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European Sustainable Development: Assessment of the Degree of Expenditure on Innovation in Power Companies in Poland

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Abstract:

Purpose: *Sustainability is an idea that has contributed to a shift in thinking about energy markets. It is already known that one of the ways of achieving development is introducing new technological solutions/innovations. Therefore, the aim of this paper is to present the results of a study of energy enterprises in Poland - DSOs and TSOs in terms of their innovativeness.*
Design/Methodology/Approach: *Following the documentary research, the main tool used in this research is index analysis, diagnosis of the current state, and detailed analysis of development trends. Descriptive statistics and single attribute value function (SAVF) were used to assess the relationship between energy production and innovation expenditures.*
Findings: *The results show that in Poland the relationship between innovation expenditures and energy production is non-existent. This may be due to the structure of energy production, which in Poland is based on coal. The evaluation of innovativeness of energy companies indicates that the dynamics of innovativeness in energy companies is still unsatisfactory.*
Practical Implications: *Current expenditures on innovation are still insufficient for an efficient energy transformation of Poland. The presented research results can be used to create new policies and development strategies on the dynamics of innovation in energy companies in Poland.*
Originality/value: *Presented research results have both research and practical value in relation to the current level of expenditures on innovation in the power sector, comparing strategic documents and policies with practical actions taken in electric power enterprises in Poland in terms of innovation and discussing the next steps necessary to achieve the objectives of the European Green Deal to be the first climate-neutral continent in 2050.*

Keywords: *Innovation, power industry in Poland, energy production.*

JEL codes: *01, 02, 04, 05, 031, 033, C2, C3, D9.*

Paper type: *Research article.*

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1. Introduction

The development of energy markets is associated with an intensive industrialization period. The nineteenth century brought technical discoveries thanks to which the experience of earlier inventors found application in the production of alternating current. Demand for new energy sources and at the same time technical possibilities have created space for the implementation of changes that have revolutionized not only the way of industrial production for the next decades but also and perhaps above all became an impulse for the creation of electricity markets.

There is no doubt that the main factor of sustainable development is appropriate technical infrastructure. Therefore, it seems important to diagnose the current state of innovation development in the Polish power industry and to compare it with selected European Union countries. This article therefore attempts to assess the state of introducing innovations in the power industry

The aim of the article is to present the results of research on energy companies in Poland - DSOs and TSOs in terms of their innovation. The article presents the main sources and channels for acquiring and implementing innovations in the power industry and shows development trends in this sector. Descriptive statistics and the SAVF (single attribute value func-tion) method were used to assess the relationship between energy production and innovation expenditures. On the other hand, a simplified nnnovation new indicator (INI) was used to measure the dynamics of innovation growth in this sector (Stankowska, 2021).

In this article, innovations are defined as all activities involving research and development in the area of new solutions. Based on the research of source documents of TSO and DSO strategic and internal documents in 2015-2020, the main areas in which innovations are implemented among the largest distribution companies in Poland and at the transmission system operator were selected. In addition, the total expenditure on innovation in Poland and selected EU countries in 2010-2020 was analyzed.

The author of the research also determined the amount of expenditure on innovations in the field of energy distribution in relation to expenditure on investments in technical infrastructure in 2015-2020, which allowed for a different look at expenditure related to innovation. Moreover, it made it possible to determine expenditure on R&D in Poland per capita, which in turn made it possible to show the dynamics of changes. For this purpose, OECD and Eurostat data as well as information from source documents of distribution system operators and the transmission system operator were used.

Innovations in the energy sector cover a very wide range of activities and initiatives. The most important areas of innovative projects undertaken include:

(1) energy storage,
(2) energy efficiency,
(3) the use of technology in the management of transmission networks.

The creators of new solutions are trying to flexibly respond to the expectations of entities operating on the electricity market. The needs are dominated by, saving and reducing costs of energy production and environmental protection. Innovations in the energy sector not only contribute to changing the energy carriers used, but also can bring closer to a real revolution in the energy sector.

Innovations in the energy sector revolve around energy efficiency and electrification. An example of revolutionary changes are, personalized offers of new tariffs prepared for the client, taking into account his preferences but also the load on the transmission network.

The demand for innovations in the energy sector is a consequence of the growing problems of the modern world, including Poland and the Polish energy market. Certainly these are, the need to save energy, rising prices of fossil fuels, development of models of inter-branch cooperation, striving to reduce negative environmental effects and, finally, growing international competition in the field of low-carbon products. At the same time, the perception of energy markets is changing. In the societies of more economically developed countries, there is an increase in ecological awareness and the growing share of energy costs in all countries.

Therefore, from the 1970s, a period of changes on the electricity markets begins, serving not only to increase the volume of installed capacity and the volume of energy production, but also to reduce the negative impact on the environment (Zhang *et al.*, 2009; Bell and Simon, 2018).

In 2017, investments in the energy sector amounted to USD 1.8 trillion in the world, which means that this segment of the energy market was the next year in a row the largest recipient of investments consisting mainly in further electrification (around 880 million people are still without access to electricity forecasts envisage an increase in the population of up to 9 billion (mainly in less developed economies), the development of renewable energy sources and the development of energy networks.

A characteristic feature of the investment is that their size in the power sector is decreasing and the main reason is the decrease in installed capacity in coal-fired power plants and a departure from nuclear power plants. The changes also apply to power networks. Investments in transmission and distribution infrastructure are related to the modernization of the line and creation of new connections to increase access to the power system, connection of new generation sources, including wind farms, development of electromobility (Brodowicz and Stankowska, 2021) and the need to increase energy security.

The Lisbon Strategy[3] adopted by the European Council in 2000 assumed that by 2010 Europe will become one of the most competitive knowledge-based economies in the world. It emphasized the importance of innovation in the economy and society as a factor of long-term economic development and improvement of people's standard of living.

In mid-2010, the Lisbon Strategy ceased to apply. In June 2010, the Council of Europe approved the Europe 2020 strategy as one of the main pillars of the strategy for sustainable development and combating climate change. Building a low-emission and environmentally friendly economy was also mentioned as being more competitive and at the same time using the existing resources more efficiently. It was this strategy that was to contribute to the development of a more innovative economy based on knowledge and new technologies. Enterprises applying advanced technological solutions contribute to the more effective implementation of the sustainable development goals. The set goals for 2020 were the base points on the way to achieve the planned energy transformation.

Unfortunately, despite the eight years since the introduction of the Europe 2020 strategy, the set goals in the area of infrastructure and development have not been achieved in all European Union countries. The resolution of the European Parliament of 14 March 2018 on the European Semester for economic policy coordination: Annual Growth Survey 2018 (2017/2226 (INI)) in Chapter 1 - Investment and Development, identified the need to increase investment and development investment in research, development and innovation, and technological modernization to boost efficiency. The European Commission was called on to develop country-specific recommendations, including in the areas of energy efficiency and resource consumption. This resulted in a revision of the goals in the 2030 perspective for all member states. After the revision, the objectives for the power sector were defined as follows:

- renewable sources should account for at least 32% share in gross final energy consumption,
- an increase in energy efficiency by 32.5% was assumed,
- the completion of the internal EU energy market was assumed.

The use of innovative technologies in the design of power infrastructure is an element significantly stimulating the development and modernization of the National Power System. This development increases the country's electricity security, ensuring uninterrupted supply of electricity to end users. Over the years, there has been a clear increase (Stankowska, 2018; 2020; 2021):

[3]2. *Treaty of Lisbon Amending the Treaty on European Union and the Treaty Establishing the European Community. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:12007L/TXT (accessed on 11 January 2021).*

- in 2009, the length of 220 and 400 kV high voltage overhead lines in Poland was 12,950 km, and in 2013 the length of the 220 and 400 kV lines increased to 13519 km,
- the length of 110 kV overhead lines in 2009 was 32 325 km and increased by almost 3% to 33251 in 2018,
- in 2011, over 70% of 110 kV lines have been in operation for over 25 years, while 80% of 220 kV lines and 23% of 400 kV lines have been in operation for over 30 years.
- at 01/01/2018, 14676 km of 220 and 400 kV overhead lines were put into operation.

This issue was previously articulated in the 2030 National Spatial Development Concept, adopted by Resolution No. 239 of the Council of Ministers of 13.12.2011, which is the country's most important strategic document. According to the adopted concept, construction of approximately 4,000 km of high voltage overhead lines is planned by 2030. These lines are classified as public purpose investments and will constitute about 30% of the length of the existing power grid infrastructure.

Due to the limited capacity of transmission lines and overloading of existing high-voltage lines, it becomes necessary to search for new technologies that ensure the reliability of power supply and security of electricity supply to consumers. At the same time, it is important to search for new technological solutions that allow the elimination of hazardous (petroleum) substances from power apparatus, which is an important element of power infrastructure. The lack of introduction of new technologies and modernization of the outdated power infrastructure may be the cause of serious system failures.

For example, the estimated total costs of one of the largest power failures in Poland, which occurred from 7-8 April 2008 in the Szczecin agglomeration, amounted to approx. PLN 54.1 million, of which over PLN 45 million were the costs incurred by plants, companies and hospitals. Damage or temporary shutdown of infrastructure may also cause serious problems in the socio-economic functioning of the entire affected region. The lack of electricity means also the inability to use hot water, gas stations, commercial premises or public transport.

The development of the energy market is associated with the development of appropriate infrastructure, including electricity infrastructure. Its development is focused on the implementation of the strategic goals contained in the Polish Energy Policy until 2030. Unfortunately, problems with the implementation of the set goals, with technological changes and economic effects caused by the COVID-19 pandemic, resulted in the need to update Poland's Energy Policy (PEP2030). Currently, the amended "Polish energy policy until 2040" (PEP2040) was based on 3 pillars, i.e.:

- just transition;
- zero-emission energy system;
- good air quality.

It is assumed that in 2040 more than half of the installed capacity will be zero-emission sources[4]. For this purpose, it is planned to develop offshore wind energy and launch a nuclear power plant, including a power system enabling power evacuation from the power plant. In order to transform the energy sector in accordance with the above-mentioned goals by 2030, it is planned to transfer about PLN 200 billion, from EU and national funds under various mechanisms, including (New draft of the Polish energy policy until 2040, 2020):

- Cohesion Policy (approx. PLN 90 billion),
- Instrument for Reconstruction and Increasing Resilience (approx. PLN 30 billion),
- Just Transition Fund (PLN 15.5 billion),
- ReactEU (allocation for Poland around PLN 4 billion),
- priority programs of the National Fund for Environmental Protection and Water Management and funds from the Common Agricultural Policy - approx. PLN 20 billion),
- new instruments, eg the Modernization Fund, the Energy Transformation Fund - approx. PLN 46 billion.

It should be emphasized that electricity grids are crucial for enabling the energy transition as they are key to ensuring energy demand and the integration of renewable energy sources into the power system.

2. Theoretical Framework

We are living in a time of dynamic changes and rapid economic development in the world, which in addition to positive effects also carries many threats. Therefore, for many years now, the issue of sustainable development has appeared in scientific literature as well as in the activities of people, organizations and governments of many countries. Taking into account the fact that an increasing number of the world's population lives in cities, actions for their sustainable development are of particular importance. In the literature on the subject, you can find many definitions of sustainable development that are more or less precise.

Therefore, one of the most frequently used definitions has been included in the norms and documents of the United Nations. In the international forum, sustainable development in the area of economic goals is understood, among others, by as meeting material needs of the population, differentiation of the GDP growth rate per capita depending on regions, transfer of capital and accumulated wealth, adaptation of

[4] *A European Green Deal. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed on 11 January 2021).; Energy Union. Available online: https://ec.europa.eu/info/energy-climate-change-environment/overall-targets/2030-targets/energy-union_en (accessed on 11 January 2021).*

production technologies to environmental protection requirements (Pearce *et al.*, 1990).

Sustainable development also involves the development of appropriate infrastructure. The English definition of infrastructure indicates its close relationship with economy, treating it as "the foundation of the base, which is the necessary basis of the economy" (Wojewódzka-Król, 1999). According to the economic dictionary, infrastructure is, "physical capital used to produce publicly available services, transport, telecommunications and gas, electricity and water supplies" (Black, 2008), while "technical infrastructure consists of all kinds of transport, energy, communication and water and sanitation, which include: roads, bus stops, railways, stations, river and sea ports, gas, energy, drainage networks, telecommunications and postal facilities" (Rutkowska, 2007).

Another element of the technical infrastructure is the energy sector, which also includes the electricity infrastructure sub-sector. Its development is also closely related to the development of the electricity market. The development of this market will also ensure the continuity and security of electricity supply as well as the possibility of social and economic development in line with the ideas of state development (Shumpeter, 1960; Wade R.H., 1990). The development of the energy sector was also associated with an increase in the emission of pollutants to the environment. This resulted in the emergence of social movements informing about the negative impact of the emitted chemical compounds into the environment and the need to store large amounts of radioactive waste resulting from combustion processes. This triggered reactions from environmental movements (Castells, 2008; Bendyk, 2004) and increased pressure on environmental protection (Zhang *et al.*, 2009 Bell and Simon, 2018).

The development of electricity markets therefore means the need to combine three areas, technical, economic and environmental. Demand factors, which stimulate innovative activity through the increase in the value of new innovations, and supply factors have a large share here (Popp and David, 2002). The development of the electricity market is associated with the need to improve the efficiency of transmission by modernizing the transmission networks while maintaining the economic profitability of the investment (Christensen *et al.*, 2010; Christensen, 2010).

The need to improve electricity efficiency resulted in a constantly growing interest in the dynamics of changes and system innovations (Rotmans, Kemp, and Van Asselt, 2001) combined with innovative forms of management (Geels, 2002). An interesting theory in this regard is the theory of a multi-level perspective (Geels, 2005), in which changes are presented as the result of multi-dimensional interactions between radical niche innovations and the current regime and external landscape. The development of the electricity market also means the necessity to adapt the electricity (distribution) infrastructure to two-way flows in the power system caused by the development of renewable energy sources.

In the old model of centralized energy, electricity flowed in one direction, from the power plant to the users. The currently implemented model of electricity production should ensure two-way flows of electricity. Liberalization of energy markets and the expansion or construction of high-voltage lines have increased international flows of electricity.

However, due to the significant increase in the share of renewable energy sources, in particular large offshore wind farms (Meeuwsen, 2007), there are potential problems for the stability of the power system. Moreover, co-financing for the production of "green energy" caused difficulties in balancing the demand and supply of energy, planning power demand and balancing the electricity market.

The development of power infrastructure also requires minimizing the environmental burdens at the stage of its construction and operation (Stankowska, 2019). It is possible by introducing innovative, more ecological solutions. It has been repeatedly assumed that product innovations are usually developed by product manufacturers, the purchase assumption about who the innovator is. However, it has now been discovered that this basic assumption is incorrect (Eric von Hippel, 1988).

Measurement of innovation is an extremely important research partner, but it is associated with the ambiguity of new innovation and the frequent choice for its evaluation. A frequently used research approach is the area of science and new technologies referred to as STI - science, technology and innovation. Often, innovation is measured on the basis of statistical data concerning, for example, the number of patents in a given enterprise (Griliches 1990; Arc Hibugi and Pianta 1996). Another approach to measuring innovation is the R&D expenditure index (Feldman, Lichtenberg), which allows for international comparison. This measure is referred to in the Lisbon Strategy, programmatically to increase the level of R&D expenditure to 3% in 2010.

However, this is not an achievable goal in the planned period, considering the current indicators of EU countries (Science, Technology and Innovation in Europe 2009)[5]. Another way of assessing innovation is looking for development opportunities calculated on the basis of the number of employees employed in the R&D sector (Porter and Stern 1999).

There are many other advanced indicators in the literature that allow for a holistic assessment of energy sustainability. For example, Synthetic Index of Energy Sustainable Development (García-Álvarez, Moreno, and Soares, 2016), Energy Indicators for Sustainable Development (EISD) (IAEA) and others. However, they require many indicators and do not allow for quick analysis. On the other hand, Stankowska (2021) proposed a simplified indicator for assessing the growth dynamics

[5] *See Table 1.*

of innovation expenditures (INI), which allows for a quick evaluation of innovation in relation to investment expenditures.

Therefore, it is important to assess the investments and expenditures on innovation in OTS and DSOs, which are necessary for the energy transformation in Poland and will allow for the development of policy and regulatory recommendations for electricity grids to enable effective Energy Transformation.

3. Research Methodology

This research uses a qualitative and a quantitative approach. My purpose is to analyze and evaluate the total expenditure on innovation in Poland and selected EU countries in the period from 2010-2020. I also determined the amount of expenditure on innovation in the area of power energy distribution in relation to the expenditure on investments in technical infrastructure in 2015-2018. I did it by collecting various data from OECD, Eurostat data as well as information from source documents of distribution system operators and the transmission system operator were used.

Descriptive statistics and single attribute value function (SAVF) were used to evaluate the relationship between energy production and innovation expenditures.For all the calculations the R programming language and RStudio IDE were used. For the additional functionality packages such as Decision Analysis and rworldmap were loaded. The author of the research made the following research thesis:

(1) There is a relationship between innovation expenditures and energy production. The higher the expenditures on innovation, the decrease in energy production occurs. This is due to the increase in energy efficiency of the economy.
(2) The use of the INI indicator allows for a quick assessment of the state of innovation of an energy company.

These contain new and significant information about measuring innovation in this sector. In order to answer the research questions formulated in this way, the following research methods were used: the method of recording and observing phenomena, the method of diagnosing the current state and a detailed analysis of development trends.The conducted empirical research made it possible to identify the main channels for acquiring and implementing innovations and new technologies in the power sector and to show trends in this sector.

The largest companies from the power sector - distribution system operators (DSOs) and TSO, i.e.

- PGE S.A.
- Energa Operator S.A.
- Tauron Dystrybucja S.A.
- Enea Operator S.A.

- Innogy Stoen Operator S.A.
- Transmission System Operator PSE S.A., (TSO).

The documents examined covered the period from 2012 to 2020. The documents examined were:

- annual reports,
- report on non-financial information,
- internal dokuments,
- information from websites.

Based on the research of source documents - strategic reports of the TSO and DSO for the years 2013-2020 and the report on non-financial information, the main areas of innovation implementation were selected. In addition, the total expenditure on innovation in Poland and selected EU countries in 2010-2020 was analyzed. This allowed for a different perspective on innovation-related expenditure.

Using an index to measure the growth rate of innovation (INI), it was determined what is the size of innovation expenditures by DSOs and TSOs in relation to investments in technical infrastructure in recent years. This allowed for a different perspective on innova- tion expenditures.

For this purpose, the study used a detailed analysis of development trends and statistical analysis of quantitative variables. As a dependent variable, it chose the amount of expenditure on innovation in the field of energy distribution in relation to the economic result or GDP. This allows to measure the dynamics of growth in the innovativeness of an electricity company.

It is done by collecting various data from source documents from the five largest energy companies in Poland - TSO (i.e., Tauron Group, PGE Dystrybucja, Energa Operator, Enea Operator, Innogy Operator) and the transmission system operator - PSE S.A. (OSD). Based on the research of TSO and DSO source documents of strategic and internal documents for 2010-2020 (PSE Annual Report, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020; PGE non-financial information report) 2013, 2014, 2015 , 2016, 2017, 2018, 2019, 2020; Energa. Annual Report 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020; Tauron. Report on non-financial information of the Tauron Capital Group. 2015, 2016, 2017, 2018, 2019, 2020; Enea. Consolidated financial statements of ENEA. 2015, 2016, 2017, 2018,2019, 2020), the main areas in which innovations are implemented among the largest distribution companies in Poland and the transmission system operator were selected.

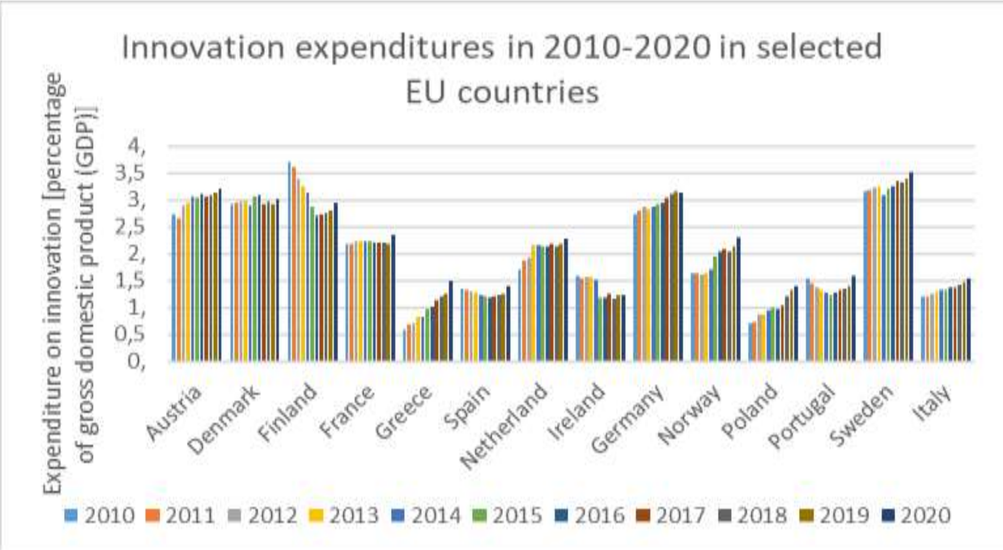
On the basis of these data, the main areas in which innovations are implemented among the largest distribution companies in Poland and at DSOs (Figure 3).

4. Results

In order to have a first insight into the analyzed data on innovation expenditures between 2010 and 2020 in selected European Union countries, a preliminary analysis was conducted. It included the standardization of the two variables to have a common scale and their plotting. In order to standardize the data, relative percentages with respect to the last year were calculated. This allowed for the relative increase or decrease of the study variables.

Gross Domestic Expenditure on research and development is presented in Figure 1. According to OECD data, average expenditure on research and development in selected EU countries in 2020 ranges from 1.23 GDP in Ireland to 3.51 GDP in Sweden.

Figure 1. *Gross domestic expenditure on research and development in selected EU countries*



Source: *Based on Eurostat:* *https://ec.europa.eu/eurostat/databrowser/view/RD_E_GERDTOT__custom_1708285/default/table?lang=en*.

In 2020, Poland reached the level of 1.39 GDP, which means an increase in expenditure compared to 2010 by 93%. Despite an almost twofold increase in expenditure in Poland, the value of GDP expenditure is still well below the average value for OECD countries of 2.32 GDP. It is therefore worth looking at the expenses incurred by the largest energy companies in Poland.

The link between innovation expenditures and energy production was examined. For this purpose, descriptive statistics (median - M, correlation coefficient - R) were performed. The results of the calculations are presented in Table 1.

Table 1. *Descriptive statistics (median - M, correlation coefficient - R)*

Country	M	R
Austria	3,06	0,24
Denmark	2,97	-0,18
Finland	2,94	0,80
France	2,22	-0,72
Greece	0,97	-0,77
Spain	1,25	0,31
Netherland	2,15	0,07
Ireland	1,26	-0,81
Germany	2,93	-0,30
Norway	1,94	0,51
Poland	0,96	0,11
Portugal	1,35	-0,18
Sweden	3,25	0,71
Italy	1,34	-0,68

Source: *Own elaboration.*

The analysis shows that there is a very strong correlation between innovation expenditures and energy production in Finland (R= 0.80), Sweden (R= 0.71) and Norway (R= 0.51). However, the correlation between energy production decreases with increasing innovation expenditures (Ireland: R= -0.81; Greece: R= -0.77; France: R= -0.72; Italy: R= -0.68). However, there is no relationship for Netherland (R= 0.07), Poland (R= 0.11), Portugal (R= 0.18).

The single attribute value function (SAVF) was determined to evaluate the impact of the factors: energy production and innovation inputs. In this study, an increasing-exponential single attribute value function was used for the innovation input factor. On the other hand, a decreasing-exponential single attribute value function was used for the energy production factor. To calculate the weights of the variables, the method of entropy weights was applied according to the formulas:

$$w_j = \frac{1 - E_j}{\sum_{j=1}^{n} (1 - E_j)} \tag{1}$$

where:

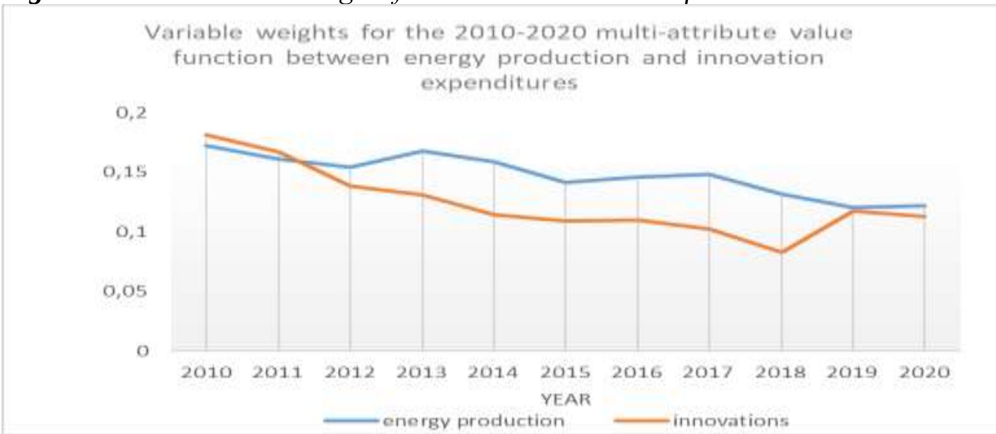
$$E_j = -k \sum_{t=1}^{m} r_{ij} ln(r_{ij}) \tag{2}$$

where:

$$k = -\frac{1}{ln(n)} \quad (3)$$

The calculation of the single attribute function value and its weight was done for each year from 2010 to 2021 and for each of the 15 EU countries. The cumulative value of the weights is presented in Figure 2. It shows the relevance of the analyzed variables and their interrelationships for the period 2010-2020.

***Figure 2**. The variables' weights for multi attribute value functions*



***Source:** Own elaboration.*

The analysis of weights shows that over the 10 years (from 2010 to 2020), the relationship between energy production and innovation input had in 2010-2011 was closely related to each other. However, after 2011, until 2018, the relationship lost its value. It was only from 2019 that the relationship started to be strongly related.

In statistical data (Eurostat, OECD, etc.) the electricity sub-sector is not reported. This subsector is described together with the entire energy sector. The author used the Innovation New Indicator (INI) (Stankowska, 2021) to assess the dynamics of innovation growth of the electricity company, according to the formula:

$$INI = \frac{EN}{EI} \quad (4)$$

where:
EN - expenditure on innovation,
EI - expenditure on investments.

$$INI = \begin{cases} 0, & when\ EN = 0 \\ (0 - 100 >, & when\ EN > 0\ i\ EN < EI \\ < 1, & when\ EI \leq 0 \end{cases} \quad (5)$$

INI = 0 - lack of innovation,
INI ϵ (0:1) - the company introduces innovations,
INI>1 - an enterprise with an innovative profile.

Based on the study of the source documents of individual power companies, the author determined the innovation expenditures and the amount of costs for electricity infrastructure in 2015-2020 (Table 2, Figure 4).

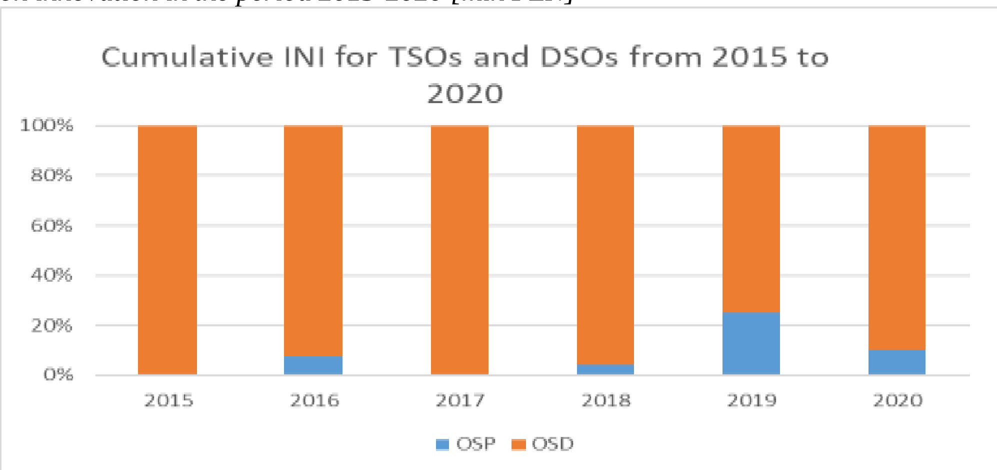
Table. 2 *Statement of enterprises' expenditure on investment in relation to expenditure on innovation in the period 2015-2020.*

Energy company	**2015** INV	INN	**2016** INV	INN	**2017** INV	INN	**2018** INV	INN	**2019** INV	INN	**2020** INV	INN
PSE	1535,9	0	1216,9	4,8	1460,4	0	1810,1	8,98	1508,6	10,57	922,5	5,72
Enea Operator	853,7	57,2	914,3	40,8	1016,2	94,7	989,7	189,2	1004,1		1164,5	
Energa Operator	1031,5	127,4	1271	60,5	1237,1	62,2	1338,8	40,2	1293,9		1195,5	
PGE Dystrybucja	1264,8	41,4	1720,7	30	1712,3	203,5	1847,8	114	2182,5	136,7	1651,2	339,7
Innogy Stoen Operator	244,8	39,5	240,7	6,5	227,52	3,4	217,4	3,5	231,8		267,9	
Tauron Dystrybucja	1555,2	104,5	1783,2	147,2	1692,2	56,3	2021,9	76	1814,3		1929,1	
	Total	**370**	**7146,8**	**289,8**	**7345,7**	**420,1**	**8225,7**	**431,88**	**8035,2**	**147,27**	**7130,7**	**345,42**

INV investments in power grids [mln PLN]
INN innovations in power grids [mln PLN]
Source: *Own elaboration.*

The dynamics of the growth of innovativeness in power companies in the period 2015-2020 use a indicator INI shows on Figure 3.

Figure 3. *Cumulative investment expenditure of enterprises in relation to expenditure on innovation in the period 2015-2020 [mln PLN]*



Source: *Own elaboration.*

By 2019, an increasing trend of innovation expenditures relative to capital expenditures is observed. Unfortunately, in 2020, there is a significant decrease in the INI ratio, which may be the cause of the COVID -19 pandemic. However, it should be noted that TSO innovation expenditures have been on an upward trend since 2017.

In Poland, in 2019, the 'Development Plan for meeting current and future electricity demand for 2018-2027 was adopted, assuming the expansion and modernization of the network and the development of IT systems. The purpose of these activities is to increase transmission capacity and reduce power losses.

The condition of Polish power networks requires urgent investments. Over 40% of high voltage lines are over 40 years old. The distribution network is a limitation for the development of renewable energy sources and connecting distributed sources, as well as providing conditions for the development of electromobility. There are also activities aimed at implementing smart grids and smart metering. The progressive fourth industrial revolution has identified three main development trends in the power sector:

- digitization (digitization), mainly related to the creation of modern methods of data collection, processing and analysis,
- diversification, implemented by developing new technologies for the production and distribution of energy obtained from alternative energy sources (renewable energy) and combined energy production (cogeneration),
- decentralization caused by organizational changes in the energy market.

Currently, there is a tendency to generate energy in a distributed system. This makes it necessary to create innovative solutions in the field of efficient energy and energy supply balancing systems, demand management and price formation systems, as well as creating new business models.

These trends were shaped by two main sources of demand for innovation in the energy sector, such as: (1) solutions enabling savings of electricity by reducing the costs of business and household operations, (2) solutions protecting the environment caused by growing awareness among society and enterprises.

In Poland two main channels of innovation implementation can be distinguished, they are: (1) producers: external sources: (a) manufacturers of power equipment, (b) manufacturers of power systems, (c) manufacturers of power cables and accessories, and (2) user: internal sources and external sources.Innovations implemented by production enterprises refer to innovations implemented by manufacturers of apparatus, power systems, power cables and equipment, automation systems, communication, control and supervision systems. On the other hand, innovations implemented by power enterprises are realized by units belonging to TSOs and DSOs or implemented on behalf of these units (e.g., they concern the following areas: customers, grid services, renewable energy, business models).

Innovations implemented by manufacturing companies mainly concern:

• activities related to the operation of power grids and systems,
• IT solutions,
• activities related to the protection of the environment.

In the area of operation of power equipment and devices, solutions minimizing downtime in the production and distribution of electricity, solutions in the field of intelligent operation of overhead and cable lines should be mentioned. In the IT area, a solution is observed in the form of intelligent systems simplifying the monitoring of the power system at the level of the transmission network and distribution network. Solutions protecting the environment, on the other hand, are focused mainly on the elimination or minimization of hazardous substances used in power equipment and devices, as well as on minimizing noise from operating devices. These innovations do not place a financial burden on the TSO at the research and implementation stages.

5. Discussion

Innovations implemented by power companies are introduced through internal and external channels. They are financed both from own resources and from external co-financing. The internal channel for introducing innovation relates to the work reported by employees of energy companies. The external channel, in turn, relates to work carried out at the request of energy enterprises, units belonging to DSOs and TSOs, research and development centers or ideas obtained directly from the market. Innovations in this area mainly cover four areas: customer, network services, distributed energy (renewable), business models, and their development is conditioned by the specificity of the operation of the power company.

The largest energy companies in Poland, i.e., the Tauron Group, PGE Dystrybucja, Energa Operator, Enea Operator, Innogy Operator, perceive innovation as a key factor in development and gaining a competitive advantage in the area of electricity distribution. This resulted in the introduction of appropriate entries in the development strategies of companies, which enabled building long-term goals and increasing the funds spent for this purpose.

In 2017, the Tauron group implemented a document entitled Strategic Research Agenda (SAB). This document defines 4 development directions in which innovations will be implemented: (1) the client and his needs, (2) intelligent network services, (3) distributed energy (4) low-emission production technologies. The approach to innovation is implemented through, among others, the "open innovation" formula and by allocating at least 0.4% of the Group's revenues to innovation, research and development (Report on non-financial information of the Tauron Capital Group for 2020). Interestingly, the ratio of investment expenditure to innovation expenditure in 2018 (3.8%) was almost 50% smaller than in 2016 (8.3%).

The strategy of the PGE Dystrybucja capital group for 2014-2020 sets goals related to innovation. By 2020, PGE allocated approximately 400 million to research and development, of which 200 million are own funds, and 200 ml comes from external financing sources (Report on non-financial information, 2018). The main works carried out in the field of power engineering concern: (1) energy distribution: smart grid, smart meters, (2) energy sales: smart facility, demand management.

Enea Operator, spending over PLN 189 million on innovation in 2018, has become a leader among energy companies in implementing innovative solutions in Poland. The development of innovation is implemented in areas related to the training of technical staff using virtual reality in the operation of power and transformer stations.

However, in order to implement the Innovation Strategy adopted by Energa for 2017-2020, a Research and Development Center was created. M. Faraday. Then, in 2018, the Strategic Research Agenda for 2019-2028 was adopted, in which a 'road map' was set out defining the directions of research, development and innovation. The implementation of innovative technological solutions in the area of energy distribution is carried out in the following areas, intelligent network, intelligent metering, advanced network asset management systems and cable diagnostics. Energa also carries out international research and development projects in cooperation with other DSOs. These projects concern the development of mechanisms for the development and integration of the future energy market and the creation of conditions for new services on the market by DSOs.

The way of introducing innovations from the producers channel is implemented as follows: (1) obtaining the status of qualified supplier, (2) meeting the requirements of the operator's technical specifications, (3) providing appropriate research and testing of implemented products, (4) after all requirements have been met, in order to apply the accepted technological innovation it is necessary to enter the technical requirements in this respect into the tender documents. There is no doubt that companies whose technical solutions were already applied in a given energy company are favored in this respect.

Polish Power Grids (TSO) are conducting research and development works, which are mainly focused on solutions regarding system services, the European electricity market and the balancing market. Unfortunately, until 2014, there was virtually no research and development work and no innovations implemented. It was not until July 17, 2015 in the update of the document entitled The strategy of Polish Power Grids until 2020, as one of the company's strategic goals, objective VII "Innovations and new technologies" have been introduced.

By 2017, the TSO carried out research projects for a total amount of PLN 9 million, while in 2018 for PLN 6.2 million. The status of ongoing research is presented in Table 4. In 2018-2027, PSE intends to spend PLN 12.8 billion for this purpose, of which about 90 percent. will be used to expand and modernize the network.

While the introduction of innovative solutions and technologies developed within a given power company are implemented in most cases, the situation is different in the case of innovations implemented by production companies. The introduction of an innovative solution for use at the TSO is only possible by introducing the given solution into the so-called Standard Technical Specification SST). Unfortunately, this is a big area for abuse, as there are no transparent rules specifying the introduction of changes in SST. This often means that the preferences of employees at the TSO dealing with the operation of equipment put favoritized companies in a privileged position.

Despite the still low investment in innovation, there is an upward trend. For example, TSO has signed agreements for funding from the Polish Operational Programme Infrastructure and Environment with a total investment value of PLN 5.9 billion, of which PLN 1.6 billion is a grant. Almost PLN 1.4 billion of subsidies was also obtained from the European CEF program. The construction and reconstruction of over 2,900 km of extra-high voltage lines and 18 substations is co-financed under both programmes[6].

On the other hand, at the end of 2020. DSOs (Enea Operator, Energa-Operator, innogy Stoen Operator, PGE Dystrybucja and Tauron Dystrybucja) have obtained approximately PLN 1 billion in grants for the implementation of 116 investment projects worth PLN 2 billion[7].

6. Conclusion

There is no doubt that research and development of new technologies is a key factor in the development of building a competitive advantage among power companies in Poland and worldwide. The presented research results will allow for a better analysis of the innovativeness of enterprises and more efficient design and implementation of innovations.

An interesting conclusion is from the correlation analysis, which shows that there is a very strong correlation between innovation expenditures and energy production in the Scandinavian countries (i.e. Finland, Sweden and Norway), which implies its strong influence on the development of the energy sector. In Poland, however, there is no correlation between these factors. This is probably due to the structure of energy production, which in Poland is based on coal, and the share of innovation in relation to GDP is still small.

The identification of the main channels for acquiring innovation enabled the identification of transparency in the procedure of introducing new solutions for energy applications. The main channels for gaining innovation are the producers channel and

[6] *PSE, https://raport.pse.pl/pl/do-pobrania/*
[7] *https://www.funduszeeuropejskie.gov.pl/*

the enterprise channel. There is also no doubt that from a financial perspective it is cheaper to acquire innovations from the producer channel than from the enterprise channel and allows to minimize business risk in the power enterprise. However, the implementation of these innovations by manufacturers is much more difficult and more time-consuming and burdened with large bureaucracy. Unfortunately, there is a lack of transparency in the procedure of introducing new solutions for use in the power industry, which is a big field for abuse.

The evaluation of power enterprise innovation with the INI index indicates that the dynamics of power enterprise innovation is still unsatisfactory. It seems that the lack of appropriate actions to significantly increase expenditures on innovation will make it impossible to transform the energy sector in Poland in the perspective until 2050.

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