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The green economy and its impact on the climate and economic growth

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Key numbers

+0.22	The positive impact of an increase in the green economy development indicator on the GDP *per capita* in EU countries, according to the PEI model for data from 2011-2019. This means that the green economy has a moderately positive impact on economic development
−0.66	the coefficient of the impact of the green economy development indicator on CO_2 emissions of the EU-27 countries, which means that the development of the green economy contributes significantly to a decline in emissions in the EU
18^{th} place	in the EU-27: Poland's place in the ranking of the development of the green economy development indicator in 2011-2019
5.2 tonnes	of CO_2 emissions per inhabitant in the EU in 2019
7.3 tonnes	of CO_2 emissions per inhabitant in Poland in 2019
Over threefold	increase in emissions in the transport sector in Poland increased in 2018, compared to 1990

By a third	(73 million tonnes of CO_2 per year) decrease in emissions related to the power industry and heating in Poland compared to 1990
2.4% of GDP	average environmental taxes in the EU-27 in 2019. In Poland, this percentage was slightly higher: 2.6%
306 MW	per million inhabitants – increase in RES capacity in the EU-27 in 2011-2019
167 MW	per million inhabitants – increase in RES capacity in Poland in 2011-2019
By 10 pp	higher GDP growth in countries with the highest green economy development indicator, compared to other EU countries

Key findings

- Between April and the end of 2021, **EUR 35 billion** was spent in Poland on rebuilding the economy in connection with the pandemic, **EUR 13.5 billion** of it on investments supporting the green transition. **For comparison, Poland's budget in 2021 amounted to around EUR 116 billion (PLN 523 billion).**
- Since 1995, the size of the Polish economy has increased 2.5-fold, while annual greenhouse gas emissions have remained at a roughly fixed level of around 400 Mt of CO_2 equivalent. This is because emissions per unit of product keep falling.
- **Since 2000, the Polish economy's energy intensity has fallen by over 40% (from 360 toe/million EUR to 209 toe/million EUR).** Nevertheless, it still uses almost twice as much energy per unit of GDP as the EU-28 average.
- **Most sectors of the Polish economy emit less than in the 1990s.** The fall in emissions in the power and heating industry, as well as in agriculture, compared to 1990 amounts to 32%, and 42% in waste management. Transport is the exception: emissions have increased by 214%.
- According to estimates using the PEI's soft model, the green economy supports a decrease in emissions (factor loading −0.66) and a slight increase in GDP (factor loading 0.22). **Investments in the green economy do not slow down economic growth, while efficiently enabling the achievement of climate targets.**
- **Based on our model, we conclude that a high share of RES in the electric power industry, heating and cooling** has the **most positive impact on the green economy development indicator,** as does establishing an optimal level of feed-in-tariffs for RES.
- **Malta, Luxembourg, Lithuania, Romania and Italy recorded the fastest growth in the development of the green economy in 2011-2019.** Poland is in the lower half of the ranking (18th out of 27 countries). So-called "new" EU member states tended to have higher green economy development indicators than "old" ones.
- **Public spending on environmental protection in the EU-27 ranges from 0.2% (Finland) to 1.4% of GDP (Malta).** In the 2010s, spending on environmental protection declined in 16 EU countries. In Poland, this spending amounted to less than 0.55% of GDP in 2019, a decrease of 0.16 pp compared to 2011.

Introduction

The concept of the "green economy" was first used in 1989 in a report entitled *Blueprint for a Green Economy*. With the development of the debate on climate change and efforts to halt it, the concept has gained popularity as a way of maintaining economic growth while achieving the climate targets set out in the Kyoto Protocol, and later in the Paris Agreement (www1). The debate on the green economy has been stimulated by the new plans of the European Commission, which, as part of rebuilding the economy after the coronavirus pandemic, intends to strengthen efforts to make the EU climate neutral by 2050.

The plans to rebuild the economy after the pandemic within the framework of environmental and climate targets are referred to as the "green recovery". Green-recovery efforts can be observed in many countries around the world, including the EU-27 countries, the US, China and South Korea. In 2020, of the USD 3200 billion spent on building the economy in 44 countries analysed by the OECD, almost 700 billion (around 22%) was invested in efforts that have a positive impact on the climate (www2).

In the EU, the green transition is considered the main factor of future economic growth. Hence member states are spending the most funds within the framework of the post-pandemic recovery on green investments. By the end of 2021, in the 18 EU countries analysed by the *Green Recovery Tracker*, EUR 210 billion out of the EUR 700 billion (30%) dedicated to stimulating the economy were spent on investments that support the green transition, and EUR 50 billion on other actions that could hamper it, such as support for burning fossil fuels.[1] In Poland, EUR 36 billion had been spent on rebuilding after the pandemic by the end of 2021, of which EUR 13.5 billion (37%) was spent on investments supporting the green transition (www3).

The high level of public investment in green sectors of the economy raises questions about their impact on lowering emissions and on economic growth. In the literature, there is no shortage of publications on the idea of the green economy, in which the authors focus on measuring progress in achieving sustainable development goals, but not on the relationship between green investments and economic growth. Their authors assess the effects of sustainable development, such as the level of CO_2 emissions and air pollution, in terms of PM 2.5 and PM 10. These indicators are a good way to measure countries' progress when it comes to achieving climate neutrality and protecting the environment. However, they do not provide information on the effectiveness of specific investment, tax or legislative efforts that seek to maximise the positive impact on the climate and the economy.

To verify the effectiveness of concrete climate-related efforts, this report examines the green economy's impact on GDP and on CO_2 emissions in the EU-27. For the purpose of the calculations using the model in this report, we define the green economy as a series of efforts by the public and private sector in sectors related to electric power generation, the circular economy and environmental protection. We look at the years 2011-2019, between the financial crisis that began in 2007 and the crisis caused by the COVID-19 pandemic.

[1] The remaining expenditures can be described as neutral for the green transition.

In the first chapter, we summarise Poland's economic development over the past 30 years against the backdrop of CO_2 emissions and of the progress in Europe. We also analyse the fall in greenhouse gas emissions in individual sectors of the Polish economy. In the second chapter, we present the results of our model and discuss the structure of the green economy development indicator and its impact on CO_2 emissions and on GDP in 2011-2019. In the second part of the chapter, we discuss more broadly the partial indicators of the green economy that make up the modeled indicator in the EU-27 countries.

↘ Box 1. Defining the green economy

There is no universally-accepted definition of the green economy (the term "green growth" also exists, closely linked to the green economy and often equated with it). However, individual institutions (such as the UNEP, the World Bank, the OECD, and the European Commission) use working definitions for the purposes of their own instruments and programs. For example, for the purposes of the Green Economy Initiative (GEI), the UN Environment Programme (UNEP, 2011) defines the green economy as one "that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities". In its efforts, the OECD tends to use the concept of "green growth", which it defines as changing the model of production and consumption to decrease pressure on the economy in a way that is economically efficient (www4). Nevertheless, all the conceptions of the green economy recognise the need to replace the current economic model with one that is more environmentally friendly (www5).

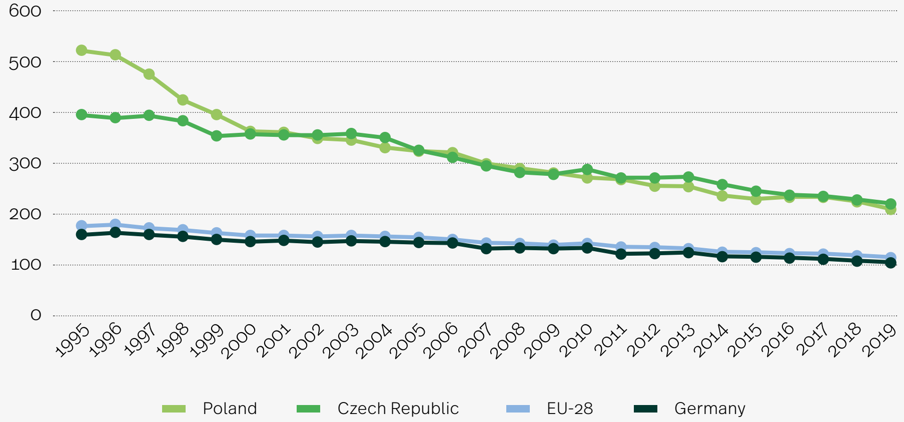
The move towards a greener economy is considered from many angles, encompassing subjects such as the development of renewable sources of energy in transport and heating, improving energy efficiency, changing the model of consumption, replacing jobs in sectors associated with the extraction, processing and use of fossil fuels with green ones, and green investments.

I. Where are we now?

1. A difficult starting point

Poland is currently among one of the most polluted regions in the EU. The country faces the challenge of making a fundamental transition towards a low-carbon economy and improving air quality in the coming decades. The difficult starting point in the energy and utility sector, which rely on fossil fuels, makes the scale of this challenge larger than in other EU countries. To a significant extent, Poland's economy is based on energy-intensive sectors. Even though Poland lowered its economy's energy consumption from around 360 toe/million EUR to 209 toe/million EUR in 2000-2019, the country still uses twice as much energy per unit of GDP as the EU average. In 2019, energy use in Poland amounted to around 104 Mtoe – around 6% of the energy use in the EU-28 and three times less than the energy used by the German economy.

↘ Chart 1. **Energy consumption of the economies of Poland, Germany, the Czech Republic and the EU-28 in 1995-2019 (toe/million EUR)**

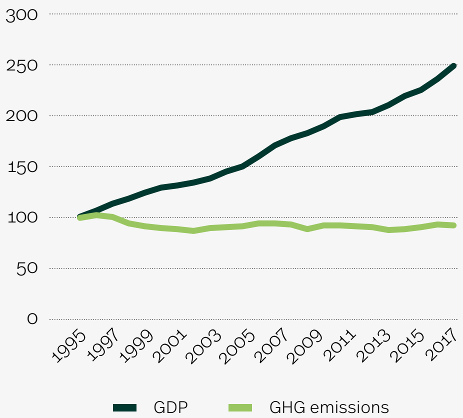


Source: prepared by PEI.

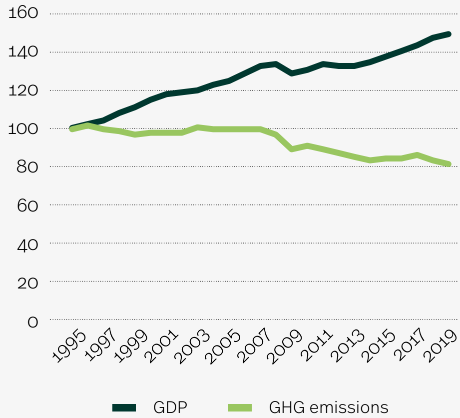
2. Poland's positive historical experience over the past three decades

Despite the difficult starting point, Poland's systemic transformation and the separation of the pathway of real GDP growth from the emissions pathway show that **the quality of the environment can improve in conditions of rapid economic growth.** Since 1995, the Polish economy has grown 2.5-fold, while greenhouse gas emissions have remained at roughly the same level of around 400 Mt of CO_2 equivalent. This is because emissions per unit of product keep falling. A similar trend is visible in the EU-27 as a whole, where emissions have fallen by 20% compared to 1995, while GDP has grown by 50%.

↘ Chart 2. **Growth in GDP and greenhouse gas (GHG) emissions in Poland in 1995-2018 (%)**



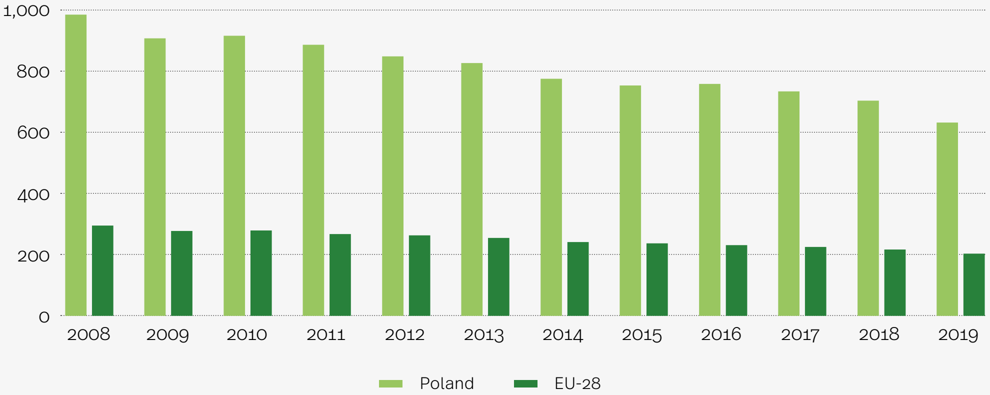
↘ Chart 3. **Growth in GDP and greenhouse gas (GHG) emissions in the EU-27 in 1995-2019 (%)**



Source: prepared by PEI based on Eurostat and European Environmental Agency (EEA) data.

Over the past decade, Poland has decreased CO_2 per unit of product (euro of value-added) by around a third. Nevertheless, compared to the EU-28, each unit of value economy in the Polish economy is associated with emitting three times more CO_2. In 2019, this indicator amounted to 633 grams of CO_2/EUR of value-added, compared to just 204 grams of CO_2/EUR in the EU-28.

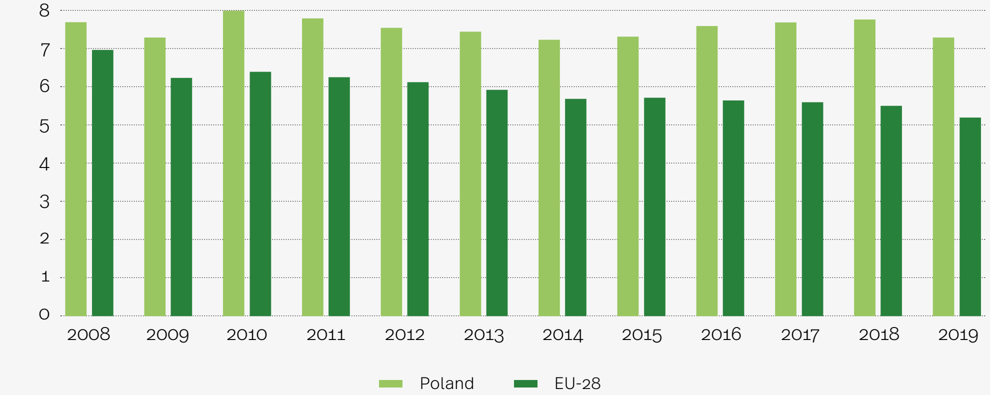
↘ Chart 4. CO_2 emissions per unit of product in Poland and the EU-28 (grams of CO_2/EUR of value-added)



Source: prepared by PEI based on Eurostat data.

Over the past decade, emissions per inhabitant in Poland have amounted to around 7.5 tonnes of CO_2 a year. In the EU, the amount decreased from 7 tonnes of CO_2 per person in 2008 to slightly over 5 tonnes of CO_2 per person in 2019 r. or 2% per year.

↘ Chart 5. Emissions per inhabitant in Poland and EU-28 (in tonnes per person)



Source: prepared by PEI based on Eurostat data.

Using the so-called Kay decomposition (Logarithmic Mean Divisia Index, LMDI), it is possible to show which factors influenced the reduction in emissions over the period studied. The main ones are:

- changes in the structure of production by shifting production from energy-intensive sectors to other sectors,
- a fall in the use of fuels,
- improvement in fuel-combustion efficiency resulting from technological progress.

If not for these factors, emissions would increase proportionally with economic growth. The starting point for decomposing changes in carbon dioxide emissions is the following Kay identity:

$$CO_2 = Popul \cdot \frac{GDP}{Popul} \cdot \frac{Energy}{GDP} \cdot \frac{CO_2}{Energy}$$

where:

Popul – Size of populations,
GDP – Gross Domestic Product,
Energy – Energy use in the economy,
CO_2 – Total carbon dioxide emissions in the economy.

The first component on the right-hand side represents the population, the second component represents GDP *per capita*, the third represents the economy's energy intensity, and the last component represents the intensity of emissions/energy used.

Chart 6. Changes in CO_2 emissions and their decomposition using the causal analysis method in 2000-2010 in Poland (%)

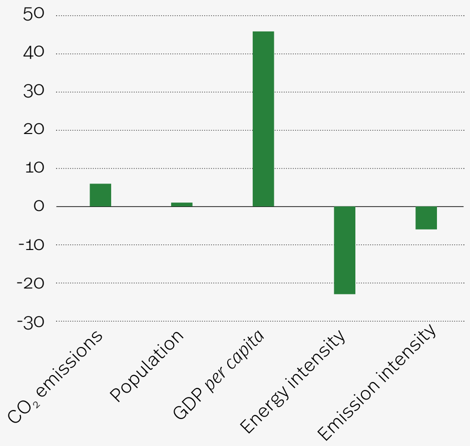
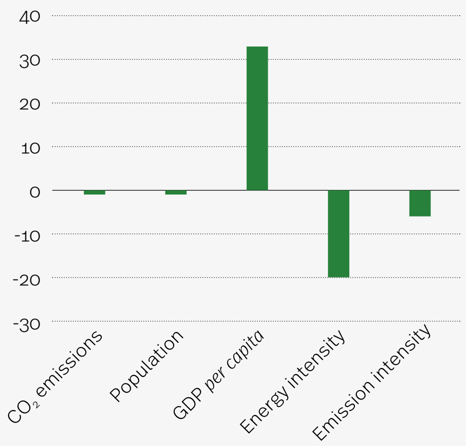


Chart 7. Changes in CO_2 emissions and their decomposition using the causal analysis method in 2010-2018 in Poland (%)



Source: prepared by PEI.

In 2000-2010, emissions (from burning fuels) in Poland increased from 290 to 307 million tonnes of CO_2 and then remained constant until 2018. Over the periods analysed, the Polish economy grow by an average of 3.9% year on year (in 2000-2010) and by 3.5% year on year (in 2010-2018). If the other factors had remained unchanged, such a significant rate of economic growth would have pushed up emissions by over 40% in 2000-2010 and by over 30% in 2010-2018. In practice, the lowering of emissions can take place by reducing the energy intensity of the economy (energy/GDP) and the intensity of carbon dioxide emissions in energy production and consumption (CO_2/energy). Technically, this translates into improved energy efficiency, the transition to carbon-neutral energy carriers, or carbon capture and storage.

Despite the significant economic development, the reduction in the growth of emissions in Poland resulted mainly from the economy's lower energy intensity, measured by energy consumption per product unit. This decrease mainly resulted from structural changes in the economy and technological progress. The improvement in the Polish economy's energy intensity reduced emissions by more than 20% (with other factors unchanged) during each of the periods analysed.

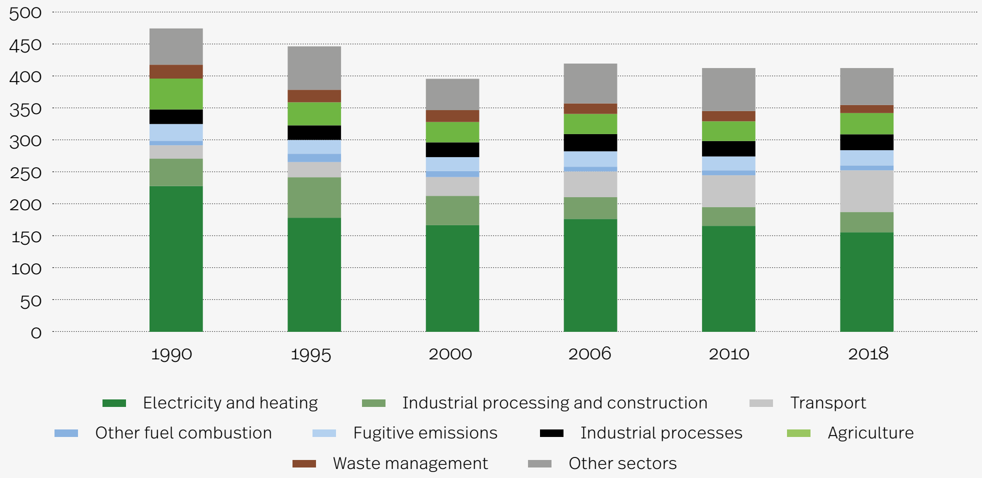
The second factor that significantly contributed to reducing emissions was the improvement in the combusted fuels' emission intensity. This decrease results from the replacement of high-emission fuels with low-emission ones and the optimisation of the combustion process. In both 2000-2010 and 2010-2018, the decrease in the combusted fuels' emissivity halted the emission increase by around 6%. The juxtaposition of these factors – technological progress, structural changes in the economy and the improvement in the intensity of fuel combustion – meant that the increase in emissions was much lower than the high economic growth in Poland in 2000-2018 would suggest.

3. The historical perspective by sector

In 1990-2018, greenhouse gas emissions in Poland fell from around 470 to 400 million tonnes of CO_2 per year. The electricity and heating sectors still have the highest share in Polish greenhouse gases emissions. However, these sectors' share in total emissions decreased from nearly 50% in 1990 to less than 40% in 2018. The share of transport (around 16%), agriculture, industrial processing and construction (around 8% each) also remains high.

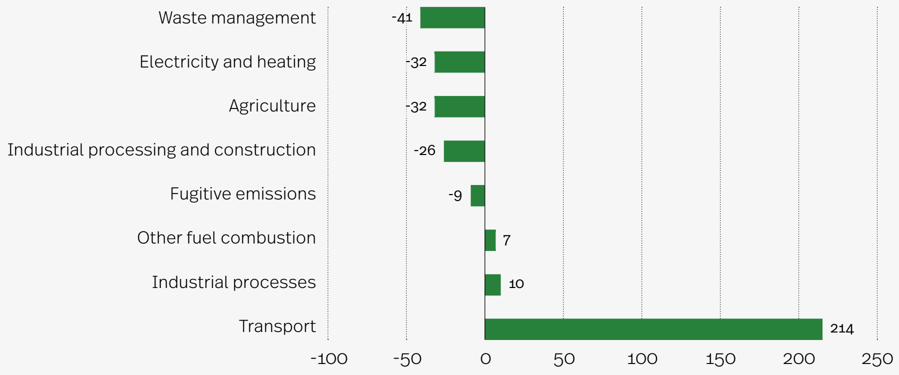
Most sectors in the Polish economy have recorded a decrease in emissions compared to 1990. The largest have been in waste management (by 41%), electricity and heating (32%), and agriculture (32%). Emissions from fuel combustion in industrial processes increased by 10%, those in the transport sector by 214%, and those in other sectors (those not included in the remaining categories) by 7%. The threefold increase in emissions in transport results largely from the increase in the number of passenger cars in Poland after 1990. In 1990-2015 alone, the number of registered passenger cars increased almost fourfold (to 20.7 million), and the number of passenger car mileages has more than tripled (to 182 billion vehicle-km) (Menes, 2018). This means that reducing emissions in the future may require not only transforming the energy sector, but also changing how the role of sustainable transport – which could play an important role in reducing CO_2 emissions in Poland – is perceived.

↘ Chart 8. GHG emissions and emission reductions in selected sectors in Poland in 1990-2018 (in millions of tonnes of CO_2e)



Source: prepared by PEI based on EEA data.

↘ Chart 9. Changes in GHG emissions by sector in Poland in 1990-2018 (%)



Source: prepared by PEI based on EEA data.

II. Green economy development indicators

1. The model's methodology

Our study's main aim is to assess the green economy's impact on GDP and on CO_2 emissions. We used a model approach. The green economy is not directly measurable and can be explained using a number of appropriately-selected indicators. Relationships between hidden variables can be measured using soft modelling (Mierzyńska, 2000; Herbst, 2009). The results of the analysis make it possible to describe both the relationship between the "green economy" hidden variable (also called in the report as "green economy development indicator") and the variables it affects (GDP, CO_2 emissions), and the reflection of the "green economy" hidden variable by selected component variables.

Various approaches to green economy indicators can be observed in the literature. Most researchers use indicators measuring effects such as emissions, the share of renewable energy sources in energy production, or the level of air pollution, measured in terms of $PM_{2.5}$ and PM_{10}. These effects are a good way of measuring national efforts to achieve climate neutrality and the energy transition. However, from our perspective, these kinds of results are not enough, as they do not provide information on the impact of individual measures relating to the green economy on economic development and climate.

Instead, an indicator based on a country's specific actions – such as the amount of investment in individual sectors of the green economy, legislation, and tariffs and taxes relating to sectors of the green economy – is used. This approach is less common in the literature, mainly due to the lack of data, which makes research on the green economy significantly more difficult (Georgeson, Maslin, Poessinouw, 2017).

In our report, we decided to show both EU countries' actions and their effects, focusing on several of the most important sub-indicators of the green economy. The choice of variables used in the model was based on green economy indicators from Eurostat, IMF and OECD databases. We then examined the impact of the green economy indicators created using them on GDP and emissions. Among the selected sectors of the green economy, there are 20 factors in the following 8 categories:[2,3]

→ Government spending on protecting the environment,
→ Private investments relating to the circular economy,

[2] The full list of indicators in each category, along with the source, is provided in the appendix.

[3] In the model, we decided to abandon some of the variables, such as the level of employment in sectors related to environmental protection, due to big gaps in the data, and we did not take into account the share of RES in the transport sector. This is because overall emissions in the transport sector were the only ones that increased compared to 1990 (by around 25% in 2019) (www7). At the same time, the level of RES in the transport sector in the EU-27 amounted to around 9% in 2019 (www8). It can therefore be concluded that the decarbonisation of the transport sector and its positive impact on the level of emissions and GDP would be difficult to determine on the basis of historical data from 2011-2019.
In the case of individual gaps in the data, we supplemented them based on the EU average, corrected by the level of GDP *per capita* in a given country in relation to the EU average. If necessary, the variables obtained were converted into a conversion factor that enables comparison between countries (for example, as a percentage of GDP). Then we calculated the average rate of change in the indicators in 2011-2019.

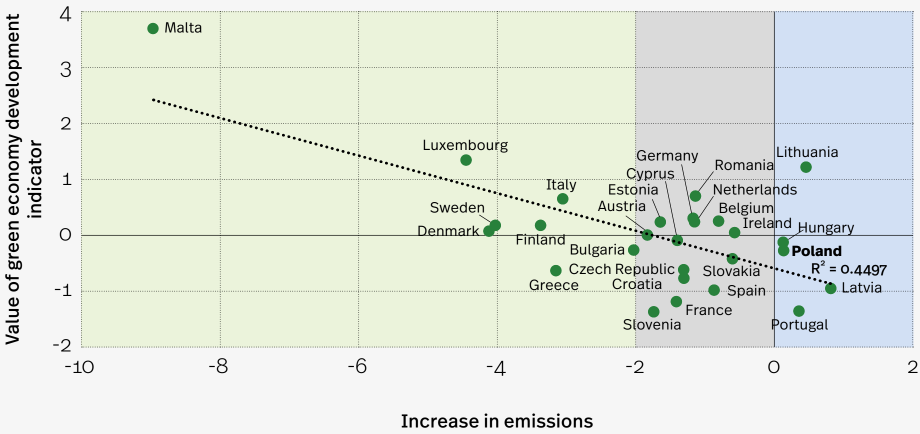
- The level of public funding for fossil fuels (variables in this category were reversed from destimulant to stimulant),
- Environmental taxes,
- Feed-in tariffs on the production of electricity from RES,
- Spending on R&D in the field of RES and CO_2 capture,
- The level of RES in electricity production,
- The level of RES in heating and cooling.

2. The model's results

The analysis of results of the soft model used to study the impact of the green economy development indicator on GDP shows that the impact is relatively small (factor loading 0.22), but positive. The determination coefficient R^2 was 0.05, which means that only 5% of the changes in the green economy development indicator explain the changes in GDP.

At the same time, the impact of the green economy development indicator on the level of emissions shows that an increase in the level of the green economy significantly reduces emissions (factor loading -0.66). This means that investments in green economy sectors have a very positive impact on reducing emissions and do not reduce economic development. At the same time, the coefficient of determination R^2 was +0.43, which means that the green economy development indicator can explain 43% of changes in the level of CO_2 emissions.

Chart 10. Impact of green economy development indicator on average growth in CO_2 emissions *per capita* in 2011-2019 in EU-27 (%)



Note: countries with the highest annual reduction in emissions *per capita* are marked in green. Grey denotes countries that do not stand out in this respect. Blue denotes countries where emissions increased during this period. The chart shows the correlation between the green economy development indicator and changes in emissions. The lower the value of the X-axis, the greater the reduction in CO_2 emissions.

Source: prepared by PEI.

Malta recorded the highest level of the green economy development indicator and a very large reduction in emissions. Luxembourg, Italy, Finland, Sweden, Denmark and Austria also recorded an average annual decline in CO_2 emissions of more than 4%. In all these countries, the green economy development indicator was positive. In just two countries, Bulgaria and Greece, emissions decreased by more than 2% per year, despite the decline in the green economy development indicator. Among the countries with a 0-2% decrease in emissions, some had a positive green economy development indicator; in others, it was negative. In the countries where emissions increased, the green economy development indicator was negative in 4 out of 5 cases.

We present the impact of the variables used to create the green economy development indicator, aggregated into 8 main categories and ranked from the most positive to the most negative, below.

↘ Table 1. **Impact of categories of green economy development indicator hidden variable**

Category	Impact
Share of RES in electricity production	Very strong, positive
Level of feed-in tariffs for production of electricity from RES	Moderately strong, positive
Share of RES in heating and cooling	Moderately strong, positive
Private investments in the circular economy	Low or absent
Spending on protecting the environment	Low or absent
Level of government support for the fossil-fuel sector	Low or absent
Spending on R&D on RES and CO_2 capture	Low or absent
Environmental taxes	Moderately negative

Note: a category's impact is calculated as the average of the factor loading of its constituent variables. Impact Assessment: Very strong, positive (factor loading between 0.7-1), moderately strong, positive (from 0.4 to 0.7), moderately positive (from 0.2 to 0.4), low or absent (from -0.2 to 0.2), moderately negative (-0.2 to -0.4), moderately strong, negative (-0.4 to -0.7), very strong, negative (-0.7 to -1).

Source: prepared by PEI.

Among the categories analysed by us, the increase in the share of RES in electricity production had the strongest positive impact on the green economy development indicator in the model (thereby increasing GDP and reducing CO_2 emissions). Increasing the share of RES in heating and cooling also had a moderately strong positive impact, as did ensuring high tariffs in the feed-in-tariff system for the production of electricity from RES.

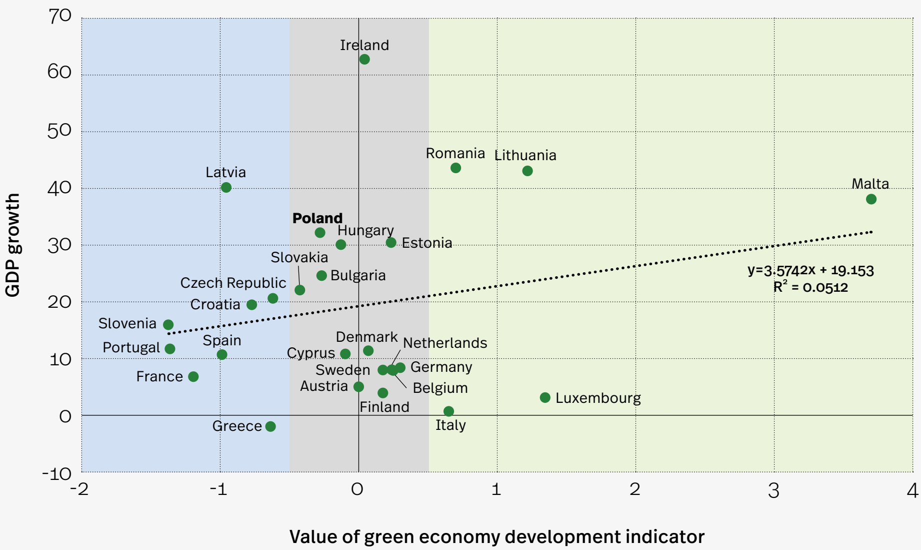
Most of the model's other components had a relatively low or no impact on the green economy development indicator. The only exception was **environmental taxes, which**

had a negative impact on the green economy development indicator. However, it should be remembered that the model takes into account the impact of the rate of the tax, not how it is spent. The final impact of environmental taxes depends on what they are spent on after reaching the budget. For example, if they are used to increase RES capacity in the electricity sector, the final impact will be positive.

Among the EU-27 countries, the green economy grew the most rapidly in Malta, which also ranks first in terms of the speed of the decline in emissions. Luxembourg is second (also in terms of the decline in emissions) and Lithuania is third; despite its high position when it comes to building a green economy, it ranks last in terms of the decline in emissions. In the green-economy ranking, Poland is in 18th place.

The development of the green economy is correlated with higher economic growth. The average total GDP growth in 2011-2019 was by 10.3 percentage points. higher for the leading countries in the value of the green economy development index compared to the countries with the lowest level of this index (25.7% vs. 15.4%). This may indicate the potential benefits of developing green technologies. Although it should be remembered that individual countries' economic growth is the result of many factors, the results obtained using the model allow us to question the need to choose between increasing the standard of living and sustainable development.

↘ Chart 11. **Impact of green economy development indicator on GDP growth in the EU-27 countries in 2011-2019 (%)**



Note: the countries where the green economy is developing the most slowly are marked in blue, while the leaders of the green economy are marked in green. Countries that do not stand out in this area are marked in grey.

Source: prepared by PEI.

↘ Table 2. Raking of the EU-27 countries in terms of green economy development indicator, as well as GDP growth and CO_2 emissions, in 2011-2019

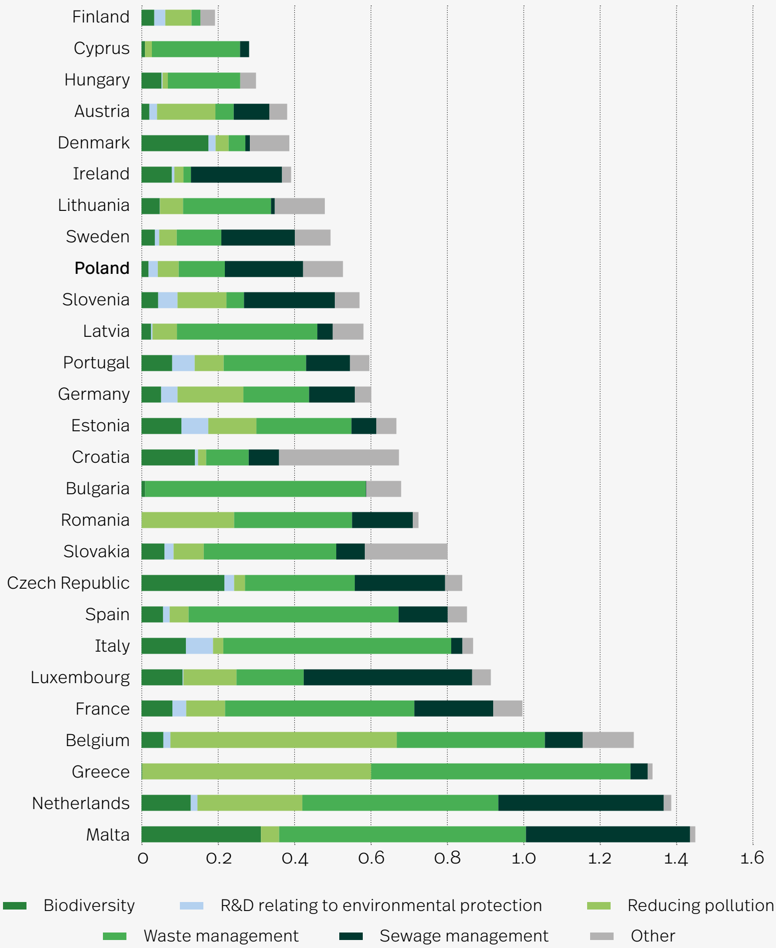
Country	Growth in the green economy	GDP growth	Decline in emissions
	place		
Malta	1	4	1
Luxemburg	2	20	2
Lithuania	3	3	27
Romania	4	2	18
Italy	5	26	7
Germany	6	18	16
Belgium	7	15	20
Netherlands	8	21	17
Estonia	9	7	11
Finland	10	22	5
Sweden	11	25	4
Denmark	12	14	3
Ireland	13	1	22
Austria	14	19	9
Cyprus	15	24	13
Hungary	16	10	23
Bulgaria	17	6	8
Poland	18	8	24
Slovakia	19	23	21
Czech Republic	20	9	14
Greece	21	27	6
Croatia	22	11	15
Latvia	23	5	26
Spain	24	17	19
France	25	16	12
Portugal	26	13	25
Slovenia	27	12	10

Źródło: opracowanie własne PIE.

3. Spending on environmental protection

One of the major elements of the green economy is government spending on environmental protection. In the EU countries in 2019, Malta (nearly 1.5%), the Netherlands (almost 1.4%), Greece (1.3%) and Belgium (also 1.3%) spent the most on this purpose, as a percentage of GDP. Finland (0.2%) and Cyprus (less than 0.3%) spent the least. In most EU countries, spending on waste and sewage management accounts for the largest share. In three of the four countries that spent the most on environmental protection (the Netherlands, Greece and Belgium), spending on reducing pollution also accounted for a significant share.

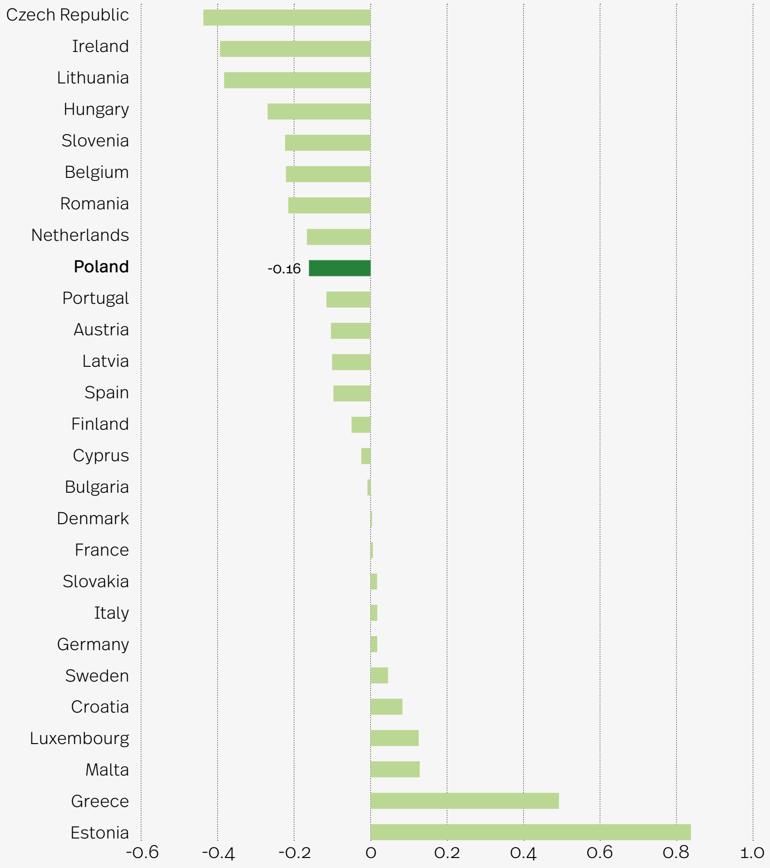
↘ Chart 12. **Public spending on environmental protection in the EU-27 countries in 2019 (% of GDP)**



Source: prepared by PEI based on IMF data.

In 2011-2019, the individual EU countries' approaches to spending on the environment varied greatly. In 11 of them, the environmental spending indicator increased or remained at a similar level. The highest increase was observed in Estonia (above 0.8 pp) and Greece (0.5 pp). However, in 16 countries, environmental protection spending as a percentage of GDP decreased, with the largest decreases in the Czech Republic (more than 0.4 pp), Ireland and Lithuania (almost 0.4 pp). Poland is also among the countries where government spending on environmental protection decreased over those eight years, by 0.16 pp.

↘ Chart 13. **Change in spending on the environment in the EU-27 countries in 2011-2019 (in pp of GDP)**



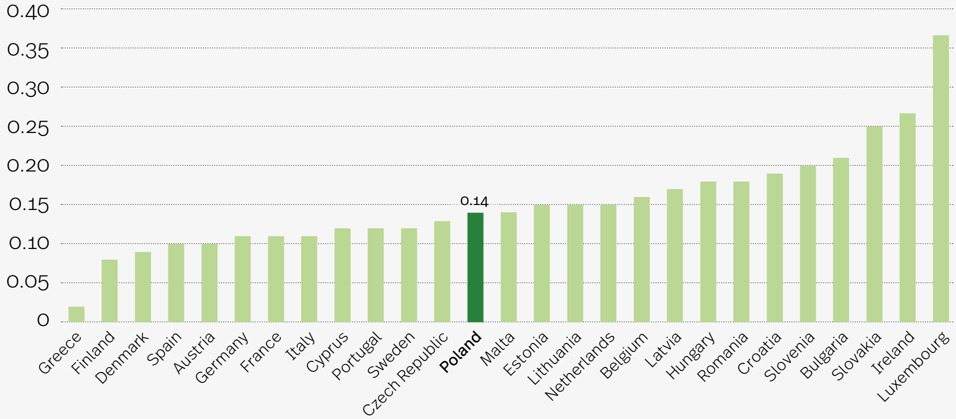
Source: prepared by PEI based on IMF data.

4. Private investment in the circular economy

Waste management is part of the circular economy.[4] According to this conception of the economy, products, materials and commodities should remain in the economy as long as possible and the generation of waste should be reduced as much as possible. It takes into account all the stages in the product life cycle, from design it to dealing with it once it is no longer in use, via production, consumption and waste collection.

In addition to government investments, private investments also have an impact on the development of the circular economy. In 2018, gross investment intangible goods in sectors related to the circular economy was highest in Luxembourg (0.37% of GDP), Ireland (0.27%) and Slovakia (0.25%). It was lowest in Greece (0.02%).

Chart 14. **Private investment in material assets in circular-economy sectors in 2018 (% of GDP)**

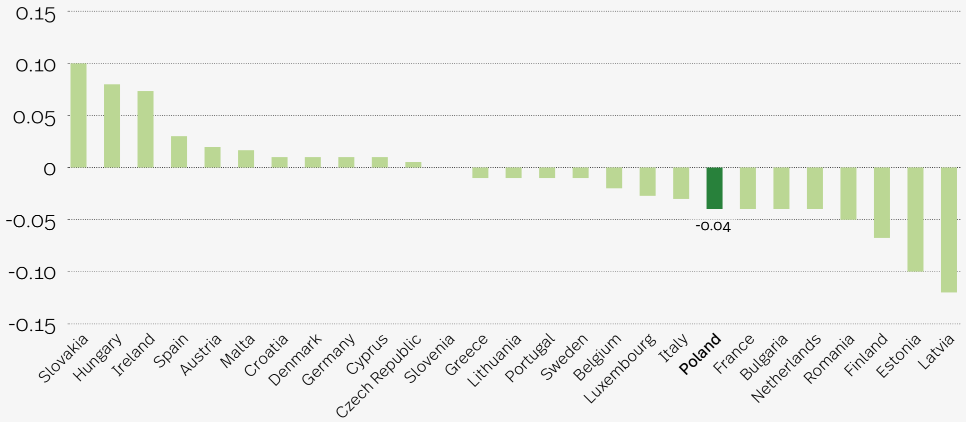


Source: prepared by PEI based on Eurostat data.

In 11 of the 27 EU countries, the level of private investment in material assets in closed-economy sectors increased between 2011 and 2019 – by the most in Slovakia (0.1 pp of GDP), Hungary (0.08 pp) and Ireland (0.07 pp). In 15 countries, decreases in investment were recorded – the largest in Latvia (0.12 pp), Estonia (0.1 pp) and Finland (0.07 pp).

[4] The circular economy includes recycling, offsetting and repairing equipment, and the sale of used goods (www9).

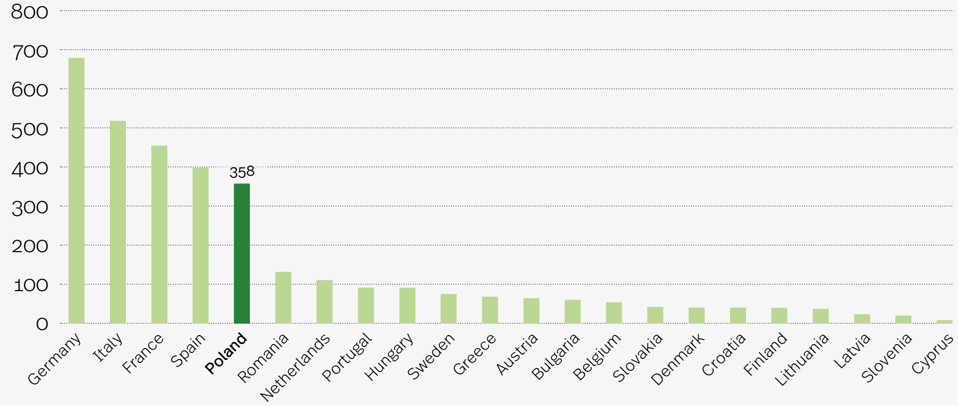
↘ Chart 15. **Change in the level of private investment in material assets between 2011 and 2019 (in pp)**



Source: prepared by PEI based on Eurostat data.

Investment in circular-economy sectors helps create jobs. In 2018, over 3.5 million people worked in these sectors (an increase from 3.3 million in 2011), the most in Germany (680.000), Italy (518,000) and France (455,000). In Poland, 358,000 people were working in these sectors in 2018, 34,000 more than in 2011.

↘ Chart 16. **Number of people working in circular-economy sectors in 2018 (thousands)**



Note: lack of data for some EU-27 countries. The data for France comes from 2017.

Source: prepared by PEI based on Eurostat data.

↘ Box 2. Recycling in Poland

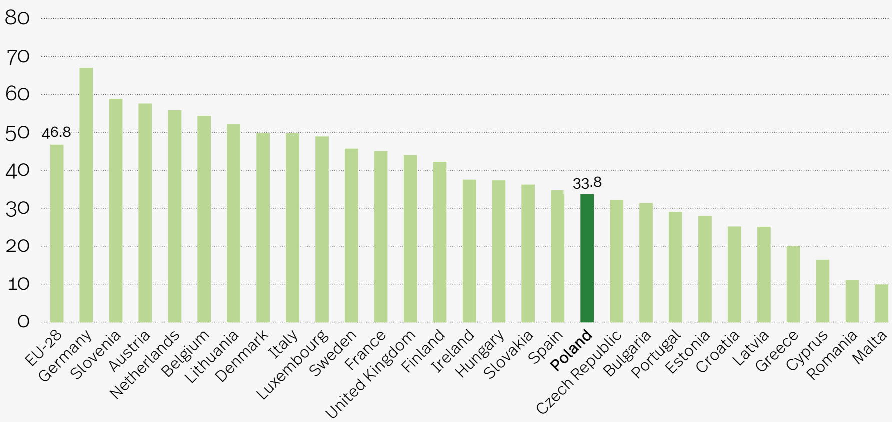
Mining and extraction are responsible for more than half of the waste generated in Poland. Another 20% comes from industrial processing, and the combined power and heating sectors are responsible for 15%. In 2018, waste that was not municipal waste (from households) accounted for around 90% of total waste. Limiting its production amid increasing production and consumption is an important condition for reducing the negative impact on the environment.

Recycling processes play a significant role in waste management. In 2018, more than half of the waste was recovered by the producer itself and transferred to other recipients for recovery. The disposal of waste by landfilling is the result of inadequate resource management, resulting in the emission of pollutants into the atmosphere, soil and water. Only the reuse, recovery or recycling of waste makes it a potential resource. This helps reduce the use of primary raw materials in production, which translates into the most efficient use of resources.

The most important tasks in municipal waste management, resulting from the need to protect the environment, come down to minimising the generation of waste, its rational management, and reducing their build-up in the environment as much as possible.

In Poland, about one-third of municipal waste was recycled, significantly below the EU-28 average (by 13 pp). In terms of the recycling of waste from electrical and electronic equipment (e-waste), Poland fared much better: 39% in 2018, 3 pp below the EU-28 average.

↘ Chart 17. The municipal waste recycling rate in EU-28 countries in 2018

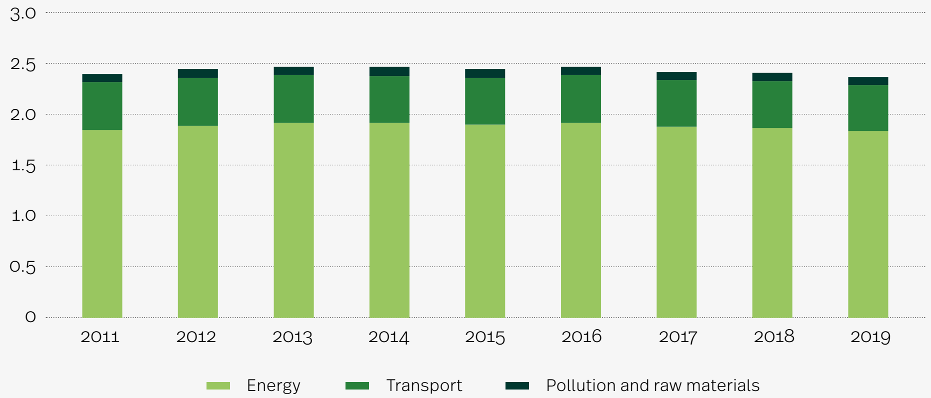


Source: prepared by PEI based on Eurostat data.

5. Environmental taxes

In 2019, environmental taxes in the EU countries amounted to EUR 330 billion, which corresponded to 2.4% of EU GDP and 5.9% of government revenues from taxes and social security contributions. This is an increase of EUR 57 billion compared to 2011; however, environmental taxes' share of GDP remained at a similar level. Most environmental taxes are fees and payments related to energy consumption and production (77.9%). Transport is responsible for 18.9% of revenue, and payments related to the emission of pollutants and the extraction of raw materials are only responsible for 3.2%.

↘ Chart 18. **Environmental taxes in the EU-27 in 2011-2019 (% of GDP)**

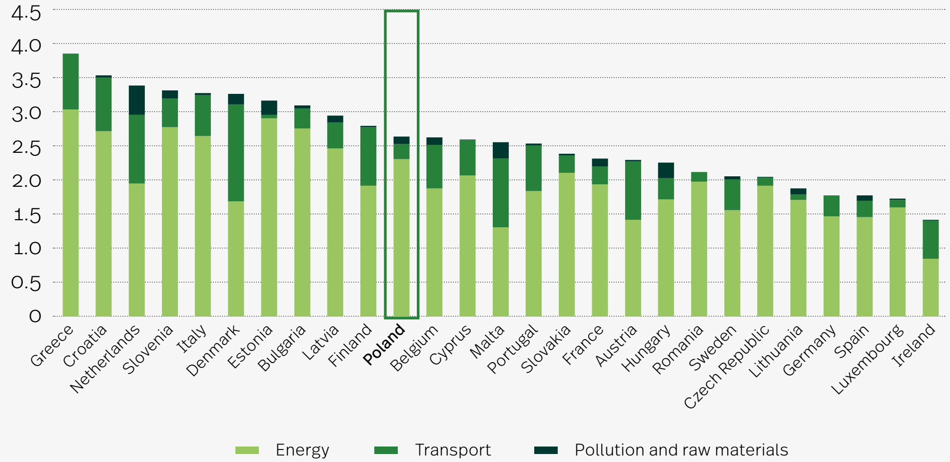


Source: prepared by PEI based on Eurostat data.

The highest environmental taxes in the EU in absolute terms were paid by the inhabitants of Germany (EUR 61 billion), Italy (EUR 59 billion) and France (EUR 56 billion). Polish taxpayers came 6th, paying EUR 14 billion in environmental taxes in 2019, of which over EUR 12 billion were taxes and charges on energy.

As a percentage of GDP, the inhabitants of Greece (nearly 4%), Croatia (3.5%), the Netherlands (3.4%) and Slovenia (3.3%) pay the highest environmental taxes. The percentage is lowest in Ireland, below 1.5%. **In Poland, it is slightly above 2.6%, 0.2 pp above the EU average.**

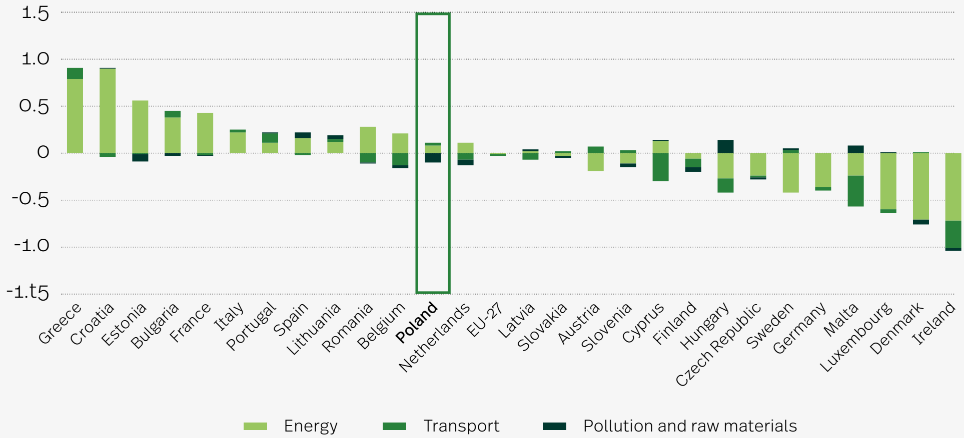
Chart 19. Environmental taxes in EU-27 countries in 2019 (% of GDP)



Source: prepared by PEI based on Eurostat data.

In 2019, environmental taxes as a percentage of GDP had increased in 12 of the EU-27 countries compared to 2011. The highest increase was recorded in Greece (by 0.93 pp) and Croatia (0.86 pp). The largest decrease was observed in Ireland (1.1 pp), Denmark (0.79 pp) and Luxembourg (0.64 pp). In Poland, this percentage remained almost unchanged (a decrease of 0.02 pp). Despite the increase in taxes on energy (0.08 pp) and transport (0.01 pp), those on pollution and raw materials decreased (0.11 pp).

Chart 20. Change in size of environmental taxes in EU-27 countries in 2011-2019 (in pp of GDP)



Source: prepared by PEI based on Eurostat data.

The households' and businesses' share in environmental taxes is similar: 46.7% of revenue comes from companies and 49.9% from consumers. Enterprises pay more in taxes on energy (50.4%, compared to 45.4%), while they less in taxes on transport (32.4%, compared to 67%) and in taxes on pollution and raw materials (42.2, compared to 55.4%).

One of the taxes in the EU most focused on the energy transition is the system of CO_2 emission allowances. In 2019, total revenue from the EU ETS amounted to EUR 12.2 billion, or 4.7% of all energy taxes. This share is growing significantly year on year due to the rising prices of CO_2 emission allowances, which in December 2021 exceeded EUR 80 per tonne (compared to EUR 20-30 per tonne in 2019) (www6). In 2019, Germany paid the most as part of the EU ETS system (EUR 2.8 billion), followed by Italy (EUR 1.3 billion), Poland (EUR 1.2 billion) and Spain (EUR 1 billion).

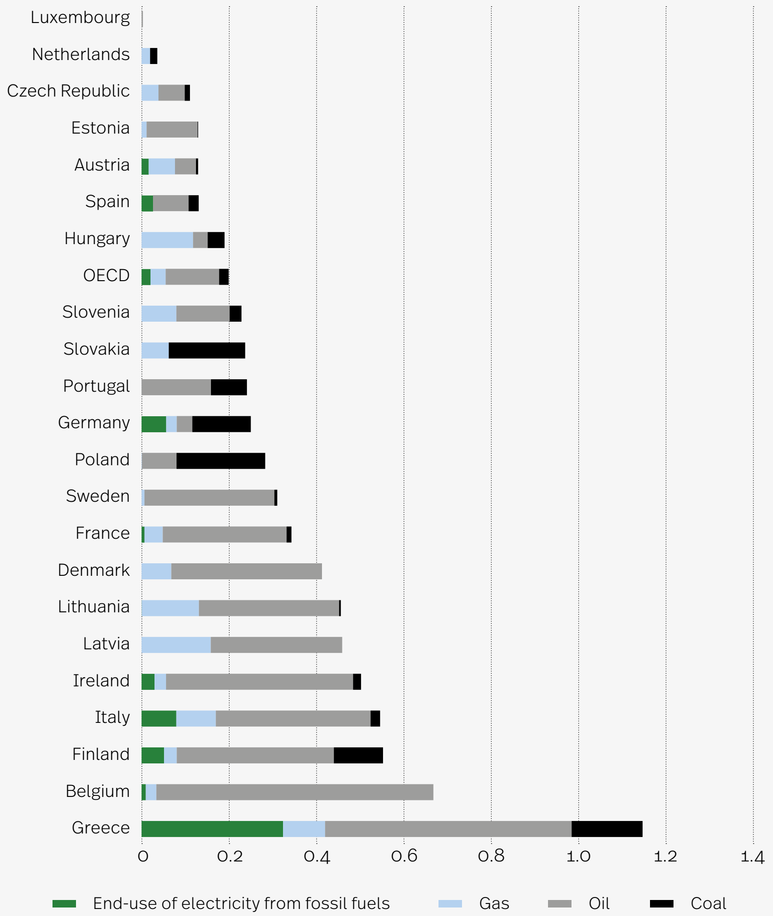
6. Public support for fossil fuels

In developing a green economy, it is crucial to limit activities that have a negative impact on the environment, mainly public support for energy based on fossil fuels. In 2020, the highest subsidies among the EU countries in the OECD – in the form of direct transfers, tax breaks or other forms of support for the production, processing and final consumption of fossil fuels – were observed in Greece (nearly 1.2% of GDP), Belgium (less than 0.7% of GDP), and Estonia and Italy (less than 0.6% of GDP). In Poland, they amounted to 0.28% of GDP, 0.08 pp above the average in the OECD countries.

In the countries with the highest public funding for fossil fuels, support for the oil extraction and processing sector dominated.[5] It is highest in Belgium (0.63% of GDP), Greece (0.56% of GDP) and Ireland (0.42% of GDP). Among the top ten countries with the highest support for fossil fuels, gas subsidies were also of great importance (0.16% of GDP in Latvia, 0.13% of GDP in Lithuania and 0.12% of GDP in Hungary). Some EU countries also offer support for reducing the cost of consuming electricity produced by burning fossil fuels for end users and support for coal. For the latter, the subsidies are the highest in Poland (0.2% of GDP), Slovakia (0.17% of GDP), Greece (0.16% of GDP) and Germany (0.13% of GDP).

[5] Oils obtained from petroleum or bituminous minerals, crude oil, and reclaimed or processed products (such as diesel, gasoline and kerosene).

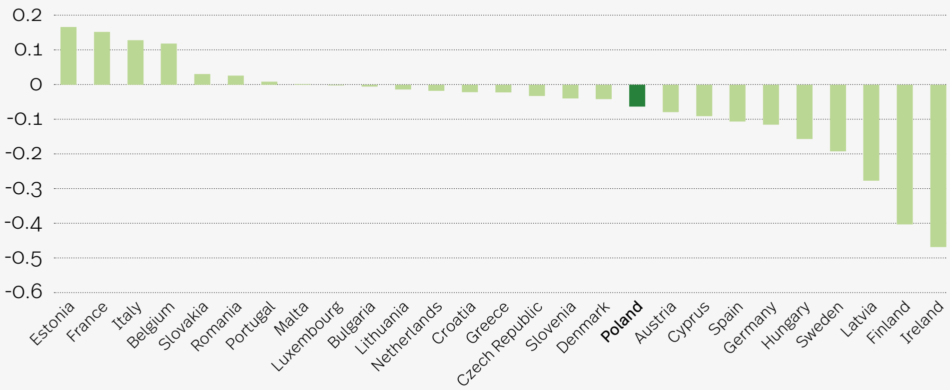
↘ Chart 21. **Public support for fossil fuels in 2019 (% of GDP)**



Source: prepared by PEI based on OECD data.

In the case of 7 of the 22 EU countries in the OECD, there has been an increase in financing for fossil fuels compared to 2011, with the largest increase in Estonia (0.17 pp) and France (0.15 pp). In the remaining cases, the financing of fossil fuels decreased; by the most in Ireland (by 0.63 pp), Finland (0.44 pp) and Latvia (0.35 pp). In Poland, subsidies for fossil fuels also decreased in the 2010s, from 0.34 to 0.28% (a decrease of 0.06 pp).

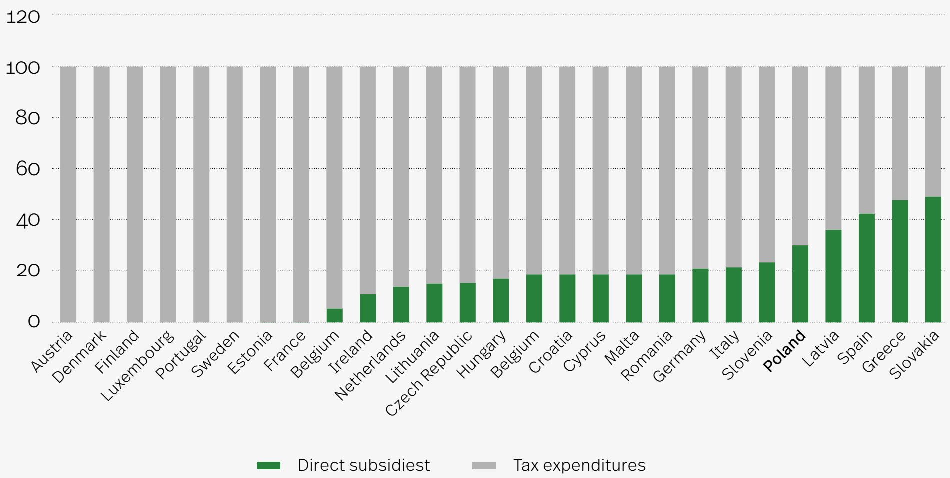
↘ Chart 22. **Change in public support for fossil fuels in 2011-2019 (in pp of GDP)**



Źródło: opracowanie własne PIE na podstawie danych Eurostatu.

EU countries' governments prefer indirect forms of support for fossil fuels. In 11 out of the 22 EU countries in the OECD, support was not provided in the form of direct subsidies; rather, it came in the form of tax relief. The share of direct payments was slightly higher in Slovakia only (51%). Subsidies also account for a significant share of the support for fossil fuels in Hungary (47%), Greece (46%), Poland (42%), Spain (38%) and Germany (32%).

↘ Chart 23. **Share of direct subsidies and tax relief in public support for fossil fuels (%)**



Source: prepared by PEI based on OECD data.

Box 3. The full cost of funding fossil fuels

The OECD data used in this report and model only shows support for the fossil fuel sector officially reported by governments. **According to a report by the IMF, its real size is several times larger, reaching USD 5.9 trillion globally in 2020 (6.8% of global GDP).** In 2025, the cost of public support for fossil fuels could reach as much as 7.4% of global GDP due to the increase in fossil fuel consumption in developing countries, according to the IMF.

The largest source of the under-pricing of fossil fuels worldwide remains the fact that the price does not include the cost of polluting the local air (42%), which has a negative impact on the community's health. The underestimated costs of global warming (29%), as well as other local externalities such as congestion and road accidents (15%), also have a significant impact. The direct subsidies for the fossil fuel sector usually included in calculations account for 8%, and tax breaks for 6%, of the total costs that it receives from countries worldwide (Perry et al., 2021).

7. Feed-in tariffs for renewable energy sources

Feed-in tariffs are an instrument of support provided as part of public aid. They aim to stimulate the development of renewable energy sources (RES), providing producers of energy from renewable sources with a stable outlook for the financing of investments by introducing fixed prices based on the cost of producing energy. In 2011-2019, EU countries introduced feed-in tariffs for photovoltaic, wind, small hydroelectric, biomass and waste power plants. Analysing the data on feed-in tariffs in 27 EU countries in 2011-2019 allows us to identify various approaches to the use of this instrument for supporting RES.

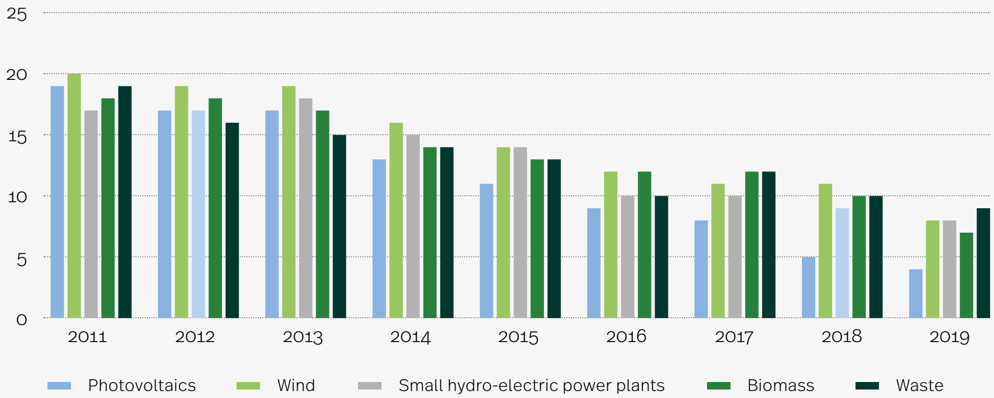
Table 3. EU countries' attitude to feed-in tariffs as an instrument for supporting particular types of RES in 2011-2019

Policy adopted on the tariffs	EU countries
Never introduced any of the indicated tariffs	Belgium, Poland, Sweden, Malta, Romania
Introduced some of the tariffs and abolished all of them	Czech Republic, Ireland, Latvia, Lithuania, Cyprus
Introduced all the tariffs and abolished all of them	Greece, Portugal, Slovakia, Slovenia, Spain, Croatia
Introduced some tariffs, kept some of them and abolished others	Finland
Introduced some of the tariffs and kept them all	Hungary
Introduced all the tariffs and kept some of them	Austria, Denmark, France, Germany, Italy, Luxembourg, Bulgaria
Introduced all the tariffs and kept all of them	Estonia, Netherlands

Source: prepared by PEI based on OECD data.

When it comes to feed-in tariffs, there is also considerable diversity in individual member states' policies, with a general tendency towards the gradual abolition of feed-in tariffs. For example, feed-in tariffs for solar power plants, applicable in as many as 19 EU member states in 2011, were only applicable in Bulgaria, Estonia, the Netherlands and Hungary in 2019. In 2011-2019, there was a downward trend in the use of tariffs: while they were applied by 22 countries in 2011, they were in force in 11 in 2019. The feed-in tariff abolished the least often was for plants that generate energy from waste, which was in force in 9 EU countries in 2019 (Austria, Denmark, Estonia, Finland, France, the Netherlands, Luxembourg, Germany, Hungary). The downward trend in the use of feed-in tariffs is part of the transitional conception of the use of this instrument, which is meant to be temporary and gradually fade away after the required objectives are achieved.

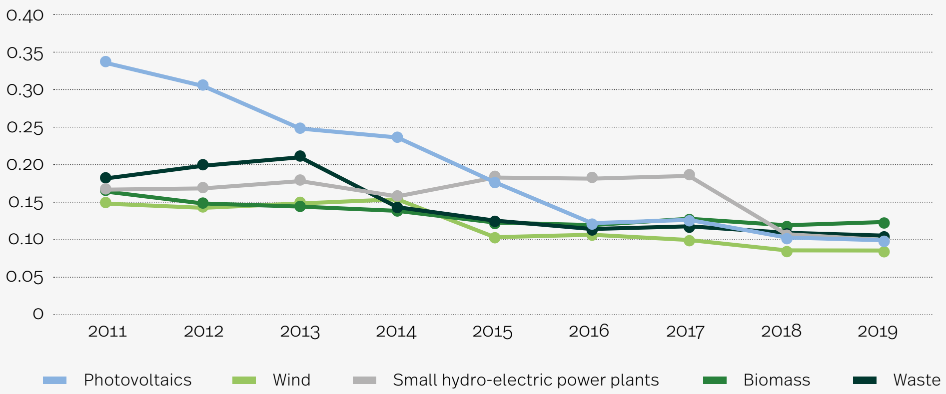
↘ Chart 24. **Number of countries where feed-in tariffs for particular types of RES were in forcet**



Source: prepared by PEI based on OECD data.

In 2011-2019, the level of feed-in tariffs in the EU countries was clearly falling. A particularly visible tendency can be seen in the case of the average tariffs for electricity from photovoltaic power plants: their average value fell more than threefold in 2011-2019, from USD 0.34 per kWh to USD 0.10 per kWh. The average tariff for biomass was the most stable, amounting to USD 0.17 per kWh in 2011 and USD 0.12 per kWh in 2019. With the gradual decline in the use of tariffs and their level, the difference between tariffs' support for individual types of RES decreased. In 2011, the average feed-in tariff for photovoltaics (USD 0.34 per kWh, maximum) was almost double the average wind farm tariff (USD 0.15 per kWh, minimum). In 2019, the difference between the average biomass tariff (USD 0.12 per kWh, maximum) and the wind farm tariff (USD 0.08 per kWh, minimum) was much lower, at 46%.

↘ Chart 25. **Average level of feed-in tariff introduced in EU-27 countries (USD per kWh)**

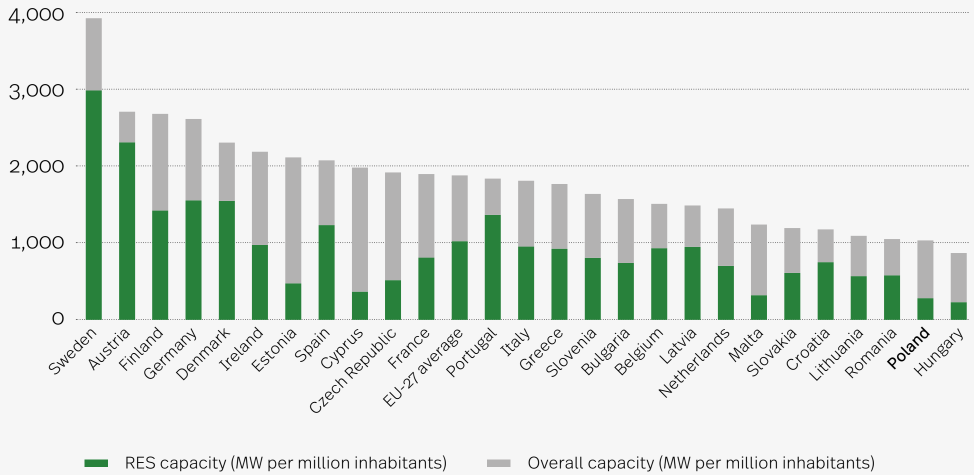


Source: prepared by PEI based on OECD data.

8. Building new RES capacities in the power industry

The years 2011-2019 were a time of unprecedented growth in installed capacity in renewable energy. During this period, an average of 306 MW of renewable energy per million inhabitants was installed in the EU countries, an increase of as much as 43% compared to 2011. Countries with a higher share of RES also show noticeably higher levels of installed MW of capacity *per capita*, which

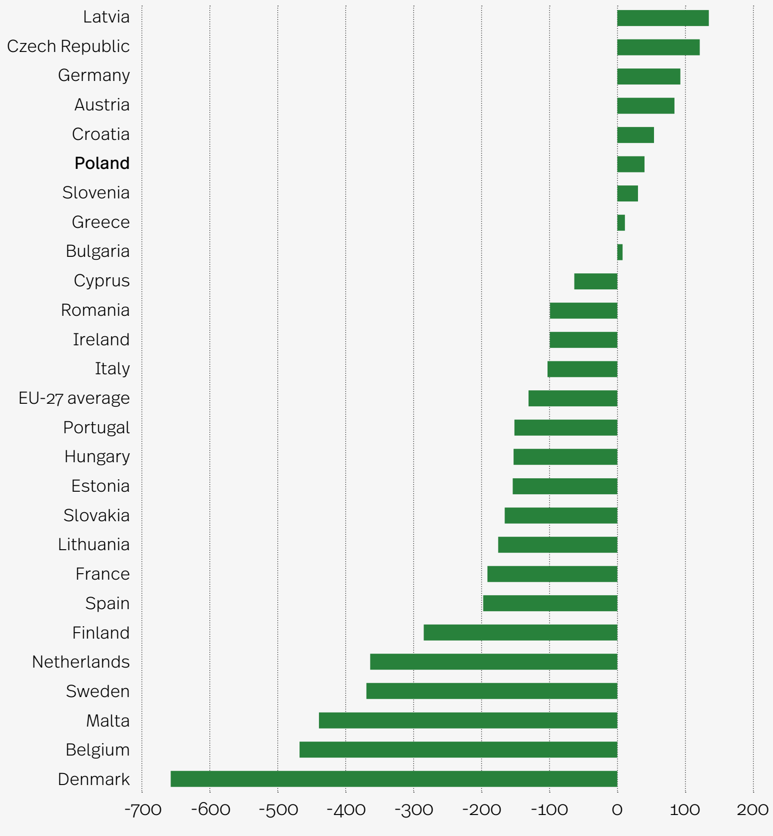
↘ Chart 26. **Capacity in renewable and non-renewable energy per million inhabitants in 2019 (MW per million inhabitants)**



Source: prepared by PEI based on IRENA data.

is related to the variability of RES generation. The increase in capacity installed in RES drives the increase in demand for new energy capacity due to the need to maintain stable generation in the energy system; additional capacity is needed in the event of unfavourable weather conditions. In 2019, EU countries where the share of RES in installed capacity per million inhabitants was below 40% (Poland, the Czech Republic, Hungary, Malta, Estonia and Cyprus) had an average of 1528 MW of installed capacity per million inhabitants. In countries in the 40-60% range, this was 1792 MW on average. In countries where this percentage exceeded 60% (Austria, Croatia, Denmark, Latvia, Sweden, Portugal), it was 2139 MW on average.

↘ Chart 27. **New capacities from sources other than renewables in 2011-2019 (MW per million inhabitants)**

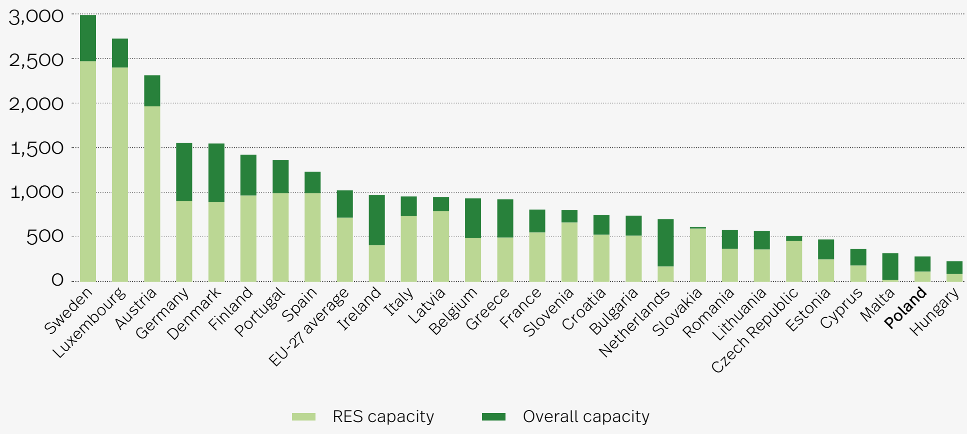


Źródło: opracowanie własne PIE na podstawie danych IRENA.

The appearance of new RES capacities in EU countries was associated with a gradual departure from energy from other sources. **In 2011-2019, 131 MW of non-renewable energy per million inhabitants was abolished in the EU-27 countries, on average.** However, some countries (Latvia, the Czech Republic, Germany, Croatia, Poland, Greece and Bulgaria) increased the amount of installed capacity in non-renewable energy, too. However, even in these countries, the average value of newly installed capacities in non-renewable energy was small, amounting to 64 MW per million inhabitants.

A comparison of the installed capacity in RES alone allows us to see the importance of years of consistently building this type of energy source, which goes far beyond the years 2011-2019. **The countries that were already leading in terms of installed RES capacity in 2011 (Sweden, Luxembourg and Austria, with over 1900 MW per million inhabitants) maintained their position.** In 2011-2019, the largest amounts of renewable energy capacity *per capita* appeared in Germany and Denmark (655.2 and 654.6 MW of new RES capacities per million inhabitants, respectively). **The highest relative increase in installed RES capacity per million inhabitants took place in Malta (more than 16-fold), the Netherlands (more than fourfold), Hungary (an increase of 162%) and Poland (141%), countries where the share of RES in the energy mix is relatively low** (Malta 8%, the Netherlands 18%, Hungary 10% and Poland 14% in 2019). This points to the emerging nature of these countries' energy markets in the process of the European energy transition.

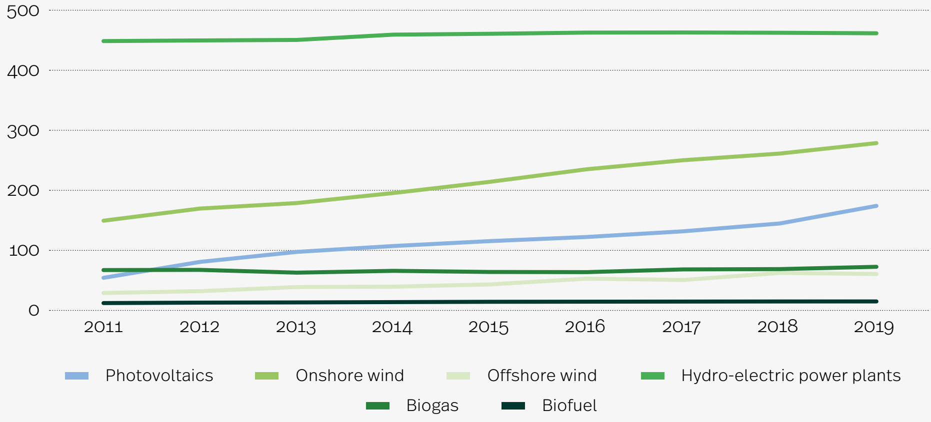
↘ Chart 28. **Increase in installed RES capacity in 2011-2019 (MW per million inhabitants)**



Source: prepared by PEI based on IRENA data.

Eurostat data shows significant differences in the rate of development of individual types of RES in the EU. **The highest average capacity increase in 2011-2019 was in onshore wind energy** (over 130 MW per million inhabitants), resulting from significant growth in Ireland (over 500 MW in new capacity per million inhabitants), Finland and Germany, and in photovoltaic energy (over 122 MW per million inhabitants) in the Netherlands (an increase of over 400 MW per million inhabitants), Malta and Belgium.

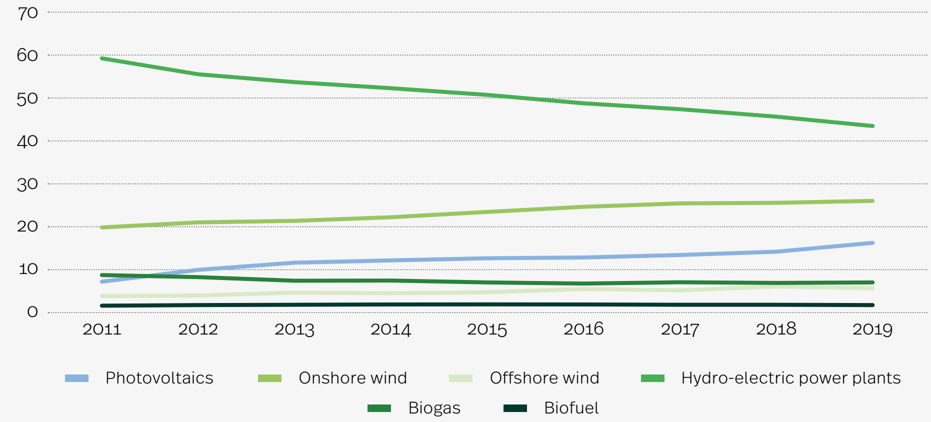
↘ Chart 29. The average amount of installed capacity of individual types of RES in the EU-27 in 2011-2019 (MW per million inhabitants)



Source: prepared by PEI based on IRENA data.

Hydroelectric power plants remain the most significant renewable energy source in the EU, but their share is declining (from 59% to 47% of RES capacity in the EU) due to the limited opportunities for further development (an average increase of only 15 MW in new power per million inhabitants). In the future, the current trends in increasing the share of onshore wind and solar farms are expected to continue. In 2011-2019, the rate of increase remained high, which meant that their share in installed capacity increased from 27% in 2011 to 42% in 2019.

↘ Chart 30. Share of particular types of RES in installed RES capacity in the EU-27 in 2011-2019 (%)

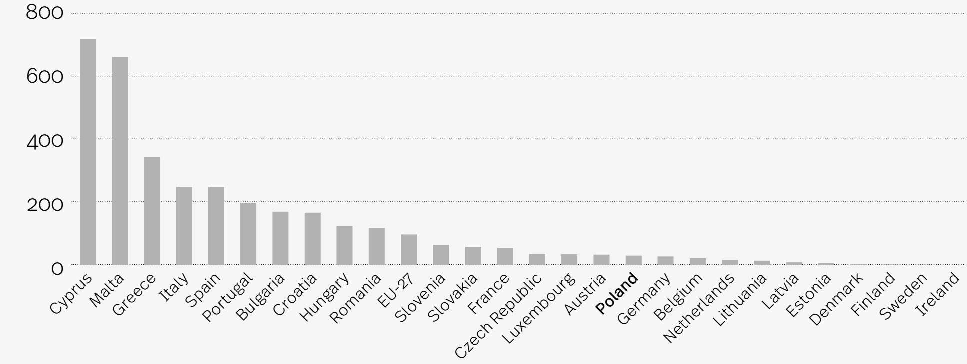


Source: prepared by PEI based on IRENA data.

9. Increase in renewable energy sources in heating and cooling

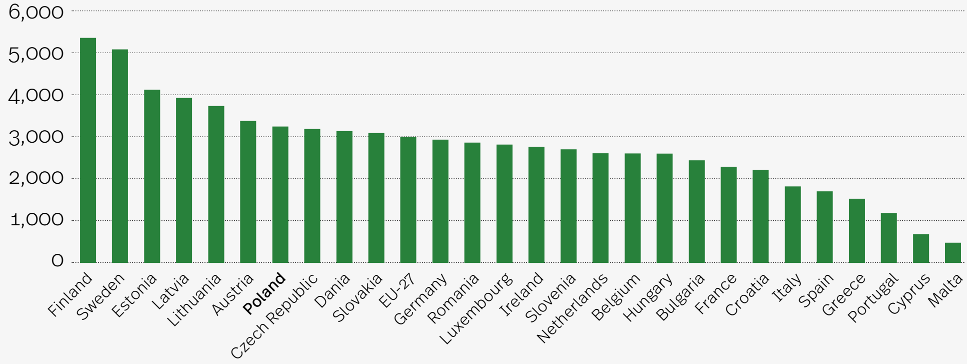
The climate varies from one EU country to another: hot summers are the main challenge for Cyprus and Malta, while most EU citizens (above all, in Finland, Sweden and Estonia) are forced to incur significant heating expenses during the winter. The variation between EU countries in terms of cooling and heating degree days is reflected in differences in the level of development of heating infrastructure and energy spending related to operating it.

Chart 31. The average number of cooling degree days in EU-27 countries in 2011-2019



Source: prepared by PEI based on Eurostat data.

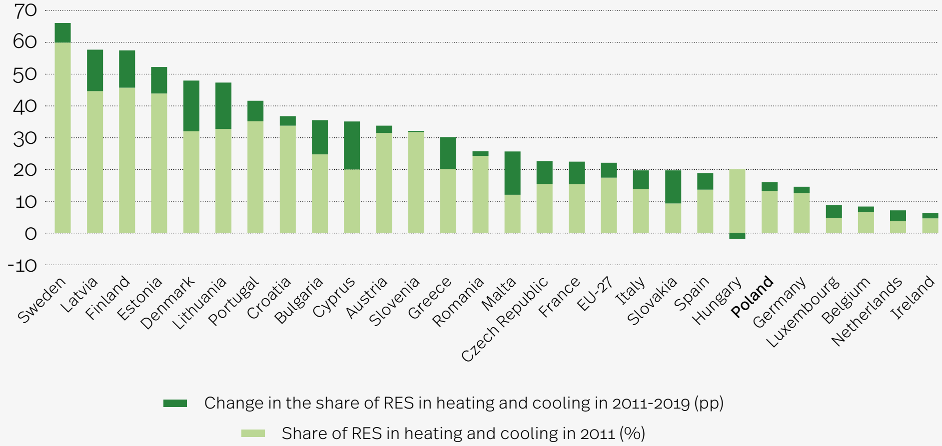
Chart 32. The average number of heating degree days in EU-27 countries in 2011-2019



Source: prepared by PEI based on Eurostat data.

In all the EU countries except Hungary, there was an increase in the share of renewable energy in heating and cooling. The average share of RES in these areas increased from 17.4% in 2011 to 22.1% in 2019 (a relative increase of 22%). This is noticeably lower than the increase in the share of RES in the EU energy mix and the share of RES in the installed capacity in the EU, which points to the slower development of renewable energy in this area.

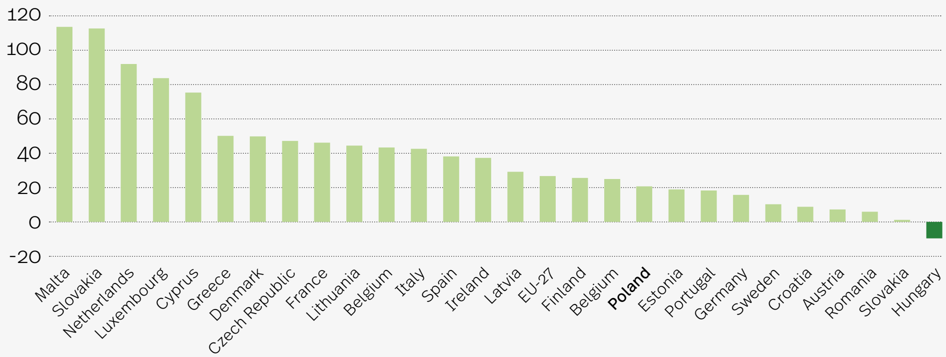
↘ Chart 33. **Increase in the share of renewable energy in heating and cooling in the EU in 2011-2019 (%)**



Source: prepared by PEI based on Eurostat data.

The highest relative increase in the share of RES in heating and cooling took place in countries where cooling is a significant energy expenditure (Malta, Cyprus, Greece), which suggests that it is easier to introduce RES in cooling than in heating. Significant growth was also recorded in certain small, densely-populated countries: the Netherlands, Luxembourg, Denmark and Slovakia.

↘ Chart 34. **Relative change in the share of RES in heating and cooling in 2011-2019 (%)**



Source: prepared by PEI based on Eurostat data.

Summary

According to the results of our model, the development of the green economy has a significant positive impact on reducing emissions and a moderate positive impact on GDP growth. This conclusion can be drawn both for the general equation in the model and for the results obtained for individual EU-27 countries. In countries where the green economy development indicator was highest, GDP growth was 10 pp higher on average in 2011-2019 than in the other countries analysed, despite significantly higher spending on environmental protection and climate.

Among the factors examined by us, an increase in the share of renewable energy sources (RES) in the power sector has the highest positive impact on the green economy development indicator. An increase in the share of RES in heating and cooling and high feed-in tariffs also have a major positive impact.

Among the EU-27 countries, the green economy indicator grew the most rapidly in Malta and Luxembourg in 2011-2019. The lowest level of green economy development, as measured using the indicator resulting from our model, was recorded in Slovakia and Portugal. In the ranking of the rate of the green economy's development in the EU-27, Poland came 18th, below the EU average. Poland fared better in terms of economic growth: the average annual rate of GDP growth *per capita* in purchasing power parity in 2011-2019 was 5.1%, which meant that it ranked 8th in the EU. At the same time, emissions remained almost unchanged in 2011-2019 (an average annual increase of 0.1%), whereas a decrease in CO_2 emissions could be observed in most EU countries.

The relatively low development of the green economy indicator in Poland in 2011-2019 results from a negative or near-zero change in most of the component variables. In particular, a significant decline can be observed in investment in the circular economy and government spending on environmental protection (as a percentage of GDP). In 2011-2019, there was also no support for RES in the form of a feed-in tariff mechanism, and the very possibility of applying them was not introduced by law until the second half of 2018 (www10). The speed of the development of RES in heat engineering also remained below the EU-27 average.[6] The increase in the share of RES in the power sector was higher and remained at the EU average (around 7% per year). It is worth remembering, however, that in both cases the low base effect contributed to the rate of change in Poland.[7] However, the slightly higher decline in public funding for fossil fuels (around 3% annually) than in most EU countries should be considered a positive.

It is worth noting that the trend of moving towards a greener economy has accelerated significantly in Poland in recent years. The share of measures with a positive impact on the climate in the funds allocated to stimulate the economy during the COVID-19 pandemic was as high as 37% by the end of 2021 (7 pp above the average for the EU countries analysed).

[6] Despite the low base effect, which acted to Poland's advantage in a model based on the speed of growth.
[7] The model measures the rate of growth. In Poland, the lower share of RES in the power industry in 2011, as well as in heating and cooling, meant that a 1% increase in the share of RES resulted in a higher rate of change than in countries with a high share of RES.

The construction of new RES capacities has accelerated significantly, too. Over the course of a year (11.2020-11.2021), installed RES capacity increased from 12 to over 16 GW (www11).

The component variables of the green economy development indicator need to be improved, not only in Poland. In 2011-2019, 16 EU-27 countries reduced the level of spending on environmental protection as a percentage of GDP, above all the Czech Republic (0.43 pp) and Ireland (0.39 pp). In 15 EU-27 countries, private investment in circular economy sectors decreased, by the most in Latvia (0.12 pp) and Estonia (0.1 pp). At the same time, public support for fossil fuels remains high, reaching almost 1.2% of GDP in Greece and above 0.6% in Belgium.

Recommended actions for the further development of the green economy should include investments in renewable energy in the power and heating sectors. This is important not only from the point of view of the model's results, but also the revision of the targets for the share of RES in the final gross energy consumption in Poland that results from the “Fit for 55” package. It seems necessary to intensify activity aimed at building new RES capacities, especially in the power sector. Meanwhile, according to the results of the RES auction in December 2021, only three out of five auctions were completed, and the bids were dominated by solar farms (361 out of 375). Eliminating both financial (insufficient tariffing, inadequate financing of investments) and legislative (the “10h law”) obstacles to new RES capacities should therefore be considered a priority in the coming years.

Developing sectors related to the circular economy also seems important. The percentage of waste recycled in Poland is still below the EU average. At the same time, sectors related to recycling, reusing and repairing goods seem to have great potential, providing over 350,000 jobs in Poland, with a level of private investment below that in many EU-27 countries. This shows the considerable potential for the further development of the sector, which could have a positive impact on recycling targets, increase the reuse of goods and create additional jobs.

Appendix

↘ Table 4. List of indicators used to build the green economy hidden variable

Category	Indicator	Source of data
Government spending on environmental protection	Spending on biodiversity and landscape protection Spending on biodiversity and landscape protection Spending on removing pollution Spending on waste management Spending on sewage management Spending on environmental protection not included elsewhere	IMF
Circular economy	Private investment in material assets in circular economy sectors	Eurostat
Public support for fossil fuel	Direct subsidies Tax expenditures	OECD
Environmental taxes	Energia Transport Pollution and raw materials	Eurostat
Feed-in tariffs for RES	Photovoltaics Wind energy Biomass Small hydro-electric power plants	OECD
Share of RES in electricity production	Share of RES in electricity production	Eurostat
Share of RES in heating and cooling	Share of RES in heating and cooling	Eurostat
Spending on academic research on RES and CO_2 capture technology	Spending on academic research on RES and CO_2 capture technology	OECD

Source: prepared by PEI.

Soft modelling

Soft modelling was created by Herman Wold (Wold, 1980; Rogowski, 1990). Its name relates to the features of the econometric model and its variables, as well as to the assumptions that enable appropriate statistical estimation and verification procedures to be used (Mierzyńska, 2000; Perło 2004; Rogowski, 2002).

It is one of the methods that allow us to analyse the relationships between hidden (unobservable) variables that are observed (measured) using indicators.[8] A given indicator may reflect or create a hidden variable. In the former case, we will call it the reflecting indicator and, in the latter case, the generating indicator. It is up to the researcher to indicate the type of indicator, although the reflective indicators should, by definition, be characterised by a high correlation with each other, whereas the generating indicators should be uncorrelated (Perło, 2004).

The soft model consists of two submodels: internal (theoretical) and external (measure). The first describes the theoretical relations resulting from the adopted theory; that is, relations between unobservable variables. The second contains the relationships between hidden variables and their indicators; that is, the definitions of the theoretical variables. Both models are related to each other; both are simultaneously used in the parameter estimation process. It is assumed that the relationships in soft models are linear.

Let hidden variables $\xi_1, \xi_2, \ldots, \xi_n$ be endogenous, while $\xi_{n+1}, \xi_{n+2}, \ldots, \xi_k$ $(k > n)$ – are predetermined. The internal model can then be written as follows:

$$[\,\xi_1\ \xi_2\ \ldots\ \xi_n\,] = [\,\xi_1\ \xi_2\ \ldots\ \xi_n\,]\,\mathbf{B} + [\,\xi_{n+1}\ \xi_{n+2} \ldots\ \xi_k\,]\,\mathbf{\Gamma} + \mathbf{V},$$

where:

$\mathbf{B} = [\,b_{ij}\,]$ – the matrix of structural parameters related to endogenous variables is the square matrix of degree n with a zero main diagonal,

$\mathbf{\Gamma} = [\,\gamma_{ij}\,]$ – the matrix of structural parameters associated with the predetermined variables has the dimension $(k - n) \times n$,

$\mathbf{V} = [\,v_{ij}\,]$ – the n-dimensional vector of random components with zero expected and finite variances.

It is assumed that the random component of the j-th equation v_j $(j = 1,2,\ldots,n)$ is uncorrelated with the explanatory variables of this equation.

[8] There are other methods for studying models containing hidden variables, such as factor analysis, principal component analysis, canonical correlation, imbalance models and the LISREL method, which is a generalisation of factor analysis (Rogowski, 1980).

The external submodel is the relationship between hidden variables and their identifiers. In the case of the soft model, it is assumed that the hidden variables are the weighted sums of their identifiers:

$$\bigvee_{j=1,\ldots,k} \bigvee_{t=1,\ldots,T} \xi_{jt} = \sum_{i=1}^{n_j} w_{ij} x_{ijt} \, ,$$

and, for each reflecting indicator, a relation measuring the strength of the reflection of the hidden variable is provided:

$$\bigvee_{j=1,\ldots,k} \bigvee_{t=1,\ldots,T} x_{ij} = p_{ij0} + p_{ij}\xi_{jt} + u_{ijt} \, ,$$

where:

ξ_{jt} – the *t*-th value of hidden variable ξ_j,
x_{ijt} – the *t*-th value of the *i*-th indicator x_{ij} of hidden variable ξ_j,
w_{ij} – the unknown weight of indicator x_{ij},
p_{ij0} – intercept,
p_{ij} – factor loading measuring the force with which hidden variable ξ_j is reflected by its *i*-th indicator,
u_{ijt} – random component with an expected value of zero, which meets the following assumptions: no autocorrelation, not correlated with hidden variables, and no correlation between the equations,
T – number of objects studied for cross-sectional data or observation moments for time series.

The structural parameters of the soft model are estimated using the partial least squares method, in three stages. The first stage involves iterative weight estimation, which allows the hidden variables' values to be estimated. In the second, the parameters of the internal and external model (factor loadings) are estimated. The estimation process ends with the calculation of the intercepts of all the relations in the model.

As a result of the estimation – in addition to the parameters of the measure model and the theoretical model – we obtain estimates of the value of the hidden variable, which can be treated as a synthetic measure. These values depend not only on the external relations, but also on the relationships between complex phenomena assumed in the internal model. The cognition process is therefore dependent on the theoretical description. Estimates of unobservable variables do not have a content-related interpretation, but changes in their values can be interpreted. If the estimates of weights and factor loadings for the indicators that are stimulants of a given hidden variable are positive, and those for destimulants negative, we can interpret changes in the "estimated" observations of a given hidden variable in such a way that a greater value of the hidden variable indicates a higher level of the phenomenon being studied on a given object. Comparative analysis is carried out by interpreting the order of these numbers.

The statistical properties of the soft model are mainly checked using the Stone-Goset test (S-G test), a measure of the accuracy of the prediction made based on the model in relation to a "trivial" prediction and on the so-called Tuckey's test. These methods are specific to soft modelling.

There are three types of S-G test.[9] The first (general) one examines the quality of prediction by all the indicators of a selected unobservable variable, the second the quality of prediction by individual indicators, and the third the quality of the reproducibility of all the indicators for individual time moments or individual objects. The relevant S-G statistics are expressed by the following formulas (Rogowski, 1990):

$$Q = 1 - \frac{\sum_{i=1}^{n_j}\sum_{t=1}^{T}(x_{ijt} - x_{ijt}^*)^2}{\sum_{i=1}^{n_j}\sum_{t=1}^{T} x_{ijt}^2}$$

$$Q_i = 1 - \frac{\sum_{t=1}^{T}(x_{ijt} - x_{ijt}^*)^2}{\sum_{t=1}^{T} x_{ijt}^2} \quad (i = 1, \dots, n_j)$$

$$Q_t = 1 - \frac{\sum_{i=1}^{n_j}(x_{ijt} - x_{ijt}^*)^2}{\sum_{i=1}^{n_j} x_{ijt}^2} \quad (t = 1, \dots, T)$$

All the values given by the formulas are limited from above by one. If Q = 1 (Q_i = 1, Q_t = 1), the reconstruction of the indicator values of the selected hidden variable (values of the *i*-th indicator x_{ij}, indicator values for the object or for moment t) is perfect. If the above measures are negative, we say that the model does not provide a good forecast, which in the case of Q_i (Q_t) means that indicator x_{ij} is "foreign" (the mechanism assumed in the model does not explain well enough the shaping of the values of the indicators of the selected unobservable variable for the object *t* or at time *t*). When the S-G test values are close to zero, the problem of the quality of the relevant forecasts remains unresolved.

To apply the S-G tests, the parameters of the soft model should repeatedly be estimated, obtaining *l* estimates for each model parameter. The standard deviation of these numbers is an estimate of the precision of the estimator for a given parameter. This method is called the Tuckey test. Using the "2s" rule, the significance of the model's parameters can be tested.

9 The basis for using the S-G test are the numbers obtained as follows: for a selected hidden variable, a matrix of observations of its indicators is created, removing every *l*-th from this matrix (*l* is chosen arbitrarily, but it cannot be a divisor of the dimensions of the indicator observation matrix), starting with the first one, and replacing it with, for example, the arithmetic mean of the remaining observations. This operation is repeated, except that we start removing data from the original matrix of observations from the second, third, etc., to the *l*-th term. With each step, forecasts of the deleted observations (x^*_{ijt}), are obtained, which provide the basis for using the S-G test.

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List of boxes, charts and tables

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