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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; Pilžys, 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

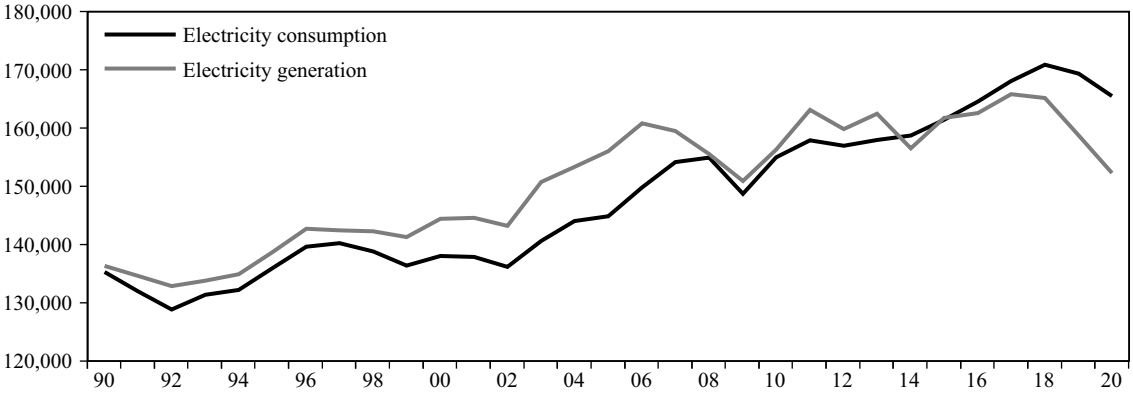

Figure 1. Domestic electricity production and consumption in 1990–2020 [GWh]

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

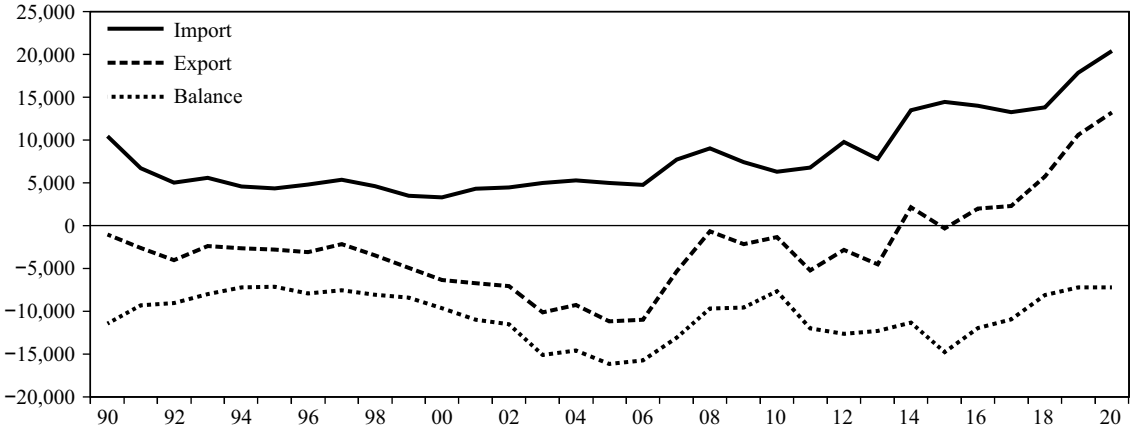

Figure 2. Electricity exchange with foreign countries in 1990–2020 – physical flows [GWh]

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

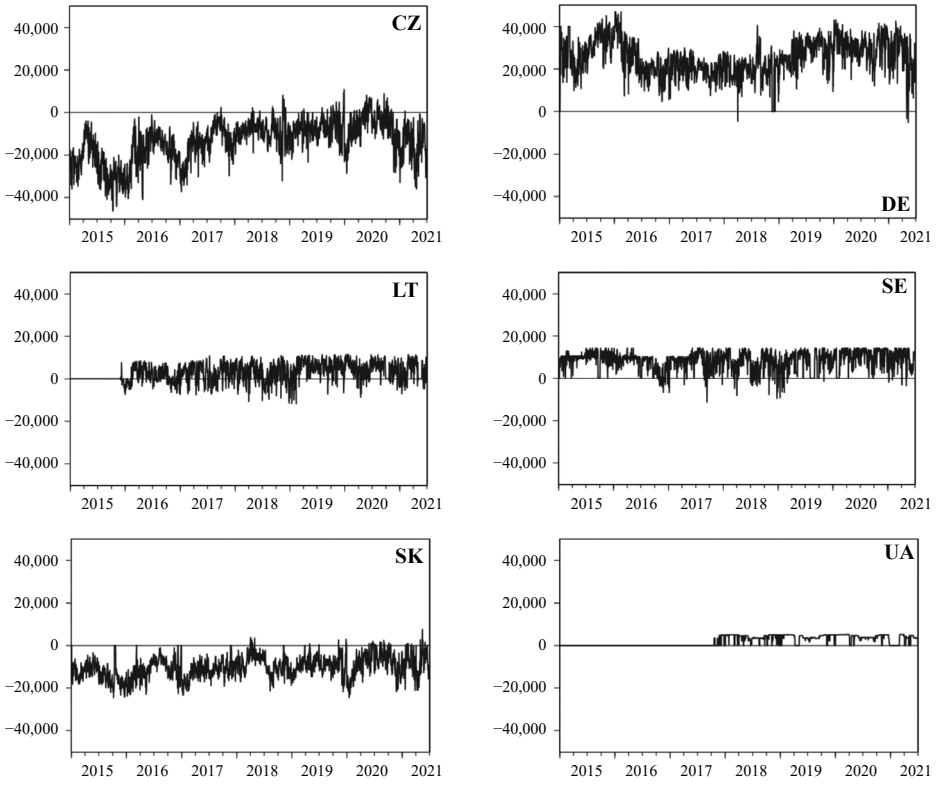

Figure 3. Daily data on the balance of cross-border physical flows from Q1 2015 to Q2 2021 [MW]

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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