016	7,072.21	4,270.21	60%	366
2017	8,149.32	4,132.26	51%	365
2018	7,459.97	4,706.21	63%	365
2019	7,913.82	4,853.09	61%	365
2020	10,318.05	4,143.70	40%	366
2021	9,260.53	4,256.45	46%	181
All	8,465.93	4,397.55	52%	2,373

Source: Entsoe Transparency Platform. Retrieved from: https://transparency.entsoe.eu/transmission-domain/physicalFlow/show (01.10.2021).

investments in wind power by the Swedes, the need to develop cross-border connections might increase in the coming years.

The data in Table 6 shows a similar trend. The average daily balance of cross-border physical flows was 9,486.90 MW in 2015. In the following four years, the average daily balance remained at a similar level (7,648.83 MW on average). In 2020, the average daily balance of cross-border physical flows increased, amounting to 10,318.05 MW (+8.76% compared to 2015). A large variation is observed throughout the year, which indicates average differences in daily balance volumes of cross-border physical flows.

Poland ↔ Lithuania

The data in Table 4 shows that in 2015, Poland was a net exporter of electricity to Lithuania. At that time, the value of exported energy was 50.70 GWh, which was only 0.34% of the total net export of electricity to Poland. In the subsequent four years, Poland became a net importer of electricity. In this period, the value of imported energy fluctuated, but averaged on over 1,000 GWh. The change from an electricity net exporter to a net importer since 2016 was due to the launch of the NordBalt interconnection (between Lithuania and Sweden). NordBalt allowed for a gradual increase in energy imports to Poland from Scandinavia and Russia.

Moreover, a similar level of imported electricity over the last four years might result from network limitations on cross-border connections (as in the case of Sweden). In 2020, net electricity import amounted to 1,778.00 GWh, which was an increase by 3,406.9% when compared to the year 2015. This was the highest percentage increase in the volume of net electricity imports among all countries analysed between 2015 and 2020.

The data in Table 7 shows a similar trend. The average daily balance of cross-border physical flows was 1,622.32 MW in 2016. In the subsequent four years, the average daily balance fluctuated, but on average it remained at 3,841.74 MW. A very large variation is observed throughout the year, which indicates large differences in the daily balance volumes of transboundary physical flows.

Table 7. Daily data on the balance of cross-border physical flows for Lithuania from Q1 2015 to Q2 2021 [MW]

		LT		
Year	**Mean**	**Std. Dev.**	**CV**	**Obs.**
2015				365
2016	1,622.32	3,751.30	231%	366
2017	2,855.74	4,170.99	146%	365
2018	2,460.13	4,698.28	191%	365
2019	5,193.78	4,059.91	78%	365
2020	4,857.29	3,757.16	77%	366
2021	3,490.01	4,515.91	129%	181
All	2,860.66	4,211.68	147%	2,373

Source: Entsoe Transparency Platform. Retrieved from: https://transparency.entsoe.eu/transmission-domain/physicalFlow/show (01.10.2021).

Poland ↔ Ukraine

The data in Table 4 shows that the net import of electricity from Ukraine in 2015 amounted to 66.5 GWh, which is only 0.47% of the total net electricity import to Poland. Since 2016, there has been a gradual increase in net imports of electricity from Ukraine. It results from the agreement signed in 2016 by the PSE and the Ukrainian authorities on the possibility of intervention purchases of electricity (in the event of a threat to the security of electricity supply). Moreover, Ukraine does not conduct an intensive EU's climate policy and has cheap labour, which ultimately translates into cheaper electricity, profitable to imports to Poland. In 2020, net imports of electricity amounted to 1,484.10 GWh and were higher by 2132% when compared to the year 2015. On the other hand, the export of electricity from Poland to Ukraine is currently impossible, because there is only one connection on the eastern border at 220 kV voltage (Dobrotwór–Zamość), where two generators with a capacity of 200 MW are

Table 8. Daily data on the balance of cross-border physical flows for Ukraine from Q1 2015 to Q2 2021 [MW]

UA				
Year	**Mean**	**Std. Dev.**	**CV**	**Obs.**
2015	–	–		365
2016	–	–		366
2017	–	–		365
2018	3,862.78	1,533.66	40%	365
2019	3,771.59	1,590.31	42%	365
2020	4,049.04	1,406.73	35%	366
2021	2,503.67	2,190.38	87%	181
All	2,062.05	2,231.00	108%	2,373

Source: Entsoe Transparency Platform. Retrieved from: https://transparency.entsoe.eu/transmission-domain/physicalFlow/show (01.10.2021).

Table 9. Daily data on the balance of cross-border physical flows for Slovakia from Q1 2015 to Q2 2021 [MW]

SK				
Year	**Mean**	**Std. Dev.**	**CV**	**Obs.**
2015	−13,451.95	4,646.04	35%	365
2016	−11,431.03	4,993.20	44%	366
2017	−11,977.73	4,154.52	35%	365
2018	−8,787.61	4,545.25	52%	365
2019	−8,817.03	3,952.49	45%	365
2020	−8,365.49	5,758.73	69%	366
2021	−7,789.64	5,862.82	75%	181
All	−10,266.74	5,194.58	51%	2,373

Source: Entsoe Transparency Platform. Retrieved from: https://transparency.entsoe.eu/transmission-domain/physicalFlow/show (01.10.2021).

excluded from the Ukrainian system and work only for the Polish system.

The data in Table 8 shows a similar trend. The data on the average daily balance of cross-border physical flows was 1,622.32 MW in 2016. In the subsequent four years, the average daily balance fluctuated, but on average it remained at 3,841.74 MW). A large variation is observed throughout the year, which indicates average differences in the daily balance volumes of transboundary physical flows.

Poland ↔ Slovakia

The data in Table 4 shows that net electricity exports to Slovakia in 2015 were 4,925.70 GWh, 33.89% of the total net electricity exports from Poland. In 2016 and 2017, net electricity exports was slightly above 4 TWh, while in 2018 and 2019, they decreased to the value of 3 TWh. In 2020, net export amounted to 3,062.10 GWh, i.e. down by 37.83% when compared to the year 2015. The electricity trade between Poland and Slovakia shows a decreasing demand for the Polish energy, which might be due to high wholesale prices per MWh.

The data in Table 9 shows a similar trend. The average daily balance of cross-border physical flows was 13,451.95 MW in 2015. In the subsequent two years, it was more than 11,000 MW, while in the period of 2018–2020, it was more than 8,000 MW. An average variation over the year is observed, which indicates small differences in the daily balance volumes of cross-border physical flows.

Poland ↔ the Czech Republic

The data in Table 4 shows that the net export of electricity to the Czech Republic in 2015 amounted to 9 556.70 GWh, which accounted for 65.76% of the total net exports of electricity from Poland. Over the next five years, there was a gradual decline in net electricity exports from Poland, on average over 1 500 GWh year-on-year. In 2020, net export amounted to 1 975.60 GWh and was lower by 79.33% when compared to the year 2015. This decrease results from high wholesale electricity prices in Poland and actions taken to counteract arbitrary power flows, the so-called circular flows. The cause of unplanned power flows in power grids was the dynamic development of wind

Table 10. Daily data on the balance of cross-border physical flows for the Czech Republic from Q1 2015 to Q2 2021 [MW]

		CZ		
Year	**Mean**	**Std. Dev.**	**CV**	**Obs.**
2015	−24,774.08	8,555.69	35%	365
2016	−18,306.64	8,066.40	44%	366
2017	−14,687.32	7,955.02	54%	365
2018	−8,970.08	5,208.80	58%	365
2019	−7,501.59	5,200.29	69%	365
2020	−6,337.71	7,386.40	117%	366
2021	−15,631.90	8,271.67	53%	181
All	−13,596.62	9,651.18	71%	2,373

Source: Entsoe Transparency Platform. Retrieved from: https://transparency.entsoe.eu/transmission-domain/physicalFlow/show (01.10.2021).

sources in Germany. Circular flows facilitated trade in energy between Germany and Austria, but it prevented trade in Poland. This phenomenon could be limited by the construction of transformers on boundary lines, the so-called phase shifters. These devices make it possible to control the flow of active power in the transmission network. In addition, at the request of Poland, Slovakia, the Czech Republic, and Hungary, the Agency for the Cooperation of Energy Regulators (ACER) recommended the separation of a price zone between Germany and Austria; the resolution entered into force on October 1, 2018.

The data in Table 10 shows a similar trend. The average daily balance volume of cross-border physical flows was 24,774.08 MW in 2015. In the subsequent years, a gradual decrease in

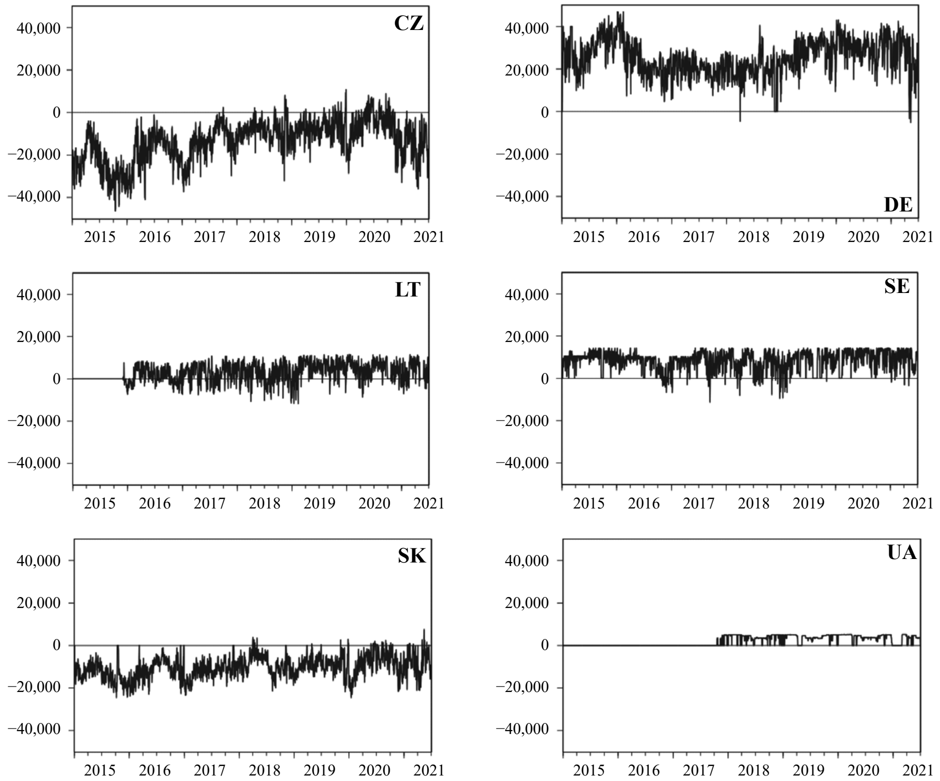

Figure 3. Daily data on the balance of cross-border physical flows from Q1 2015 to Q2 2021 [MW]

Source: Entsoe Transparency Platform. Retrieved from: https://transparency.entsoe.eu/transmission-domain/physicalFlow/show (01.10.2021).

the average daily balance volume was visible (on average –23.34% year-on-year). On the other hand, the variation of average daily balance volumes of cross-border physical flows is greater from year-to-year. Initially, it was medium, then large, and in recent years a very large variation has been visible throughout the year, which indicates increasing differences in daily balance volumes of cross-border physical flows.

Concluding remarks

This paper aimed at describing the integration process of the Polish energy market within the European Union. With the purpose of achieving the research goal, first, the energy policy of the EU and Poland in the scope of creating a common energy market was presented. Then, the shape of synchronous and asynchronous interconnections in Poland was shown. Finally, the domestic production and electricity consumption was analysed, and the exchange of electricity with foreign countries in the period of 1990–2020 was indicated. In addition, a balance of actual flows for individual countries between 2015 and 2020 was indicated. The leading exporters and importers of electricity were presented, as well as it was shown how the role of the Polish electricity market changed from an exporter to an importer.

In the author's opinion, the problem of the integration of the Polish energy sector with the European energy market is of limited interest in the scientific literature. Most of the studies need to be updated, because they refer only to selected countries and omit the recent regulatory changes. This article was intended as a response to the need to systematise knowledge on the EU's and Polish energy policy in the field of a single electricity market; its purpose was to present synthetically the development of the Polish energy market integration.

The study confirmed the hypothesis that the degree of the integration of the Polish energy sector with the European energy market increases with the introduction of new energy market regulations in the EU. This is particularly visible from the perspective of possibilities to increase electricity import to Poland after introducing the Third Energy Package in 2007 (including Directive 2009/72/EC). At present, the main directions of electricity imports to Poland are primarily Germany and Sweden. The opportunity to purchase cheaper energy resulted in Poland being a net importer of electricity between 2016 and 2020.

The countries to which Poland exported electricity in 2016–2020 include mainly Lithuania, Slovakia, and the Czech Republic. Sometimes, there is a shortage of electricity due to windless or frosty weather and the closure of nuclear units in selected countries. In such cases, Poland exports electricity from coal-fired power plants in order to close the energy balance of the neighbouring countries. However, the conducted research has confirmed that the electricity supplies from Poland to these countries are steadily decreasing. As a result of further changes resulting from Directive 2019/944/EC, it might turn out that, with the current structure of the energy mix, Polish electricity will rarely be exported due to high CO_2 emission prices, among other reasons. This situation can only change when a lot more solar and wind power capacities appear in Poland. Then, energy prices on the Polish market can much more frequently fall below the rates seen in the neighbouring countries.

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The Development of Biogas Production in the Context of Energy Transition: The Case of Poland

Abstract

Objective: The aim of this article is to identify the chances of further development of biogas production as a way to diverisfy the structure of energy production in Poland. Another one is to analyse biogas production as a part of getting closer to achieving the targets of the climate and energy framework of the European Union and Polish long-term energy sector strategies.

Research Design & Methods: The research methods used in the study include: the analysis and study of the literature, heuristic techniques for data analysis, the SWOT (strengths, weaknesses, opportunities, threats) analysis.

Findings: The production of biogas can be beneficial for local economic growth, environmental awareness, and social wellbeing. There is a strong need to overcome the barriers of further development of biogas production as well as analyse the opportunities, given that a type of renewable energy source is further developed. Biogas production can help meet the national and international goals concerning energy transition, developing low-carbon economies, and addressing modern economic trends.

Implications / Recommendations: The aim of this paper is to investigate the chances of further development of biogas production in spite of current changes in Polish agendas. The topic is of great importance when analysing the strategy of Poland to develop a low-carbon economy. It is also a significant part of current discussions between the scientific community and business practitioners in terms of energy transition in Poland. What is worth noting is that Polish strategies concerning the development of renewable energy production should be aligned with the climate and energy targets of the European Union, which can prove problematic. Polish energy mix is still based on energy production from coal, while the EU is steadily increasing gross energy production from renewable energy sources.

Contribution / Value Added: The analysis defines the role of biogas in circular economy as well as in modern economy with the consideration of environmental economics and sustainable development. It underlines the importance of biogas in energy transition in Poland, taking into consideration the *Energy Policy of Poland until 2040* (Pol. *Polityka energetyczna Polski do 2040 r.*)

Keywords: biogas production, energy transition, Polish energy production, renewable energy

Article classification: research article

JEL classification: O13, Q01, Q28, Q42

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Introduction

Ensuring sustainable global development should be related to increasing the share of energy produced from renewable sources in total gross electricity generation. It is of great importance to implement new solutions, which would ensure the acquisition of clean energy and would not be associated with negative environmental impact during the process. Nowadays, a paradigm shift in energy production can be witnessed. Initially, energy systems had been monopolistic and centralised, whereas currently, decentralisation is becoming clearly visible. Energy can be seen as a specific type of a commodity, where the recipient is both a customer and a participant in the energy market. Current international discussions have been dominated by the analyses of the possible scenarios of developing low-carbon economies.

The regulations of the European Union contain a number of policies and strategic documents directly related to the issue of biogas production. This kind of a renewable resource finds its place in documents concerning the production of energy from renewable sources in general, as well as in regulations relating to the development of circular economy systems, the promotion of clean technologies, mobility, environmental economics, and bioeconomy.

In 2018, the European Parliament adopted new energy goals, in which particular emphasis was placed on increasing the use of energy from renewable sources and improving the energy efficiency of the Member States. It has been established that by 2030, the share of energy from renewable sources in total energy consumption is to be at least 32.5%, and that at least 14% of fuels used in transport are to come from renewable sources. The plans of the European Parliament include the goal of achieving an emission-free economy that would start functioning by 2050. This would allow compliance with the provisions of the Paris Agreement, as well as allow a limitation of the emission of harmful gases into the atmosphere, as well as it would make it possible to overcome environmental problems, which are considered as one of the major challenges that the humanity is facing. The mentioned provisions are consistent with the conclusions on the “Clean Energy for All Europeans” legislative package and the “Clean Planet for All” vision. The principles and priorities of the EU have been defined with regard to a debate of the ministers of energy of the Member States, which took place during the informal meeting in Bucharest in 2019. The findings were then discussed by the Working Party on Energy, which was followed by deliberations of the Committee of Permanent Representatives of the European Union (Council of the European Union, 2019a).

In 2019, the EU’s Green Deal has been introduced as the new strategy to ensure economic growth and the transition towards a sustainable model of the economy. The actions of the Member States would contribute to making Europe the first climate-neutral continent. The goal is to be achieved by 2050. The main elements of the Green Deal are connected with renewable energy production, i.e. climate action, clean energy, and eliminating pollution. The financing will be covered by the EU’s Green Deal Investment Plan. The two main streams of funding will total in €1 trillion, from which €528 billion will come from the budget of the EU and the Emissions Trading System. The remainder will be covered by the InvestEU programme (Norton Rose Fulbright, 2021).

In order to adjust to international resolutions concerning energy production, the Council of Ministers of Poland adopted the „Energy Policy of Poland until 2040”, which is based on achieving just transition, building a zero-emission energy system, and ensuring good air quality. Energy transformation – i.e. one towards low-carbon economy – can facilitate guaranteeing energy security, achieving fair cost distribution, and protecting the interest of some social groups (Ministerstwo Energii i Środowiska, 2021, p. 7). Furthermore, Poland’s membership in the EU’s structures makes it necessary to adjust national strategies to international provisions, thus redefining the national structure of energy production.

The article attempts at supplementing the reflection on the role of biogas in the structure of energy production in Poland. It depicts the necessity of change in order to meet the goals adopted by the EU. The author believes that intensifying the production of biogas in Poland can positively influence local economic growth, environmental awareness, and social well-being. The main research questions in this article are:

- How can biogas production contribute to the energy transition, with particular attention to energy transition in Poland?
- What are the strengths, weaknesses, opportunities, and threats for biogas production in Poland?

In order to answer these questions, an analysis of the literature concerning the role of biogas in energy transition has been performed. The place of biogas production in energy transition and circular economy has been described in order to highlight the flexibility of this renewable energy source. Obtaining basic information on the state of biogas production in Poland became the reason to use the techniques of strategic planning, i.e. performing a data-driven and fact-based SWOT (strength, weakness, opportunities, threats) analysis of the production of biogas in Poland. The creation of a SWOT matrix enables an in-depth insight into the state of biogas production in Poland.

Literature review

Biogas can be described as “Gaseous fuel produced from biomass, as defined in point 24 of Article 2 of Directive (EU) 2018/2001, including energy-carrying gas that is primarily methane and mixtures that are partially methane produced from biomass feedstocks through anaerobic digestion, gasification, or other processes” (The International Council of Clean Transportation, 2019, p. 2). The production of biogas makes it necessary to obtain appropriate amount of biomass, i.e. organic material of plant or animal origin. This renewable resource can be used directly to produce electricity and heat in cogeneration (combined heat and power – CHP). Taking into consideration the method of obtaining, the following types of biogas can be distinguished (Główny Urząd Statystyczny, 2020, p. 42):

- Landfill biogas – a result of anaerobic fermentation of landfill waste;
- Biogas from sewage sludge – produced by the anaerobic fermentation of sewage sludge;
- Other – this group contains two types of biogas, which are: agricultural biogas obtained in the process of anaerobic fermentation of biomass from crops energy, plant production residues, animal manure, and biogas obtained in the process of anaerobic digestion of biomass from waste in slaughterhouses, breweries, and other food industries.

In the literature of the subject, one can find various scientific articles and industrial reports concerning the topic of the place of biogas in energy transition (Lyytimäki et al., 2018, pp.1–11; Lyytimäki, 2018, pp. 65–73; Faller & Schulz, 2017, pp. 1–8; Xuequing et al., 2021, pp. 1–20; Frankowski, 2017, pp. 15–32; Kurczyńska, 2020). Biogas production has also been analysed with regard to sustainable development (Marchaim, 1992; Pawlita-Posmyk & Wzorek, 2018, pp. 1043–1057; Khoiyangbam et al., 2011; Meeks et al., 2019, pp. 763–794; Lybæk et al., 2013, pp. 171–182) as well as barriers and chances of its development (Surendra et al., 2014, pp. 846–859; Gottfried et al., 2018, pp. 632–647; Brudermann et al., 2015, pp. 107–111; Igliński et al., 2015, pp. 93–101). A wide range of available references indicates a specific flexibility of biogas both as a renewable energy source and as a part of contemporary economic trends. It also shows the need to redefine the approach to the problem of the inclusion of biogas in the energy mix. The process is dependent on many factors, such as the legal status of biogas production or the impact of the investment on the local society.

Biogas production in terms of energy transition and circular economy

Biogas production can play an important role in terms of the basics of energy transition and circular economy, which is due to the fact that the necessity of natural environment preservation and the promotion of sustainable development have both been taken into consideration. The specific role of biogas can also be analysed in the context of low-carbon energy transition. The implementation of the concept of circular economy may serve as a way of improving self-sufficiency with regard to energy. Furthermore, it is related to energy efficiency and the use of renewable energy sources, both of which can be seen as key pillars of energy transition (Kalchenko et al., 2019, p. 2).

The adoption of an action plan regarding circular economy by the European Commission (2015) – which is intended to support and stimulate the transition of the EU's Member States to the circular economy – can indicate the necessity of the implementation of the plan by individual Member States. Financial support for the initiative is to be provided by the European Structural and Investment Funds, the Horizon 2020 programme, and the European Fund for Strategic Investments and the LIFE+ programme. The emphasis has been placed on the development of innovative solutions and the development of investments accompanying the initiative (Council of the European Union, 2019b). The purpose of closing the loop is to address individual stages of the life cycle of a product: from its production, through consumption, and ending with waste management and the re-use of raw materials.

Biogas production is in line with the concept of circular economy, which is often seen as a specific type of remedy for contemporary economic, environmental, and social problems. At the same time, it can be described as a shift in the way that societies use and treat products. Circular economy is regenerative in nature, aiming at achieving the maximum utility of components and materials. The higher the degree of waste reuse in industry, the more the process is aligned with the concept (Sariali, 2007, pp. 31–34). The use of biogas generated from waste, which is produced in a regenerative manner, does not increase the amount of carbon dioxide in the atmosphere, because biogas plants are qualified as a source of energy with zero CO_2 emissions. Energy combustion of biogas is associated with CO_2 emissions which are nearly identical to the amount that is able to be consumed by plants or animals, which are the source of substrates for its production (IEA Bioenergy, 2018). Research related to the production of biogas from various raw materials has shown that its use can lead to minimal CO_2 emissions. Therefore, in absolute terms, the amount of CO_2 that can be absorbed from the atmosphere due to the complete cycle of energy production can be higher than the amount of CO_2 produced during the supply of raw materials and the operation of a biogas plant (Naglis-Liepa & Pelse, 2013, pp. 18–25). In consequence, biogas is a carrier of renewable energy, essential for the transition towards decarbonisation. Furthermore, one of the main advantages of using biogas is the flexibility of energy generation. In this case, the production of energy is not as prone to fluctuations as photovoltaics or wind energy are. The dependence on unpredictable climatic factors is low and energy production is resistant to seasonality, as the amount and type of substrate can be relatively easily controlled (Hoffman, 2017).

In the social context, biogas could be used in a much wider sense than it is today, and it could be successfully used in industries requiring access to warm air, e.g. in laundries, carpentry shops, and other places where there is a need for quick drying. The use of purified biomethane can also be of great importance in gastronomy and the food industry, where continuous heating and the possibility of its regulation are required.

The opportunity for further implementation of solutions that are in line with the concept of circular economy can also be seen when analysing the benefits of the construction of micro and small biogas plants, as well as looking into biodegradable waste processing centres equipped with a biogas installation. Their impact would be significant to the needs of a micro-region; in the case of Poland, this would be a commune or a municipality (Pol. *gmina*), or a poviat (Pol. *powiat*). Micro biogas plants are characterised by a simplified structure, which is why the process of their placing and starting up the production is much faster. In addition, they are mobile and easy to relocate. The frequently used solutions include the use of container micro biogas plants. The structure is placed in two containers – one of them is used for the fermentation of wet substrate, while the other one is for the production of energy in cogeneration. Due to a smaller scale of the investment in comparison to a classic biogas plant, micro biogas installations are based on the use of a limited type of substrates in appropriate proportions. For rural households, it can be animal faeces, enriched with a trace amount of co-substrate, which is an addition that stabilises the production process. In the case of cattle breeders, the appropriate amount of substrate can be provided by a herd of 60 LU (large livestock unit), while the appropriate amount for plant substrates will be provided by approx. 6 ha of maize cultivation and a small number of animals, e.g. pigs. These amounts would enable the operation of a 10 kW reactor for a year. A herd of approx. 100 LU or the cultivation on an area of 20–26 ha would enable the proper functioning of an installation with a power of approx. 40 kW (Kubiak, 2018). Electricity and heat generated by such facilities could be used for meeting the individual needs of producers, while the surplus could be used at the local level. Such a procedure would make the development of distributed energy easier, and the continuous improvement of biogas technologies could result in the intensification of activities, resulting in the creation of self-sufficient energy areas or energy clusters.

Even though biogas production can play a significant part of renewable energy production, there are many barriers that should be taken into consideration while analysing the chances of its implementation in the energy mix. These can be separated into various groups, i.e. economic, market, technical, institutional, environmental, and socio-cultural (Nevzorova & Kutcherow, 2019). They should be considered separately both for individual countries (with particular emphasis on the characteristics of a given region) and for individual investments in biogas plants.

Research methodology

Biogas production in Poland – basic information and the European context

In the period of 2005–2018, a significant increase in the volume of biogas production could be observed in the Member States of the EU. In 2018, it was 705 PJ, which meant an increase of 531,3 PJ compared to the production level observed in 2005 (173,7 PJ). In the analysed period of time, the contribution of biogas generated in the degassing process of landfills remained at the same level. The largest contribution to the increase in biogas production was made by the group classified as “other”, while the smallest – by biogas obtained in the wastewater treatment process (Figure 1).

Recent years have shown a steady growth in the number of biogas plants located in Europe (Figure 2). In the years 2009–2017, the total number of biogas installations operating in Europe increased from 6,227 to 17,432. From 2010 to 2012, there was a twofold increase in the number of operating biogas plants. Biogas production has been boosted due to the growing numbers of agricultural installations (those in which the main substrate is the organic matter acquired from agriculture). In 2009, there were 4,797 installations of this type, whereas in 2016 – 12,496. In the years 2015–2017, the number of biogas plants in Europe started to stabilise.

The volume of biogas produced in individual countries of the EU is very diverse. The leading country for the production of biogas energy is Germany, where the total biogas production reached 319.5 PJ in 2018. It accounted for approx. 45% of the total biogas production in the EU’s Member States (705 PJ).

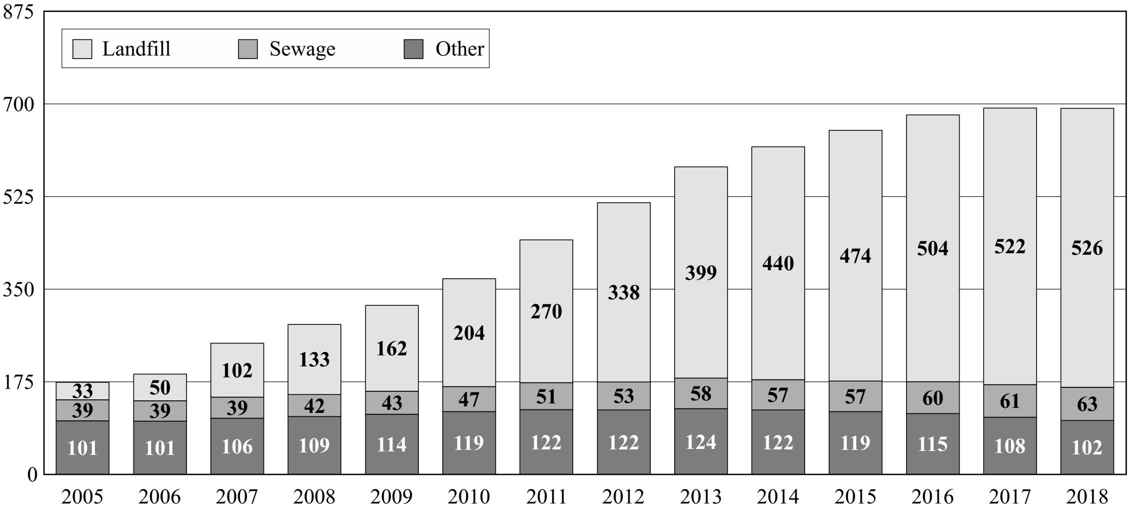

Figure 1. Biogas production volume in EU member states in 2005–2018 (PJ)

Source: own elaboration based on data retrieved from Eurostat, 2020.

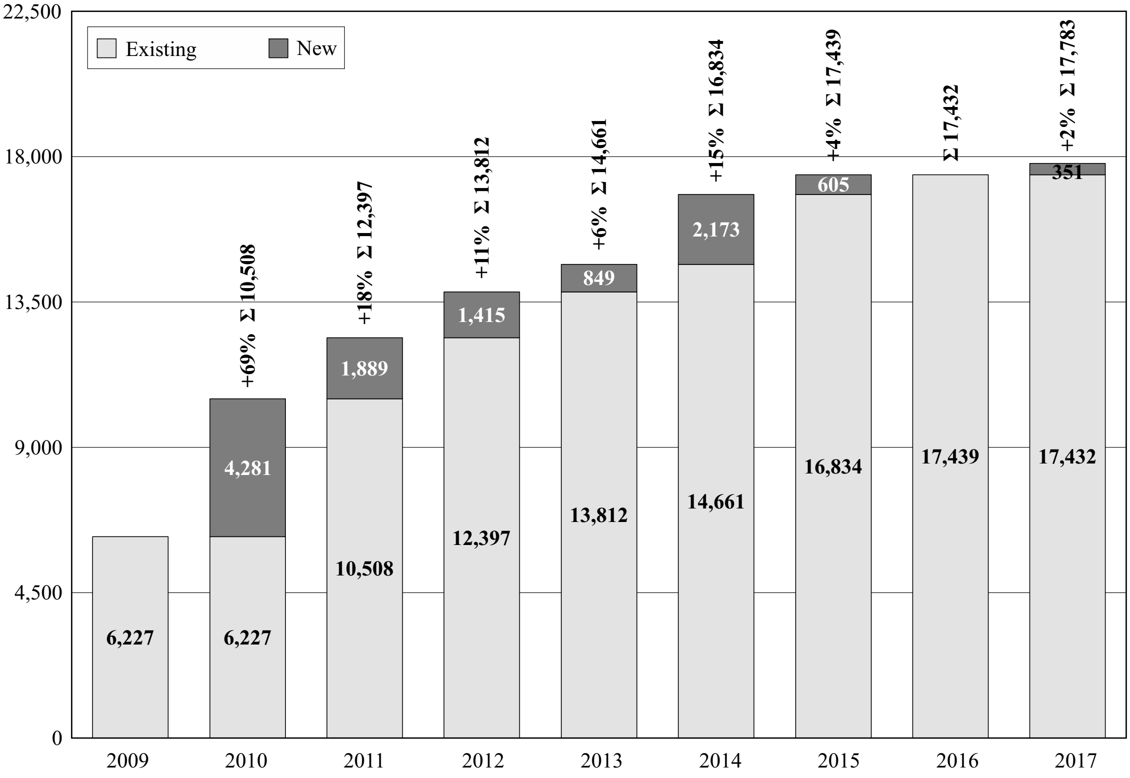

Figure 2. Change in the total number of biogas plants in European countries in the years 2009–2017

Source: European Biogas Association, 2018.

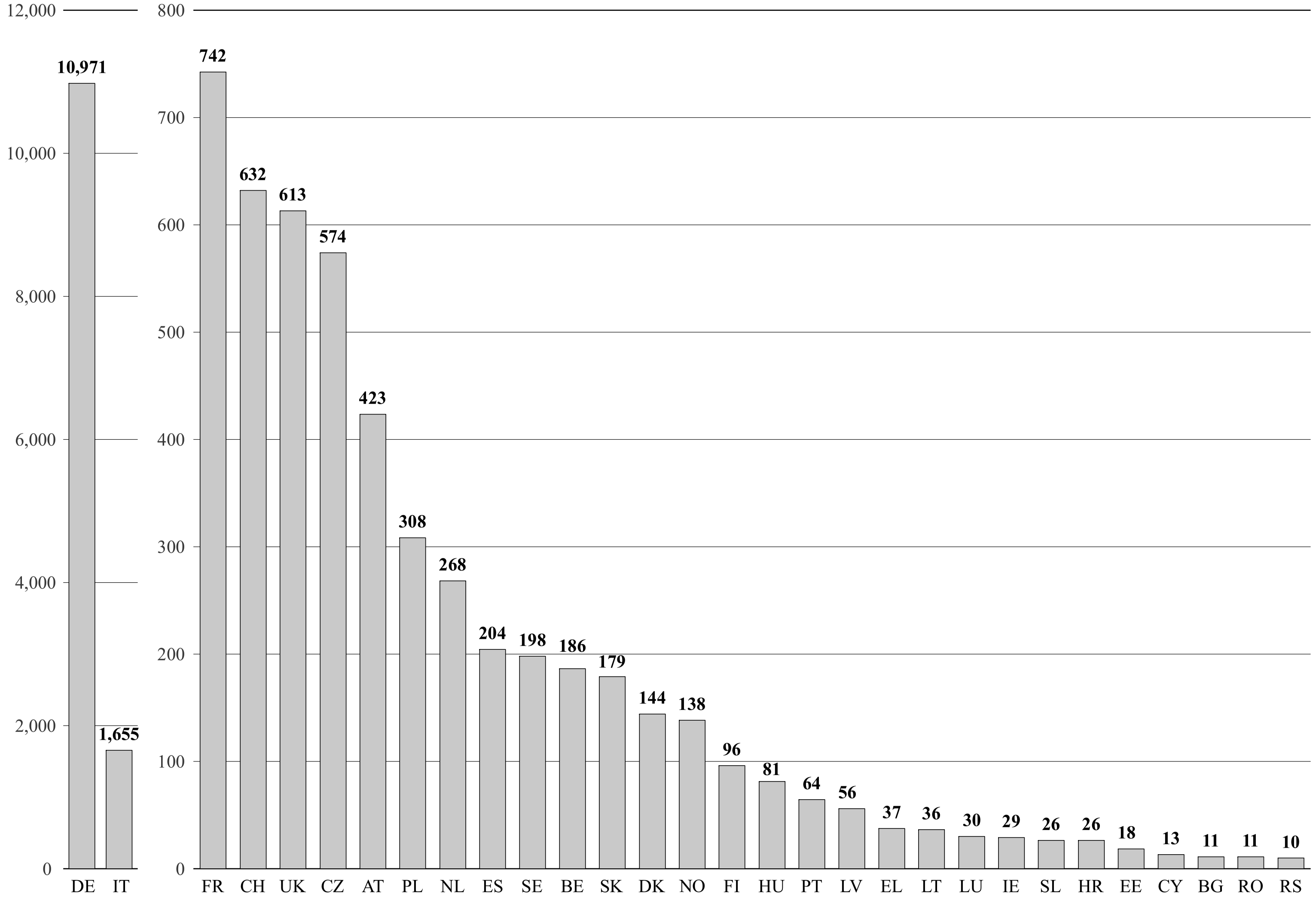

Figure 3. The number of biogas plants by individual European countries in 2017

Source: European Biogas Association, 2018.

Germany was also a country with the highest number of biogas plants in 2017 (10,971). The next country in the rank was Italy, with significantly lower number of plants of this kind (1,655). In 2017, there were 308 biogas plants located in Poland (Figure 3). According to the Polish 'National Support Centre for Agriculture' (Pol. *Krajowy Ośrodek Wsparcia Rolnictwa – KOWR*), by the end of 2020, there wer 116 agricultural biogas plants operating in Poland. All in all, 335 biogas plants were operational at that time (Portal komunalny, 2022).

In Poland, biogas production is on the 4th place in terms of energy production from renewable sources. The share of biogas in overall energy production from renewables increased from 2,55% in 2015 to 3,15% in 2019 (Figure 4).

Between 2015 and 2019, a great increase in the amount of biogas produced in Poland could be observed (Figure 5). It was used mainly to generate electricity and heat. Even though the overall biogas production was on the rise, the amount of produced landfill biogas was slowly decreasing (a decrease by 17,4% in 2019 when compared to 2015). It could be because of the fact that the plants producing this type of biogas are less prone to localisation processes due to the necessity to place them near landfills. When analysing the dynamics of sewage biogas production, a slow growth could be witnessed (an increase by 24,8%). The largest increase in biogas production was in the group of "other biogas" (66,9%) (Główny Urząd Statystyczny, 2020, p. 43).

It is estimated that the potential of biogas production in Poland could reach 31 TWh, which would constitute approx. 18% of overall energy production in Poland in 2019. Considering the potential of agricultural waste processing, Poland could produce 13,5 billion m^3 of biogas annually. If Polish maize production reached similar scale to that visible in Germany, and if this were used as a substrate to produce biogas, the potential of energy production from this source would reach 8 GW. Considering agricultural biogas production, the main factor blocking the location of new biogas investments includes high costs of such undertakings, especially at the early stages of the project (Balicka-Sawiak, 2021).

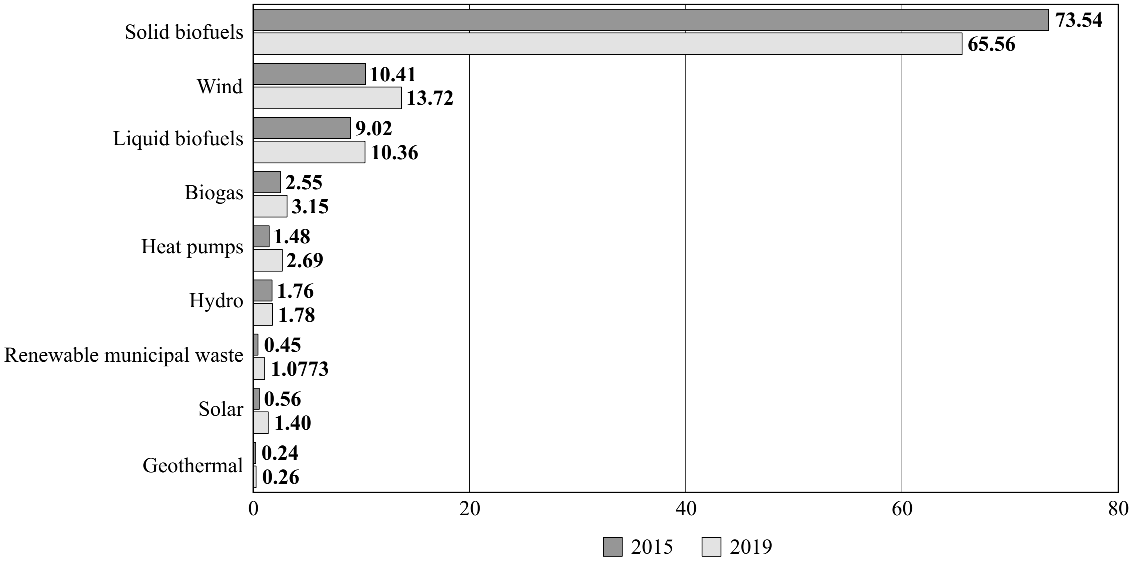

Figure 4. The structure of energy production from renewable energy sources by carriers (% of overall energy production from renewable energy sources)

Source: own elaboration based on data retrieved from Główny Urząd Statystyczny, 2020.

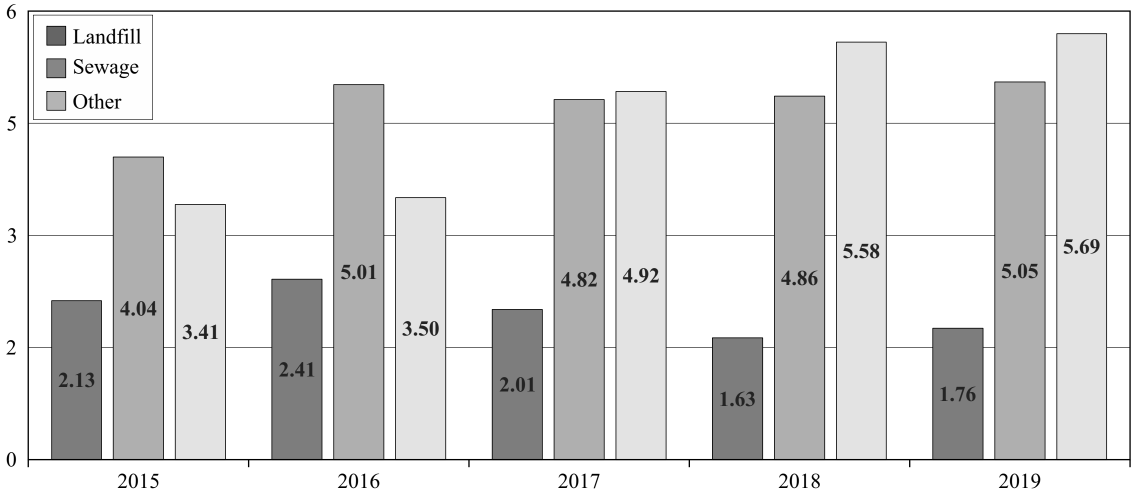

Figure 5. The structure of biogas production in Poland between 2015 and 2019 by types (in thousand TJ)

Source: own elaboration based on data retrieved from Główny Urząd Statystyczny, 2020.

Biogas production in Poland in terms of the PEP2040

The route of Poland towards energy transition can be described as difficult in terms of long-term strategic planning. The PEP2040 contains decisions of strategic importance which are connected to the selection of technologies that should be used in order to build a low-carbon energy system. The strategy is in line with the Paris Agreement, which was concluded in 2015 during the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change. It can be viewed as Poland's national contribution to the implementation of climate and energy policy of the EU. Further development of biogas production in Poland contributes to the fulfillment of the following specific objectives of the PEP2040 (Ministerstwo Energii i Środowiska, 2021, p. 6):

- Specific Goal 1: Optimal use of local raw materials for energy production;
- Specific Goal 2: The development of power infrastructure for various generation sources and networks;
- Specific Goal 6: The development of renewable energy sources;
- Specific Goal 7: The development of district heating and cogeneration;
- Specific Goal 8: Improving energy efficiency.

According to the PEP2040, high priority should be given to offshore wind energy and to plans to build the first Polish nuclear power plant. The construction of this type of energy source in Poland is a contentious issue, but the analyses of the possibility of using this type of energy cannot be omitted. In 2010, the Ministry of Economy developed the Polish Nuclear Power Programme, which was supplemented by appropriate forecasts. At the same time, public consultations were conducted with the participation of about 100 domestic entities. The document presented the process of implementing nuclear power, operating infrastructure facilities, and decommissioning them after their operating period. The implementation of the programme is scheduled for 2011–2030, while its updates would take place every four years. The draft was adopted by the Ministry of Economy in October 2013, and by the Standing Committee of the Council of Ministers in January 2014. According to the assurances of the director of the Nuclear Energy Department of the Ministry of Energy, by 2043, two nuclear power plants should be built in Poland, one of which would be located in the centre of the country and the other in its northern part (Business Insider Polska, 2019).

Simultaneously with large-scale energy production, decentralised energy systems are also planned to be developed, e.g. photovoltaic installations or agricultural biogas plants. The biogas and biomethane sector is expected to be a significant part of energy policy, which will affect the meeting of the EU's goals. In the mid-2020, at the initiative of the Deputy Minister of Climate and Environment, academics and the representative of biogas and biomethane sector as well as the transportation sector all agreed on producing the "Letter of intent about the establishment of a partnership for the development of the biogas and biomethane sector and the conclusion of a sectoral agreement" (Regatrace, 2020). It aims at joint activities to be undertaken for the further development of Polish biogas and biomethane sector. Agricultural biogas plants can help solve some of the problems of the Polish energy transition, including restrictions on the use of nitrates, the increasing costs of using natural fertilisers, and the fluctuating prices of agricultural products.

SWOT analysis for biogas production in Poland

A frequent volatility of support systems and other barriers to the development of biogas production in Poland (such as legal inconsistency and social anxiety) negatively affect the willingness of business entities to invest in the process. This kind of situation is unfavourable – especially considering agricultural biogas production – and it indicated the need to use strategic planning techniques, such as the SWOT analysis, to evaluate the situation of biogas in Poland. The method can be seen as one of the key tools used to analyse situations of strategic importance. It reduces their complexity and the quantity of information that ought to be taken into consideration. The creation of a SWOT matrix can improve the process of decision-making, as it enables the assessment of various alternatives

Table 1. SWOT analysis for biogas production in Poland

Strengths	Weaknesses
• The flexibility of energy production, free from seasonality;	• Location of new plants forces the necessity to overcome the resistance of local community; the NIMBY (not in my backyard) location dilemma;
• Wide range of substrates that can be used in biogas production;	• Low governmental financial help for future in-vestments;
• Independence from climatic factors, i.e. wind or sun;	• No public awareness programmes showing the advantages of biogas production;
• Implementation of innovative solutions on the micro scale;	• Time-consuming and lengthy realisation process;
• The creation of new job opportunities in surrounding areas, i.e. green jobs or renewable energy jobs;	• A wide range of spatial restrictions related to the location of new biogas investments, i.e. environ-mental ones;
• A way to utilise waste and fulfil the provisions of circular economy and sustainable development;	• Problems with the connection to the electrical or gas grid;
• Building a society based on knowledge and territorial specialisation;	• The lack of properly educated and experienced staff in terms of running a biogas plants;
• The possibility of using post-fermentation pulp (the so-called digestate) as a fertiliser;	• A possibility of the generation of odour and explosion hazard.
• Low price of renewable energy in comparison to non-renewable alternatives.	

Table 1 – continuation

Opportunities	Threats
• The development of biogas production technology, i.e. one connected with minimising the nuisance of locating new biogas investments or increasing the quality of produced biomethane;	• Ambiguity and constant changes in Polish legislation concerning the production of energy not only from biogas, but also from renewable sources in general;
• The chance to use upgraded and purified biogas in transportation, i.e. as a transportation fuel for road vehicles;	• The necessity of maintaining strategic connections in terms of substrate availability and fluctuations in the prices of substrates;
• Renewable energy source development is postulated in international regulations;	• Development of biogas production can result in increased competition in the process of gathering the substrates;
• The introduction of feed-in tarrif and feed-in premium for biogas production as a way to attract potential investors;	• Investing in coal energy production and the strength of professional groups related to coal mining in Poland;
• A chance to create energy clusters and energy cooperatives.	• The development of other renewable energy sources in the vicinity of planned biogas investments;
	• The destructive impact of discussions on the development of nuclear energy in Poland.

Source: own elaboration.

in multifaceted-decision-related situations (Helms & Nixon, 2010). Performing a SWOT analysis is useful when conducting research that aims at highlighting the strengths, weaknesses, opportunities, and threats in strategic planning. It can be valuable when analysing the advantages of – and barriers to – the development of biogas production in Poland. The benefits of using this method include acquiring a comprehensive set of information that can be applied, e.g. analysing different kinds of RES in Poland (Table 1).

The current situation of the Polish energy sector is difficult and controversial in terms of deciding about which scenario of long-term energy strategy should be seen as the default one. Discussions about it are a consequence of socio-economic considerations and problems related to the impact of energy on the quality of life. On the one hand, solutions based on bringing short-term benefits are proposed, while on the other hand, an attempt is made to create a specific vision of the country's development, one based on a long-term approach and focusing on the analysis of phenomena occurring in the country's external environment.

Concluding remarks

The inclusion of renewable energy in the structure of energy production must be considered individually for each country. The use of RES implies the need to take into account unique features of a given region as well as an individual set of substrates that can be used during the production. The process of the location of biogas plants should be accompanied by political and social research, which seems to be difficult to conduct. Biogas production can be seen as a significant element for the process of energy transition, which is constant and which is a natural result of the changes in the way that societies see the way of energy production and use.

The multifaceted nature of biogas through the use of anaerobic digestion is its undeniable strength. Biogas production systems consist of processes related to the treatment of waste, which is linked with the protection of the environment; it also allows the transformation of low-value materials into those of higher value. Biogas is used to produce electricity and heat from waste. Therefore, value is generated from materials that would not be used otherwise. The flexibility of biogas production is its strength, which should be taken into consideration when deciding about the long-term strategy of implementing renewable energy solutions into the energy mix.

The volume of biogas production in the EU is gradually increasing, but in the last five years, the change has been less dynamic. The level of biogas production differs greatly in individual Member States. The increase in biogas production is related to the increase in the number of biogas plants. The leading country in the production of biogas is Germany, which is responsible for the production of approx. 45% of the total biogas production among the EU's countries. The most intense dynamics of locating new units in 2017 was visible in Germany, Italy, and France.

Biogas production in Poland is also in the phase of growth. However, compared to the production leaders in the EU, this volume of produced biogas is small. High hopes are placed in the production of agricultural biogas, which is seen as an opportunity for an increase in the use of biomass, as well as a way to develop rural areas by means of using modern technologies in their area and providing new jobs. Agricultural biogas plants can contribute to solving some of the problems of the Polish agriculture, including restrictions on the use of nitrates, the increasing costs of the use of natural fertilisers, and the fluctuations in the prices of agricultural products. There is a large legal inconsistency in Poland related to the production of biogas. A frequent volatility of support systems negatively affects the willingness to invest in the production of agricultural biogas. The SWOT analysis can be seen as an attempt at summarising the determinants of – and obstacles to – the development of biogas production in Poland.

Improving the flexibility of electricity generation in Poland is important, both in the context of broadly understood energy security and in terms of the economic efficiency of energy production processes. Taking into consideration the strengths and opportunities that biogas production gives in the micro scale as well as at the macro level, it can prove to be beneficial for promoting this kind of renewable energy. The weaknesses and threats should also be taken into consideration in order to make the location of new biogas plants easier from the point of view of the investors, as well as to make the investment decisions less risky.

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The Total Cost of the Sterilisation of Materials Used During Surgery for Postpartum Haemorrhage

Abstract

Objectives: The aim of this research paper is to determine the incomes and outgoings related to postpartum haemorrhage implementation for organisations which support prospective payment as the Diagnosis Related Groups (DRG) in United States. We have to take into account surgical costs associated with care provided for these specific patients. Among these costs, surgical acts have to be calculated in association with the sterilisation of materials which can be used more than once.

Research Design & Methods: Patients' evaluation has been held from data collected in obstetrical and sterilisation departments of a university hospital (in Paris), which provides surgical care. The research was based on data from 2014 and 2015. All estimated costs are seen from the hospital's point of view. Surgical care is provided according to the following acts: manual exploration of the uterus (uterine cavity), exploration with valve, hysterectomy, caesarean scar, vaginal packing or unpacking, hypogastrium (iliac vascular ligation), and repair of other organs, such as bladder and embolisation. We take into account the sterilisation of materials used during surgical acts, as well as the staff which was involved in this study.

Findings: 262 patients were taken care of with regard to postpartum haemorrhage, and 255 patient files were studied. Average age was 31.42 +/- 5.5 years old. The cost of surgical procedures goes from 275 EUR for uterus exploration to 875 EUR for hysterectomy. Cost per sterilisation cycle for material used during surgical procedures was about 100 E per cycle and about 33 E per act, no matter the nature of the act.

Implications / Recommendations: The sterilisation of medical devices used in these interventions represents a significant part of the fixed cost: 7.5% to 11.4%. These results make it possible to elaborate one or more future DRGs' "bleeding of the delivery".

Contribution / Value added: This study is an example showing that the current reforms do not favour the quality-of-care coverage. This can contribute to the strengthening and to the recognition of the coverage of postpartum haemorrhage as one of the first causes of maternal deaths, the reduction of which is a priority for public health, as well as a concern for the users. This study is also a contribution to managed care empowerment. Managed care helped to slow down the growth of health care expenditures.

Keywords: postpartum haemorrhage; managed care; DRG; healthcare expenditures; sterilisation of medical devices; cost of surgery

Article classification: research paper

JEL classification: I10; I12; I18

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Introduction

Managed care shifts power away from doctor to payers. For example, managed care contracts place limits on services, whereas a fee-for-service reimburses regardless of the doctor bills. From around 1983, managed care emerged as a market force that grew sharply until 1993. In regions where managed care secured a solid foothold, doctors were forced to compete for patients, putting economic pressure on them to change the way they practice. They now had incentives to consider less expensive medications, decline to provide services of a questionable value, and seek other cost-effective ways to provide care. This pitted payers against seeing a doctor who could provide a service for less money. Supply and demand for doctors had real meaning now. The advent of managed care fundamentally changed the marketplace of physicians by sharply reducing doctors' control over their practice and income (Simonet, 2014; Simonet, 2019).

Competition for patients is to be considered under the need to take care of patients according to quality standards, as well as the need for reducing mortality and morbidity in the public health area.

In public health, this is exactly the priority: to reduce maternal mortality (Ben Hmid et al., 2006; Direction et al., 2007; Kister, 2018a, 2018b, 2019). In France during the 1970s, to prevent morbidity and prenatal mortality, a political action was held. In 1998, a framework in multiple stages of obstetrical and neonatal cares was developed. Health care programmes – such as a perinatal plan – have been implemented during the second-generation Regional Health Organisation Plans (1999–2004) (Fr. *SROS II for schémas régionaux d'organisation sanitaire de deuxième génération*). The Law of August 9th, 2004, concerned a public health policy to provide public health aiming at maternal and prenatal issues. Until the Bill of April 27, 2004, issued by the Ministry of Health, perinatal morbidity and mortality was a major theme of regional health care organisation schemes of the third era (*SROS III*: 2006–2011) (Lernout, 2007; Chevreul et al., 2015; Bréchat, 2006). In 2002, maternal mortality rate was estimated to be at 9 to 13 deceases per 100 000 births (Direction, 2007; Subtil et al., 2004). About 50% of the deceases that occurred between 1996 and 1999 could be considered as preventable (Direction, 2007). The major consequences of maternal mortality is postpartum haemorrhage, with 17.3% of maternal mortalities (Subtil et al., 2004) as well as high blood pressure and embolism (Lévy et al., 2004). Surgery (d'Ercole et al., 2004) and embolisation (Pelage et al., 2004) is used to support postpartum haemorrhage (Saucedo, 2020; Saucedo et al., 2021; Morau et al., 2021; Deneux-Tharaux, 2017).

Knowing incomes and outgoings related to postpartum haemorrhage implementation is essential for health care organisations which do such activities and support prospective payment, known in France as the T2A. The T2A – as in the American Diagnosis Related Groups (DRGs), done in Medicare programme – financed each hospital stay for each French hospital (Segouin, 2006a; Segouin, 2006b; Sahraoui et al., 2006; Stępniewski, 2007; Bura Riviere, 2018; Guesdon-Caltero, 2020). If the T2A contributes to financing hospital stays, it is for each health care department to forecast incomes and outgoings (2005–1474 Bill Act from November 30th, 2005). Even though a maternal mortality decrease is a major public health aim, relative DRGs to postpartum haemorrhage do not exist (Deneux-Tharaux et al., 2017; Rossignol et al., 2021; Saucedo et al., 2020; Saucedo et al., 2021; Deneux-Tharaux et al., 2021). There is no health-and-economical study determining income for future DRGs-related "postpartum haemorrhage" (Morau, 2021). This income has to take into account surgical costs associated with care provided to these specific patients. Among these costs, surgical acts have to be calculated in association with the sterilisation of materials which can be used more than once. This study has been realised at the request of public hospital managerial staff and of the Ministry of Health; its purpose is to provide guidelines to those obstetricians in health care departments who deal with postpartum haemorrhage and applied the T2A financing. The aim is to elaborate and follow up future DRGs' "postpartum haemorrhage" (Stępniewski & Bugdol, 2010).

Materials and methods

Patients' evaluation has been held from data collected in obstetrical and sterilisation departments of the Grand Hospital (a university hospital) providing surgical take care from 1st January, 2014, to 31st December, 2015. Materials used for embolisation acts can be applied only once. Only materials used during surgical acts can be applied more than once; this concerns those which are sterilised, and the associated cost of each material used more than once be studied (e.g. the sterilisation cost). An analysis of production costs has been realised based on the observation of real costs assumed by hospital. As a consequence, estimated costs will be seen from the hospital's point of view.

Material

Selection of health care hospitals

Study places have been searched based on the following criterium – it needed to be a public university hospital with surgical care during postpartum haemorrhage. Surgical care is provided according to the following acts: manual exploration of the uterus (uterine cavity), exploration with valve, hysterectomy, caesarean scar, vaginal packing or unpacking (supposed to be the same act), hypogastrium (iliac vascular ligation), and other organs' repair, such as bladder and embolisation. Hospitals could take into account the sterilisation of materials used during surgical acts, and the staff was involved in this study.

Based on these requirements, the Hôspital Lariboisière – Fernand Widal as well as the Assistance Publique – Hôpitaux de Paris (APHP) were selected for analysis.

Studied materials

Those have been used during surgeries on postpartum haemorrhage performed from 1st January, 2014, to 31st December, 2015.

Method

Standard costs method was used (Castiel, 2004, 2008), e.g. medical and paramedical staff concerned by each surgical act described materials used in a standard way during act realisation, as well as personnel present by a patient's side. Costs have been induced. Materials and goods used in operating theatres have to be considered as fixed costs. Staff cost is variable, because it depends on time used for each patient. Obstetricians, leaders, and nurses of operating theatres have meetings twice. They determined the materials used and the lengths of surgical acts, as well as which materials could be induced in a sterilisation process or used only once. Hourly cost of each staff category present in operating theatres was applied (the employer's cost). Increases in pay due to night work and/or Sunday work were taken into account based on each staff category (medical or paramedical personnel).

Costs analysis framework

Fixed costs

One can notice 10 different topics. Each item is related to quality and quantity: **1. Set-up** involves all items related to patient set-up in operating theatres (covers, bibs, pyjamas, etc.); **2. Debridement act** involves the use of antiseptic solution (Betadine®, compresses, etc.); **3. Dressing** involves dressing the medical team; **4. Draping** involves washing used on the operation area; **5. Materials used once** involve all materials used only once (manifolds, syringes, etc.); **6. Patient transportation** involves from anything concerning a move from a patient's room to operating theatres as well as the return to the room or the post-op recovery room, as well as the materials used during the very transportation (pants, covers, gloves, etc.); **7. First disinfection** involves materials and disinfection goods used for materials which can be used again before the transportation to sterilisation department; **8. Anaesthesia** involves drugs used for anaesthesia; **9. Cleansing enema**, but only the one relating to the exploration with valve; **10. The sterilisation** of for those materials which are used more than once.

Further, the price of each item is the price paid by the hospital. The total amount of these items makes the fixed cost: quantity x unit price sum for all items.

Variable costs

To appreciate variable costs, we created the hypothesis that regardless of the surgical act, staff on operating theatres is the same: when a patient goes to operating theatres for stopping haemorrhage, an act that will be made is unknown. Staff is here 24/7 and they do what is necessary. On the one hand, we looked into the act duration for each patient (the time of arriving and the time of departure in operating theatres). On the other hand, we looked into hourly costs (for hospital) for each category of staff that is present on operating theatres, including stretcher-bearers. It was not obvious to recognise the real wages of all the people present on operating theatres, which is why we included the average wage supported in this hospital for each category of staff. Based on this, we made the hypothesis as to 152 working hours per month for paramedical staff and 200 working hours per month for medical staff. Corrections were made when, for example, the surgeon was either a senior or a head resident. Weighting was made according to the staff's real arrangement. For example, obstetrician staff consists of three seniors and one head resident. Therefore, in this case, per one out of four acts, we assumed that surgeons' salary was the one of head resident, while per three out of four acts, surgeons' salary was the one of senior surgeon. More than this, for each staff category (medical and paramedical), bonuses wages were added for night work and/or Sunday work: the date and time of arriving and the time of departure were known for each patient. The variable cost was calculated for each patient: the duration of an act multiplies by hourly cost for each staff category present in operating theatres. Stretcher-bearers' work could be considered as a fixed cost, because we made the hypothesis that this work lasts one hour (half an hour for going to operating theatres and half an hour for return). However, we considered this cost as variable: it can be made at night and/or on Sunday.

Another variable cost was included: the use of drugs as catecholamines or others, if it occurs.

Sterilisation

Costs framework was elaborated for sterilisation according to each surgical care during postpartum haemorrhage. It is also a retrospect study, because costs study were not previewed with regard to taking care of a patient. For each step of sterilisation, staff categories were specified (functions, working place), concrete roles of each one with human resources were discussed, and the used goods were explored, also for intervention places. Time was measured by two observers with the help of chronometer. The mean time was taken into account when differences between the two measures occurred. Costs were evaluated with regard of the employer. For each action, cost production and cost time were calculated. Cost time was appreciated in cost per minute. For each category of staff, monthly wage was provided by the employer or by the official scales of salary. As we did for the variable cost, night work and/or Sunday work was considered. Depreciation allowance for the sterilisation of equipments was calculated with straight line method of depreciation on the basis of only one machine (the more recent one, because we did not know the one used immediately for material sterilisation of each act). To induce the sterilisation cost, we assumed that one sterilisation cycle was made only for one material at a time; we took into account the theoretical maximal capacity for each machine, although it was not real; we induced an average cost of a cycle for one material at a time. Then, we had to create a material basket (container) for the studied surgical act with regard to the theoretical sterilisation cost by a material.

Statistical analysis

The data issued from average differences analysed by t-Student with Epi Info 6.0, ENSP, France, tested at 5%.

Results

From 1st January, 2014, to 31st December, 2015, 262 patients were taken care of with regard to postpartum haemorrhage, and 255 patient files were studied. Average age, calculated at the date of arriving, was 31.42 +/- 5.5 years (n=255).

Surgical acts frequency

Surgical care is made according to the following acts: a manual exploration of the uterine cavity, the exploration of the valve, hysterectomy, vaginal packing (and unpacking), hypogastrium (iliac vascular ligation), and embolisation. There are no caesarean scars and no other organs' repairs (e.g. the bladder's).

Embolisation made alone or coupled with another surgical act. Table 1 specifies the sharing out of distribution. Ninety-one patients got embolisation (35.7%). Among them, 23 got an additional surgical act, or they got a surgical act as the first action. That is to say that 68 patients got embolisation only. In total terms, 52 patients (20.4%) got a surgical act different from embolisation (for 29 patients, it was a surgical act alone). Therefore, the surgical intervention rate is low in postpartum haemorrhage.

Surgical acts costs

The average cost of surgical acts is provided in Table 2. One can notice that 12 patients got surgical act twice, or even a third one (for two patients only, it was unpacking).

Table 1. Surgeries distribution according to care strategies

	Hysterectomy	Ligation	Packing	Uterus explo.	Valve explo.	Embolisation	Total
Embolisation	2	0	3	5	13	68	91
Other act	3	3	7	3	13	0	29
Total	5	3	10	8	26	68	120

Source: own elaboration.

Table 2. Cost of surgical procedures in the care of postpartum haemorrhage (in euros) (n = 52)

	Hysterectomy	Ligation	Packing	Uterus explo.	Valve explo.
Age (years)	34.6 +/–6.02	37.7 +/–4.62	31.9 +/–4.98	29.63 +/–3.96	30.88 +/–5.22
Number (n)	5	3	10	8	26
Fixed costs:	422.22 (48.2%)	370.37 (61.6%	403.94 (55.7%)	109.67 (39.9%)	122.9 (40.6%)
Variable costs:	452.84 (51.8%)	231.18 (38.4%)	321.59 (44.3%)	165.37 (60.1%)	179.58 (59.4%)
Total	875.06	601.55	725.53	275.04	302.48
Average length of act	2h21	1h30	1h51	0h47	1h00

Source: own elaboration.

Sterilisation

Three visits were paid to the sterilisation central service, with one such visit lasting half a day, as well as three talks with staff were held. We could not take into account data related to garbage and that related to labelling sterilised materials (the time necessary for labelling).

Sterilised surgical materials determination

Table 3 considers sterilised surgical materials used according to each included surgical act.

Sterilisation steps and costs per act (and per cycle) determination

For all steps, it was estimated that the hospital pharmacist used 5 minutes by cycle for validation, the head nurse used 5 minutes, too, for managing orders and for interventions'a follow-ups. The pharmacist spends 10 minutes more daily for managing problems observed in the course of the day.

Step 0: *Materials used in operating theatres*

Step 1: First disinfection in operating theatres (7 minutes for the nursing auxiliary and 30 minutes for the stretcher-bearers)

At the end of the surgical act, the used material is gathered by the nursing auxiliary (NA) of operating theatres; it is then put in a detergent bath (Hexanios G+R ®, Anios) (1 bag for 5 litres of water). The material details, date, and the time of beginning the first disinfection are noted. Two minutes are needed to fill the form. It takes fifteen minutes to dip materials in the detergent bath. At the end of this step, the form is completed with the ending time of disinfection; the NA empties the bath and gathers all materials in a container which is placed in a plastic bag (for protection) for transportation. The time for this is 5 minutes. Materials are sent on a patient cart to the Sterilisation Department by the NA, and then she/he returns to operating theatres. She/He goes through several operating theatres and collects materials for transportation. This takes one hour.

Step 2: The sterilisation process – Sterilisation Department

Taking care of materials is done instantly, if necessary, due to the increase of activity. The sterilisation process comprises the following 4 steps:

1. *Receipt and check (4 minutes – NA)*

Materials on receipt are verified both, on quantitative and qualitative basis, following sheet form, by NA; pre-disinfection is verified. That

Table 3. Identification of material which can be sterilised by the act of surgery

	Hysterectomy	**Ligation**	**Packing**	**Uterus explo.**	**Valve explo.**
Container «Delivery»					x
Container «Hysterectomy»	x				
Container «Stomach»	x	x	x		
Valves container					x
Cupule				x	x
Curette				x	x
Big cupule	x	x	x		
Pozzi's crowbar	x	x	x		
Needle case	x	x	x		
Leriche's valve	x	x	x		
Rochard's valve	x	x	x		

Source: own elaboration.

takes 4 minutes. Materials are disposed in washing baskets with optimal manner to optimise washing up. Baskets are put in washing machines. Time of beginning varies according to occupational rate of washing machines. Data put on form sheet are computerised. This engages follow up of sterilised materials in sterilisation department. All these actions take one hour.

2. *Washing up*

Three washing up process is used in the sterilisation department: hand washing (it is an exception, only used for materials which cannot be put in water for a long time), ultrasonic washing method (for materials which are difficult to wash), and washing by automatic machines with one or several chambers (T 840, Hamo-Steris). The materials used here are almost treated by washing machine in multi-chambers machine for 45 minutes. We included this machine for washing up in the cost evaluation. The NA computerises data for the follow-up of washing up: the material's name, the department, date and time, the washing machine used, the names of the people who did the washing up.

3. *Packaging and control (15 minutes for the NA and 50–90 minutes for a nurse depending on the surgical act]*

3.1. *Control*: each material is verified (working conditions, cleanliness, drying) at the end of washing up done by the NA. Drying can be carried on with medical oxygen (not observed and counted). The material is categorised. All these steps take 10 minutes.

3.2. *Packaging*: A nurse from the relevant department doing packaging. The nurse needs 20 minutes to prepare herself/himself: 15 minutes to undress in operating theatres, to go to the sterilisation department, and to dress her; 5 minutes to verify materials according to the surgical act, and to complete the form of the follow-up. Packaging needs 10 more minutes for manual exploration of the uterus, i.e. up to 35 minutes for exploration with valve and up to 50 minutes for hysterectomy, packing, or hypogastrium (iliac vascular ligation). The nurse needs 5 more minutes to undress herself in the sterilisation area.

3.3. *Loading the sterilisation machine and data capture*: done by the NA during 5 minutes

4. *Sterilisation during 90 minutes* (Autoclave Matachana S1000 – 8 baskets)

Unloading sterilisation machines and controls (20 minutes – NA). Sterilised materials are waiting for cooling for about 30 minutes. During this time, the NA verifies sterilisation cycle parameters for 5 minutes. After material cooling, the NA compares the materials with those mentioned on the form. The NA proceeds to labelling and puts materials in baskets depending on the department. This takes 10 minutes. Data is computerised once again and distribution sheet is edited (5 minutes).

Step 3: Operating theatres return [30 minutes]

Sterilised material is put in the waiting area in the sterilisation department until a nurse comes from the operating theatre to pick up the sterilised materials. The waiting time varies from few minutes to several days, depending on the operating theatres' needs.

Table 4 presents the numbers of each material processed – theoretically – by the washing machine and the sterilisation machine.

Sterilisation costs are 1.75 EUR per act for manual exploration of the uterus (99.9 EUR per cycle), 14.02 EUR per act for exploration with valve (98.36 EUT per cycle), 31.73 EUR per act for hysterectomy (90.64 EUR per cycle), and 33.07 EUR per act for packing or vascular ligation (94.5 EUR per cycle). Tables 5–8 provide the calculus for material sterilisation used for each surgical act.

Table 4. The estimated number of items that can be handled by a cycle of a washing machine and a steriliser

Material (sterilised item)	Sterilised item volume estimation	Average items handled by cycle
Delivery container	Small container	16
Hysterectomy container	Big container	8
Stomach container	Big container	8
Valves container	Small container	16
Cupule	Small bag	200
Curette	Big bag	80
Big cupule	Big bag	80
Pozzi's crowbar	Big bag	80
Needle case	Big bag	80
Leriche's valve	Small container	16
Rochard's valve	Small container	16

Source: own elaboration.

Table 5. Cost per sterilisation cycle and by the act of manual exploration of the uterine cavity (EUR)

Cost by cycle	Units	Unit price	Total
Staff:			
Personnel NA:	2 h	10.83	21.66
Personnel nurse:	0.83 h	15.43	12.81
Personnel stretcher-bearer:	1 h	10.34	10.34
Personnel pharmacist:	0.08 h	43.55	3.63
Personnel head nurse:	0.08 h	31.56	2.63
Equipments:			
Washing machine (Tunnel T 840, Hamo Steris)			
Depreciation	1 cycle	19.95	19.95
Detergent	0.21 l	4.55	0.95
Lubricant	0.04 l	6.1	0.24
Electricity	9 kwh	0.05	0.45
Water	0.14 m3	4.07	0.57
Maintenance	1 cycle	9.48	9.48
Autoclave 8 baskets (S1000, Matachana)			
Depreciation	1 cycle	6.23	6.23
Electricity	20 kwh	0.05	1.00
Water	0.3 m3	4.07	1.22
Maintenance	1 cycle	1.92	1.92

Table 5 – continuation

Cost by cycle	Units	Unit price	Total
First-disinfection realised at operating theaters (disinfectant)	1	0.15	0.15
Dressing materials:			
Overall	1	3.46	3.46
Forage cap	1	0.02	0.02
Overshoes	1	0.15	0.15
Overpants	1	3.02	3.02
Soap	1	0.54	0.54
Total per cycle:			99.87
(2 items sterilised)			

Cost per material used	Units	Nb per cycle	Unit cost	Total
Cupule	1	200	0.50	1.181
Curette	1	80	1.25	11.813
				5.906
				11.813
				1.181
				1.181
Total sterilisation per act of exploration of the uterine cavity			1.75	

Source: own elaboration.

Table 6. Cost per a sterilisation cycle and by an act of exploration with valve (EUR)

Cost by cycle	Units	Unit price	Total
Staff:			
Personnel NA:	0.5 h	10.83	5.42
Personnel nurse:	1.75 h	15.43	27.00
Personnel stretcher-bearer:	1 h	10.34	10.34
Personnel pharmacist:	0.08 h	43.55	3.63
Personnel head nurse:	0.08 h	31.56	2.63
Equipments:			
Washing machine (Tunnel T 840, Hamo Steris)			
Depreciation	1 cycle	19.95	19.95
Detergent	0.21 l	4.55	0.95
Lubricant	0.04 l	6.1	0.24
Electricity	9 kwh	0.05	0.45
Water	0.14 m3	4.07	0.57
Maintenance	1 cycle	9.48	9.48

Table 6 – continuation

Cost by cycle	Units	Unit price	Total
Autoclave 8 baskets (S1000, Matachana)			
Depreciation	1 cycle	6.23	6.23
Electricity	20 kwh	0.05	1
Water	0.3 m3	4.07	1.22
Maintenance	1 cycle	1.92	1.92
First-desinfection realised at operating theaters (disinfectant)	1	0.15	0.15
Dressing materials:			
Overall	1	3.46	3.46
Forage cap	1	0.02	0.02
Overshoes	1	0.15	0.15
Overpants	1	3.02	3.02
Soap	1	0.54	0.54
Total per cycle:			98.36
(4 items, 50 minutes for packaging)			

Cost by material used	Units	Nb per cycle	Unit cost	Total
Cupule	1	200	0.49	1.181
Curette	1	80	1.23	11.813
Valves container	1	16	6.15	5.906
Delivery container	1	16	6.15	11.813
				1.181
				1.181
Total sterilisation per an act of exploration with valve			14.02	33.075

Source: own elaboration.

Table 7. Cost per a sterilisation cycle and by an act of hysterectomy (EUR)

Cost per cycle	Units	Unit price	Total
Staff:			
Personnel NA:	0.5 h	10.83	5.42
Personnel nurse:	1.25 h	15.43	19.29
Personnel stretcher-bearer:	1 h	10.34	10.34
Personnel pharmacist:	0.08 h	43.55	3.63
Personnel head nurse:	0.08 h	31.56	2.63
Equipments:			
Washing machine (Tunnel T 840, Hamo Steris)			
Depreciation	1 cycle	19.95	19.95
Detergent	0.21 l	4.55	0.95

Table 7 – continuation

Cost per cycle	Units	Unit price	Total
Lubricant	0.04 l	6.1	0.24
Electricity	9 kwh	0.05	0.45
Water	0.14 m3	4.07	0.57
Maintenance	1 cycle	9.48	9.48
Autoclave 8 baskets (S1000, Matachana)			
Depreciation	1 cycle	6.23	6.23
Electricity	20 kwh	0.05	1
Water	0.3 m3	4.07	1.22
Maintenance	1 cycle	1.92	1.92
First-desinfection realised at operating theaters (disinfectant)	1	0.147	0.15
Dressing materials:			
Overall	1	3.46	3.46
Forage cap	1	0.02	0.02
Overshoes	1	0.15	0.15
Overpants	1	3.02	3.02
Soap	1	0.54	0.54
Total per cycle:			90.64
(6 items, 50 minutes for packaging)			

Cost per material used	Units	Nb per cycle	Unit cost	Total
Cupule (big)	1	80	1.13	1.181
Rochard's valve	2	16	5.66	11.813
Leriche's valve	1	16	5.66	5.906
Stomach container	1	8	11.33	11.813
Pozzi's crowbar	1	80	1.13	1.181
Needle case	1	80	1.13	1.181
Total sterilisation per an act of hysterectomy			31.72	33.075

Source: own elaboration.

Table 8. Cost per a sterilisation cycle and by an act of vaginal packing (or unpacking) and vascular ligation (EUR)

Cost per cycle	Units	Unit price	Total
Staff:			
Personnel NA	0.5 h	10.83	5.42
Personnel nurse:	1.5 h	15.43	23.15
Personnel stretcher-bearer:	1 h	10.34	10.34
Personnel pharmacist:	0.0833	43.55	3.63
Personnel head nurse:	0.0833	31.56	2.63

Table 8 – continuation

Cost per cycle	Units	Unit price	Total
Equipments:			
Washing machine (Tunnel T 840, Hamo Steris)			
Depreciation	1 cycle	19.95	19.95
Detergent	0.21 l	4.55	0.95
Lubricant	0.04 l	6.1	0.24
Electricity	9 kwh	0.05	0.45
Water	0.14 m3	4.07	0.57
Maintenance	1 cycle	9.48	9.48
Autoclave 8 baskets (S1000, Matachana)			
Depreciation	1 cycle	6.23	6.23
Electricity	20 kwh	0.05	1
Water	0.3m3	4.07	1.22
Maintenance	1 cycle	1.92	1.92
First-disinfection realised at operating theaters (disinfectant)	1	0.15	0.15
Dressing materials:			
Overall	1	3.46	3.46
Forage cap	1	0.02	0.02
Overshoes	1	0.15	0.15
Overpants	1	3.02	3.02
Soap	1	0.54	0.54
Total per cycle:			**94.50**
(6 items, 50 minutes for packaging)			

Cost per material used	Units	Nb per cycle	Unit cost	Total
Cupule (big)	1	80	1.18	1.181
Rochard's valve	2	16	5.91	11.813
Leriche's valve	1	16	5.91	5.906
Stomach container	1	8	11.81	11.813
Pozzi's crowbar	1	80	1.18	1.181
Needle case	1	80	1.18	1.181
Total sterilisation per an act of packing or unpacking, and vascular ligation			33.08	**33.075**

Source: own elaboration.

Discussion

The used methodology allowed us to determine the costs of surgical acts in postpartum haemorrhage (n = 52): costs are from 275.04 EUR for manual exploration of the uterus (n = 8), 302.48EUR for exploration with valve (n = 26), 601.55 EUR for vascular ligation (n = 3), 725.53 EUR for packing or unpacking (n = 10), and up to 875.06 EUR for hysterectomy (n = 5) (Castiel & Bréchat, 2008). The sterilisation of medical devices used in these interventions represents a significant part of the fixed cost: 7.5% to 11.4%. This cost is doubtless under the estimated in its component "variable Costs in staff" if one takes into account the database of the said cost accounting of the "TEACHING HOSPITAL of Angers" (author MSSPS, publisher DHOS): 145 EUR against 43 EUR in table 5. This can provide some explanation, partially by the fact that the time of unloading of the sterilisers and the control of the cycles and the sterilised articles varies according to the composition of the verified load; the accounted times correspond to the time of check of a load consisting exclusively of containers (or baskets).

The embolisation act is committed for 36% of postpartum haemorrhage. It is completed by a secondary surgical act for 25% of embolisations. The cheapest act is the uterine revision. It is also the fastest one to be performed. Because surgical practice is always joint, the observed patients' size is low by surgical act (Lernout, 2007). Elements of the "Strategy of care by the invasive methods" of the text of the recommendations from 2004 can be found (d'Ercole et al., 2004; Pelage et al., 2004)]. These results can give a trend in a domain which is still little explored (Segouin & Bréchat, 2006a; Jourdain, 2000).

Even if at the moment the cost of the sterilisation of medical devices in the public institutions of health is not often valued, it must be taken into account when calculating the costs of surgical activities (Stępniewski & Michałek, 2001). In the case of the care of post-partum haemorrhage, the cost of sterilisation was calculated following the example of other participating services (or departments) (Rossignol, 2004). It is to be taken into account for quality acts as well as by the sanitary planning (Castiel, 1997).

These results were sent to the ministerial sponsors in order to elaborate and to follow-up one or more future DRGs' "bleeding of the delivery". In 2012, it was not found in the last textbook of DRGs, updated 1st March, 2011[1]. "Pathological pregnancies, the deliveries and the affections of the postpartum" appear in the major category of diagnosis n°14. Bleedings benefit from a level of severity of 3 on the scale of 4 for "bleeding during the delivery with anomaly of the coagulation", "Other bleedings during the delivery" and "Bleeding during the delivery, without precision"[2]. These 3 associated comorbidities (AC) can be taken into account if none of the major diagnoses from the list of 34 occurs[3]. Elements of supervision can be accounted, along with an average duration of stay (high and low border). This individually complex coding makes it possible to arrive at the DRGs. Therefore, receipts for postpartum haemorrhage under care in a public hospital can benefit from DRGs at the level of 5464–3331.64 EUR (DRGs 14Z02C – "Deliveries with major complications") or 5308–5514.51 EUR (DRGs 14C02C – "Caesareans with major complications"). If a patient does not stay for a long time, receipts will come from DRGs at the level of 5307–4627.43 EUR (DRGs 14C02B – "Caesareans with other complications") or of DRGs at the level of 5463–2532.95 EUR (DRGs 14Z02B – "Deliveries by vaginal childbirth with other complications"). If there is a hysterectomy, it will be DRGs at the level of 5309–5602.61 EUR (DRGs 14C03Z – "Deliveries by vaginal childbirth with other interventions"). If these receipts cover

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[1] V. 11 of classification, V. 13.11c of grouping function, Bulletin Officiel n°2011/5 bis.

[2] Last textbook of grouping function, V. 13.11c, Bulletin Officiel n°2011/5 bis.

[3] The list of DRGs, excluding the major-category list.

the costs of the calculated surgical acts, several remarks can be formulated.

In spite of the request of the Ministry of Health, this research did not press on the initial objective which was the elaboration and the follow-up of one (or) future DRGs' "bleeding of the delivery" or "postpartum haemorrhage". It raises the question of the transparency of the elaboration of the health policy and its financing, but also the legitimacy of the new governance and the credibility of the T2A-EPRD (Bréchat, 2010). The complexity of coding to arrive at the DRGs also raises the question of the investment of the department and the establishment to realise this coding. Financial constraints can urge the services or departments to cheat in order to benefit from DRGs better provided in euros, taking the risk of being controlled and sanctioned. Not considering evolutions of the practices according to the evolution of the T2A also risks discouraging professionals and managers in charge from investing in innovation, as embolisation of the bleeding of the delivery.

This study is an example showing that the current reforms do not favour the quality coverage of care (Bréchat, 2008). We find one of the two evolutions of the liberal thought in the space of the law conceived of by Koubi (2008): a service (or department) regardless of the quality of the provider for the "public" care, understood as an indefinite mass, which confirms the substitution of the customer to the user of public service (see also: Stępniewski & Bugdol, 2010). These evolutions must be considered in the European context and for all public services (Allouache, 1998). Nevertheless, the reduction of maternal mortality remains a priority of the public health. This study shows that the current reforms do not favour the production of the health, but, rather, the consumption of care (Evans, 1990).

This study is also an example illustrating that a lot of progress needs to be made in France concerning the consideration of the carbon tax, which is one of stakes in the health systems of the 21st century (Gray, 2011). Efforts must be made with regard to the purchases of equipment, and our study can contribute to it.

This set can participate in the strengthening and in the recognition of the coverage of post-partum haemorrhage as one of first causes of maternal deaths, the reduction of which is a priority of public health and a concern of the users (Bréchat, 2010; Green, 2007).

Conclusion

The costs of surgical coverage care of post-partum haemorrhage can be calculated to give marks to the piloting and to the follow-up of these activities within the framework of the implementation of the T2A-EPRD and the business parks. They can also participate in the elaboration and in the follow-up of one (or more) future DRGs' "bleeding of the delivery".

They can especially integrate those of a health course or a capitation (Bréchat, 2016) which are less counterproductive fundings "for the health of the populations" than the T2A (Batifoulier, 2017). The systems did this perform much better than those that stayed at the T2A (Castiel & Bréchat, 2019).

This study is a contribution to managed care empowerment. Managed care helped to slow down the growth of health care expenditures. As managed care grew, health care spending declined, and as managed care declined, health care expenditures rose. The managed care leads, for example, to the evaluation of costs for surgical coverage care of postpartum haemorrhage. Policymakers at the risk of the wrath of seniors would prioritise direct care, and it would be essential to know the costs of taking care of these patients. Another way is to coordinate doctors' efforts to answer the rising demand for healthcare and for physicians; in any case, the demand for physicians is rising faster than the supply, and it is already too late to try and produce all the doctors that would otherwise be needed today. If one really thought that the solution was more medical doctors (MDs), this should have started ten years ago. And it was not the case. Therefore, the way to fill this gap is probably going to be through nurse practitioners and physician assistants, who are a lot quicker and easier to train than MDs are. It could also be beneficial to develop prevention and health pathways. Adopted managed care is another solution for producing more care for anything under supply control. Managed care is making the market more efficient under the constraints of knowing the real costs of intervention.

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