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EU Carbon Emissions Market Development and Its Impact on Penetration of Renewables in the Power Sector

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Abstract: This paper focuses on the analysis of the EU carbon trading scheme and its impacts on regional power system development and penetration of renewable energy sources (RES). The aim of the article is to analyze the forecasts of carbon dioxide (EUA) prices for the years 2019–2030 and to apply the results of this forecast in regional power system planning. The data employed in this paper come from many sources, including empirical data of the selected analytical companies, such as Thomson Reuters among others. The current low prices for carbon dioxide emission rights do not encourage the reduction of greenhouse gas emissions, in particular carbon dioxide, and do not have a significant impact on the penetration of renewables. This paper presents the results of two scenarios (for 2021 and 2030) developed after the analysis of the EUA price impact on penetration of renewable energy sources in West-Pomeranian region assuming different electricity production and the EUA price forecasts. The results of two regional energy development scenarios run for 2021 and 2030 indicate changes in the structure of renewables in West-Pomeranian region. The results also show that the increase of EUA price has a significant impact on the increase of costs for power production and increase of unit cost of the installed 1GWh. In addition, the forecasted EUA price in 2030 is 3% lower as compared with 2021, which has its impact on the increased share of electricity produced by co-firing biomass with other fossil—from 42% to 68% in the electricity generation structure of West-Pomeranian region.

Keywords: Emissions Trading System (EU ETS); European Allowance (EUA); carbon dioxide; renewable energy sources; regional power system planning

1. Introduction

One of the negative by-products of our economic system is carbon dioxide, the emission of which is inevitably accompanied by the combustion of fossil fuels used for energy production. Concentrations of carbon dioxide (CO_2), methane and nitrous oxide in the atmosphere have increased by 40% as compared to the pre-industrial era, mainly due to the combustion of fossil fuels, as well as due to the emissions related to changes in land use [1,2]. Countries around the world have developed emission trading schemes as a means to place a price on greenhouse gas (GHG) emissions. Such GHG trading systems are now in place in Europe, North America, and parts of Asia. The European Union (EU) has introduced the European Emissions Trading System (EU ETS), also known as the Community market for carbon dioxide (CO_2) emission rights, or the EU ETS system. It is currently the world's largest CO_2 trading system. The EU ETS was launched in 2005 with a pilot phase, followed by Phase 2 up until 2012 and then Phase 3 from 2012 to 2020. Phase 3 is closely linked to the EU energy goals for 2020.

The 20–20–20 goals assume a 20% (or even 30%) reduction in CO_2 emissions as compared to the 1990 levels, 20% of the energy spent on consumption coming from renewables and a 20% increase in energy efficiency of the EU Member States. Therefore, for Poland, the same as other EU Member States, it is important to assess the impact of an increase in carbon price on the penetration of renewables. Today, the EU ETS is the only carbon market based on binding national and regional legislation [3].

Since the structural reform under the ETS Directive adopted by the European Union as part of the Energy and Climate Package on 12 December 2008, the purchase of CO_2 emission rights on the stock exchange is made by the energy industry and electricity generation companies after using the allocated pool granted to the EU Member States. Since 2012, trade in CO_2 emission allowances (EUA) is mainly carried out at the ICE exchange in London and EEX in Leipzig. The European Union and its separate Member States are introducing new allowances for the CO_2 market through auctions at the ICE and EEX exchanges on the basis of new regulations adopted by the European Commission.

It is expected that new regulation will have an impact on the EUA price increase as recent development of EUA prices were very low, showing the ineffectiveness of the developed scheme due to a large surplus of carbon allowances available in the market [4–7].

GHG emission trading is increasingly becoming popular globally, but doubts about its practicality and effectiveness in terms of promoting renewable energy have hampered its adoption [8]. The empirical research on the effects of EU ETS on the deployment of renewable energy remains limited [4–7]. In the beginning, it was expected that EU ETS would have a significant impact on GHG emissions' reduction and faster penetration of renewables; however, low EUA prices due to EUA surplus in the market were not able to provide a strong stimulus for renewable energy development of the EU member states [9].

EU ETS, in its first stage, appeared to only indirectly benefit research and development on renewables and indirectly contribute to the diffusion of renewables [10]. Blanco and Rodrigues [11] proved that EU ETS has not provided sufficient incentives to stimulate wind power industry development, therefore, other policies and measures to internalize societal benefits from renewables should be pertained [10]. Polzin et al. [12] analysed the effects of EU ETS on renewable energy investments and discovered that EU ETS can strongly effect institutional investments in renewable energy sources. Other authors [12] proved that additional support schemes are necessary for the deployment of renewable energy sources, for example, EU ETS alone is not able to provide enough stimulus for faster penetration of renewables in electricity markets. There are no studies dealing with the impact of a GHG emission trading scheme on the penetration of renewables over a long-term period, therefore, it is important to investigate these impacts taking into account future EUA price forecasts. The analysis of impact from EUA price on the costs of electricity generation is very useful when it comes to assessing the profitability of investments in renewable energy and costs optimization in the course of energy sector development on the regional level.

The aim of this paper is to analyze future EU ETS development and forecast the EUA prices up to 2030 by taking into account new EU regulations amending EU ETS scheme and then also to assess the impact of this forecasted EUA price on the penetration of renewable energy sources at the regional level.

The rest of this paper is structured in the following way: Section 2 presents a literature review on EU ETS scheme and its impacts; Section 3 provides an analysis of the EU ETS scheme and discusses its future developments; in Section 4 an analysis of EUA price forecast and its main drivers is performed; Section 5 describes the regional power system development model for the analysis of renewable electricity development, taking into account the forecasts of EUA prices for 2021–2030; finally, in Section 6, the conclusions are outlined.

2. Literature Review

Though there are several studies dealing with GHG emission trading and its impacts, the empirical studies on EU ETS's impacts on the deployment of renewable energy remain limited [4–11].

The study by Yu et al. [8] used the cross-national panel of 60 countries during the 2002–2013 year period, to analyze the influence of EU ETS on the penetration of renewable energy sources. The main findings revealed that EU ETS has a positive impact on the increase of the share of renewables in total electricity production. The relation between EU ETS and renewable energy penetration was analyzed and it was discovered that the implementation of the scheme had the trend effect on the share of renewables in total electricity output. Therefore, the study found that EU ETS was successful in boosting renewable growth in EU to some extent.

Venman [13] employed the multi-criteria assessment method to evaluate EU ETS. The study found that despite over-allocation of permits during the first trading period, GHG emission abatement was in the range of −2.5% to −5%. The study [13] proved, however, that the GHG abatement target was likely to be below the efficient level, though it was grasped in quite a cost-effective way, even if free allocation provided for few distortional effects. Ellerman et al. [14] provided a comprehensive review of EU ETS during 10 years of operation and found that as phase III started in 2013, the price of EUA was less than EUR 5. In 2008, it was predicted that it will be less than EUR 30. The EUA price dynamics have generated a harsh debate around EU ETS and its future. These debates have reflected differing views of the objectives of climate policy and impacts of economic crisis on energy demand and EUA demand [15,16]. In 2012, the debates about EU ETS mainly concentrated on the following issues: back-loading, restructuring of scheme, and targets set for 2030 [17,18]. Villoria–Saez et al. [19] assessed the effectiveness of emission trading schemes across world regions and conducted an investigation of carbon emissions in relation to GHG emissions penalties in EU, US, Australia, Canada, China, and New Zeeland. The study analyzed the optimal penalty for emissions trading schemes and suggested changes in existing GHG schemes in order to enhance their effectiveness. Villoria–Saez et al. [19] noted that GHG emissions have decreased about 1.6% per year in investigated countries since GHG Trading Schemes employment. Other authors analyzed the interaction of EU ETS with other climate change mitigation policy schemes [20] like white certificates [21] and found that their interaction has a positive impact on GHG emissions reduction. White certificates are given to the producers whenever an amount of energy is saved and the producer can use the certificate for their own target compliance or can sell to (other) parties who cannot meet their targets. This scheme is analogous to the closely related concept of GHG trading. There are many studies dealing with the main drivers of EUA price and the impact of different EUA allocation methods on EUA price [22–27]. F. J. Convery in his study [22] analyzed the origins and development of EU ETS by providing a comprehensive review of the main drivers of EUA price by exploring the linkages among credits and energy sector assets, including electricity, oil, coal, and natural gas. These interactions were investigated by applying diverse statistical tools by analyzing the economic relationships, correlation, and cointegration of these variables. Hinterman [23] analyzed allowance price drivers in the first phase, and Anger et al. [24] defined the public interests groups having an impact on allowance allocation under EU ETS. Hepburn et al. [25] investigated the impact of auctioning of EU ETS phase II on the price of EUA. D. Demailly and P. Quirion [26] assessed GHG abatement, competitiveness and leakage under grandfathering versus output-based allocation and found the output allocation more favorable for GHG emission reduction. F. Alvarez and F. J. Andre [27] assessed the impact of auctioning versus grandfathering allocation of EUA on EUA price by defining the weakness of the grandfathering method for GHG emission restrains. Sartor et al. [28] analyzed the effectiveness of benchmark-based allocations in EU ETS third phase and also emphasized several weakness and limitations of the benchmark approach. The study [29] provided an in-depth analysis of the auctioning system in the EU ETS III phase by pointing out necessary improvements in the auctioning scheme. Fan et al. [30] analyzed policy adjustments in EU ETS Phase III and their effect on carbon prices. Other studies [31–34] also analyzed the price of EUA development during various phases of EU ETS by revealing the main determinants of EUA prices during different trading periods. Several studies [35,36] dealt with governance of EU ETS, monitoring and reporting issues under EU ETS.

3. The EU System of Trading in Carbon Dioxide Emission Allowances

Trading in carbon dioxide emissions is based on the provisions of the 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) and the annual climate conference of States Parties, the Conference of the Parties (COP) to the UNFCCC Framework Convention. The international treaty entered into force on 16 February 2005.

The CO_2 emissions trading system developed in the USA has become a model for the European Commission, which proposed the Directive 2003/87/EC based on it, introducing carbon trading in the Emission Trading Scheme (ETS) in the European Union. The European Union is the only group of countries in the world that have introduced a mandatory system of CO_2 emissions trading on such a large scale. According to UBS, the cost of ETS for the European economy has so far amounted to 287 billion dollars [36].

The European Emissions Trading Scheme (EU ETS) consists of incorporating the limit of cumulative emissions of certain greenhouse gases emitted by installations covered by the scheme, which after a certain period of time are lowered, which causes the accumulated emissions to fall. [37–44]. Enterprises within the set limit receive or buy emission allowances. As a result of receiving or buying emission allowances, enterprises can trade according to their needs. Limiting the total number of emission allowances available on the market forces companies to reduce their energy consumption. Each enterprise must annually allocate sufficient allowances to cover its total emissions. The result of no redemption of the number of allowances per enterprise is imposed high penalties. If the company reduces its emissions, it may retain additional allowances to meet its future needs or sell them to another company that has none. The trading system aims to reduce carbon dioxide emissions. The high prices of carbon dioxide emissions also make it worth investing in clean low-carbon technologies [45–67].

The EU Emissions Trading Scheme (EU ETS) was revised at the beginning of 2018 to enable the Union to achieve its 2030 emission reduction targets, including the year in which the ETS emissions should be 43% lower than in 2005 [38].

The changes mainly include:

- strengthening the role of the EU ETS as the driving force of investment by increasing the rate of annual reduction of entitlements to 2.2% in 2021 and strengthening the market stability reserve;
- continuing the allocation of free allowances as a safeguard for the competitiveness of the industrial sectors on the international market, while ensuring that the rules for determining the free allocation are targeted and take into account technological progress;
- supporting industry and the energy sector to enable them to meet the innovation and investment challenges associated with the transition to a low-carbon economy through various financing mechanisms for low-carbon technologies [3].

On 17 December 2018, the European Commission published a report on the functioning of the European CO_2 market in 2017. Emissions in 2017 EU ETS increased by 0.17% compared to 2016 (Table 1). The increase in emissions in 2017 was mainly caused by industrial sectors, while emissions in the energy sector decreased. Emissions from aviation are still growing. The increase was 4.5% compared to 2016. Over the past few years, the surplus of allowances in the EU ETS has been systematically decreasing and at the end of 2017 was 1.65 billion EUA allowances. The main reason for the drop in the surplus was primarily the introduction of the so-called back loading, or delayed sale at the auction of 900 million EUA allowances.

In the primary market, in the years 2013–2017, a total of 21.40 million EUA unused allowances were sold (Table 2). Romania (12.4 million) and Bulgaria (7.8 million) had the largest share in sales. A total of 120.719 million EUAs per Member State eligible for derogation remain to be used. The largest share in this number is Poland, which has 113.3 million, which in 2019 intends to sell about 55.8 million of this pool at auctions [39,40].

Table 1. Emissions in the EU ETS system in the period 2011–2017 (in million tonnes of CO_2 equivalent).

Year	2015	2016	2017
Verified emissions (total)	1803	1751	1754
Change compared to the previous year		−2.88%	0.17%
Verified emissions from the energy sector	1005	957	949
Change compared to the previous year		−4.78%	−0.84%
Verified emissions from the industry sector	798	794	805
Change compared to the previous year		−0.50%	1.39%
EU-28	2.2%	1.9%	2.4%

Source: Own elaboration based on [39–41].

Table 2. Purpose of unused entitlements from the derogation in 2013–2017.

Member Country	The Number of EUAs from 10c, which was Sold at Auctions (in Millions)	The Remaining unused Number of EUAs with 10c (in Millions)
Bulgaria	7.8	1.1
Cyprus	0.0	0.0
Czech Republic	0.2	0.2
Estonia	0.3	0.4
Hungary	0.0	0.9
Lithuania	0.7	0.4
Poland	0.0	113.3
Romania	12.4	4.4
Total	21.4	120.7

Source: Own elaboration based on [39–41].

Auctions of EUAs through the EEX platform, which are issued by 27 Member States, sold 89% of the auction pool available for 2017, and through the ICE exchange, this share was 11%. The total revenue of all Member States in 2017 amounted to approximately EUR 5.6 billion [42].

In 2018, EUA's allowances increased in value by approximately 203.64% (including the price difference from 29 December 2017 to 31 December 2018) and ended the year with EUR 24.64. The arithmetic average for EUA allowances in 2017 was EUR 15.88.

In 2018, a total of 231 auctions were conducted within the primary market, which sold nearly 932.988 million EUA allowances (Table 3). The weighted average auction settlement price was EUR 15.25. All EU Member States achieved revenues of nearly EUR 14.231 billion, which on average gave revenues of about EUR 61.606 million for the auction. A total of 21 participants applied for the auction [39,40].

The most effective country in terms of the obtained price of EUA allowances (15.91 euro) was Great Britain. The second place in this category was the Polish auction with the result of 15.5 euro/EUA.

Table 3. Summary of the EUA auction held in 2018.

Auctions	Number of Auctions Carried Out	Number of EUA or EUAA Allowances Sold	Average Participants	Revenues in [EUR]
POL (EUA)	23	78,030,000	25	1,209,978,210
EU-25 (EUA)	143	568,276,000	21	8,779,977,020
GER (EUA)	45	185,639,000	24	2,633,639,510
UK (EUA)	20	101,053,500	13	1,607,327,615
Together EUA	231	932,988,500	21	14,230,922,355

Source: Own elaboration based on [39–41].

4. Analysis of Price Forecasts of the Carbon Dioxide Market

Currently, the EU Emissions Trading System (EU ETS) as a key element of the implementation of the European Union policy objectives in the field of climate and energy policy objectives is mainly determined by market regulations. It is the formal and legal structure, in addition to the factors resulting from the market environment, that was the main creator of the increase in the prices of CO_2 emission allowances (EUA) in the analyzed period. The current price of EUA fluctuates around 22 EUR per EUA [41].

The main factors driving the price of CO_2 emission allowances (EUA) in the analyzed period were, among others [37,41]:

- debated and then adopted selected legislative proposals, proposed by two committees of the European Parliament: Committee on the Environment, Public Health and Food Safety (ENVI) and Committee on Industry, Research and Energy (ITRE) on the structure of the EU ETS system in 2021–2030.
- Adoption, despite the objections of Poland, Hungary, Cyprus, Croatia, Lithuania, Latvia, Italy, Romania, and Bulgaria, all proposals adopted in the European Parliament regarding the issue of ETS at the level of 43% were adopted, which is lower than in 2005 (Phase IV of the EU ETS).
- Publication of the European Commission information on the current volume of allowances available on the market, which shows that currently there are 1.59 billion excess allowances on the market.
- Against and not respecting the United States of the Paris Agreement.
- The prolonged period of high temperatures which resulted in an increase in the intensity of use of coal-fired power plants, and thus contributed to the increase in demand for EUA units, which directly translated into higher prices.
- in 2017, information appears that, despite "Brexit", the United Kingdom will remain a participant of the EU ETS at least until the end of 2020. This is a particularly important issue from the point of view of the functioning of the EU ETS. Initially, it was postulated that the British CO_2 emission allowances should be marked by the country of origin's signature, which was supposed to defend the system against the drop in prices caused by the sale of allowances owned by Great Britain.
- From 2018, a new MiFID 2 regulation package aimed at strengthening the markets of financial instruments became effective. It is worth noting that the CO_2 emission allowances at the beginning of the year became a financial instrument, which translated into an increase in the interest of the financial institutions in the market.
- In 2018, the Council of Europe approved the reform of the EU Emissions Trading Scheme (EU ETS) for the period falling after 2020. System reform is a clear step of the European Union towards achieving the objective of reducing greenhouse gas emissions.
- Agreement between the EFTA countries and the European Commission on the auctioning of carbon allowances in the years 2013–2018. The subject of the auction, which will be carried out in 2019, will be 42 million allowances.
- The opportunity for the UK to leave the EU ETS as Brexit.
- The adoption by the European Parliament in 2018 of a resolution on the implementation of the Paris Agreement, which emphasized the need to limit the temperature increase to 1.5 °C and raise the EU reduction target to 55% by 2030.

Analyzing the forecasts of carbon dioxide (EUA) pricing for five selected analytical companies in the years 2018–2021 (Table 4), we can see an increase in the average price to 23.17 and 25.16 EUR. It can be noticed that the current rate of increase in the prices of allowances results from the purchases for which financial institutions stand. It should also be remembered that the surplus of allowances on the market, from 2019 will be reduced annually.

Table 4. Current forecast of prices for EUA allowances for 2018–2021 by five selected institutions (in euros).

Institutions	2019	2020	2021
Energy Aspects	27.00	33.00	33.00
Refinitiv (Thomson Reuters)	20.00	20.00	20.00
Nomisma Energia	20.60	22.10	24.00
Engie Global Markets	22.75	24.10	20.25
Vertis	25.50	26.60	27.20
Average price	23.17	25.16	24.89

Source: [43].

The forecast of EUA prices presented in Table 5 by five institutions provides very similar results. The average price was applied to forecast the price of CO_2 emission allowances in 2021–2030. The forecast of EUA price is based on the Thomson Reuters model, which includes, among others, the adoption of the general GHG reduction target of 40% by 2030, the amendment of the EU ETS directive, and the share of installations from Great Britain in the EU ETS system also after 2020. (Table 5).

Table 5. Current forecast of prices of EUA allowances in 2021–2030 according to Thomson Reuters (nominal prices, real, in euro).

Forecast of EUA Prices											
Years	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2021–2030**
Nominal EUA price	23.7	23.7	23.3	22.8	22.2	21.7	20.9	22.1	23.8	26.2	23.04
Real EUA price	22.3	21.9	21.2	20.3	19.4	18.6	17.6	18.4	19.5	21.2	20.04

Source: Own study based on Ref. [43].

In the years 2021–2027, the prices will fall from 23.7 to 20.9. EUR. The reason for this condition may be most likely:

- reducing the demand for carbon dioxide emission allowances for electricity producers securing energy contracts under the so-called "Headging needs", in relation to the currently adopted strategy;
- from 2023, from 24% to 12%, the coefficient determining the number of allowances that will go to the "IAS intake rate" will be reduced;
- high prices of allowances at the end of the current accounting period will be an incentive to reduce emissions by changing fuel.

In the years 2028–2030, the price will increase from 22.1 to 26.2 EUR. It should be noted that the accumulated surplus of carbon allowances will run out at the end of the next period. In reserve, in 2030 there will be 600 million allowances EUA.

The low number of CO_2 emission allowances available after 2030 and the introduction of more ambitious climate targets after 2030 will force EU ETS participants to adhere to additional emission reductions and the additional purchase of allowances for stock in the period 2028–2030. This will contribute to the increase in prices of carbon dioxide emission allowances [44].

It should be noted that in the base scenario of the Thomson Reuters model, there is no guarantee that the assumptions made will not change. It may turn out that the European Union may introduce more ambitious climate goals that will translate into valuable carbon dioxide emission allowances. The pace of the RES implementation, the final shape of Brexit, and Germany's departure from coal is an uncertain factor in the baseline scenario of the Thomson Reuters model.

Each change in the assumptions in the adopted base scenario of the Thomson Reuters model will have a very significant impact on the projections of carbon prices in the future.

5. Construction of Regional Power System Development Model for Analysis of Renewable Electricity Development, Taking into Account the Forecasts of EUA Prices in 2021–2030

The article proposes an original model for the optimization of the regional power system development with penetration of renewable energy sources in the West Pomeranian Region, exploring various types of technologies that may appear in the system. With the help of the optimizing multi-criteria model, two scenarios optimizing the regional power sector development were presented [45,46]. The model includes forecasts of prices for EUA allowances in the years 2021–2030. The lexicographic method was used to search for compromise solutions.

As a research object, the West Pomeranian Region was chosen and the time range for empirical research was set for 2018–2030.

The West Pomeranian Region, which is the object of research, is particularly predestined for the production of renewable energy sources (RES), especially wind energy and energy from biomass. The area of the West Pomeranian Region is characterized by low stocking of animals and surpluses of unused agricultural biomass (hay and straw). The largest biomass boiler in the country is located in the studied area (Szczecin Power Plant). The boiler burns 80% of the forest biomass, that is branches, wood chips or sawdust; the remaining 20% is biomass of agricultural origin. The Szczecin power plant, due to the price of biomass, imports "green coal" from other regions of the world, without using the surplus of agricultural biomass located in the West Pomeranian Region [47].

Unfortunately, the administrative area of the West Pomeranian Region does not coincide with the power supply region. According to the statistics kept by the Energy Regulatory Office, the installed capacity of electricity as at 31 December 2017 in the West Pomeranian Region was 2778.8 MW, of which RES accounted for 825.107 MW. The total electricity production in the region was 8877.5 GWh, of which 7425.8 GWh was from conventional sources and 1451.7 GWh from renewable sources [47].

As a result of the functioning of the support system in Poland related to certificates of origin, the generator of electricity in a renewable energy source obtains two types of guaranteed revenues:

- revenues from the sale of property rights from certificates of origin and
- revenues from the sale of electricity.

Certificates of origin for RES are:

(a) Green certificates—the co-financing system for renewable sources producing electricity has been conditioned on the ability to obtain certificates of origin. Therefore, all types of renewable energy sources based on renewable primary fuels can benefit from the following type of support.
(b) Brown certificates—these are certificates that create a certificate of production and at the same time introduce biogas for distribution to the gas network.
(c) Yellow certificates—a co-financing system in the form of yellow certificates directed to entities producing electricity in high-efficiency cogeneration, in installations fired with gaseous fuels.
(d) Purple certificates—a co-financing system in the form of purple certificates directed to units fired with methane released and captured at underground mining works in active, liquidated or liquidated hard coal mines or gas obtained from biomass processing within the meaning of art. 2 para. 1 point 2 of the Act on bio components and liquid biofuels, regardless of the installed capacity of such units.

Depending on the technology of electricity production from renewable energy sources (RES), power plants will produce a different amount of power annually. This is due to the fact that especially power plants based on renewable energy sources rarely work with nominal power. Therefore, the model introduces a maximum power utilization factor to be able to compare individual technologies with each other [50–53]. Maximum power utilisation rates for specific power production plants are given in Table 6 [48].

Table 6. Maximum power utilization rate.

Power Plants	Installed Capacities	Units	Coefficient of Use Maximum Power
Theoretical maximum production for 1 MW of power plant	8.76	GWh	100.0%
Photovoltaic power plant	0.97	GWh	11.1%
Wind power plant good location	2.10	GWh	24.0%
Biomass power plant	2.19	GWh	25.0%
Hydroelectric power plant	2.7	GWh	30.8%
Biogas power plant	3.35	GWh	38.3%
Waste power station	2.75	GWh	31.5%
Coal power station	6.9	GWh	78.8%

Source: [48].

For the construction of optimization models, the values of technical and economic parameters were first calculated and the minimum or maximum levels of balance conditions (rather than by-side conditions) were established [49]. The model adopted 24 decision variables.

The following decision variables were introduced:

- x_1: production of conventional electricity (kWh)—electricity coming from fossil fuels (e.g., hard and brown coal, oil, natural gas);
- x_2: production of electricity from co-firing (kWh) electricity from the same generation unit, from the combustion of biomass or biogas with other fuels used to generate electricity;
- x_3: hydro power production (kWh) until 31 December 2018—electricity coming from an industrial plant, converting potential energy of water into electricity;
- x_4: production of hydropower (kWh) from 01 January 2018—energy coming from an industrial plant, converting potential energy of water into electricity;
- x_5: solar energy production (kWh)—power generated inside the Sun as a result of thermonuclear transformations, mainly the synthesis of hydrogen atoms;
- x_6: electricity production from household windmills (kWh)—electricity generated from a set of field devices used for generation and storage of electricity for the purposes of its use in one or several houses;
- x_7: production of electricity from wind farms (kWh) until 31 December 2018—energy defined as a generating unit or a set of these units using wind energy connected to the grid at one connection point for the production of electricity;
- x_8: new installation producing electricity from wind (kWh) from 1 January 2018—energy defined as a generating unit or a set of these units that use wind energy connected to the grid at one connection point to generate electricity;
- x_9: production of electricity from biogas (kWh)—electricity generated from gas obtained from biomass, in particular from installations for processing animal or vegetable waste, sewage treatment plants and landfills;
- x_{10}: energy from biogas in high-efficiency cogeneration with a total installed electric power of less than 1 MW in (kWh)—electricity generated from gas obtained from biomass, in particular from installations for processing animal or vegetable waste, sewage treatment plants and landfills;
- x_{11}: new installation producing electricity from biogas (kWh) from 01 January 2018—electricity generated from gas obtained from biomass, in particular from installations for treating animal or vegetable waste, sewage treatment plants and landfills;
- x_{12}: production of electricity from biofuels (kWh)—energy from biofuels obtained from raw materials derived from biological processes, possibly to be used in electrical power equipment;
- x_{13}: production of electricity from biomass combustion in existing boilers (kWh)—energy coming from plant or animal substances that are biodegradable, coming from products, waste and

residues from agricultural or forestry production, as well as the industry processing their products, and other parts of waste that are biodegradable;

- x_{14}: new installation producing electricity from biomass combustion in new boilers (kWh) from 01 January 2018—energy coming from substances of vegetable or animal origin that are biodegradable; coming from products, waste and residues from agricultural or forestry production as well as from the industry processing their products, and other parts of waste that are biodegradable;
- x_{15}: total electricity production (kWh)—total annual production of electricity from various energy sources;
- x_{16}: volume of raw materials for biomass burning—energy willow (kWh)—fast growing species with high biomass production potential, it is perfectly suited for energy use;
- x_{17}: size of crops for biomass burning—miscatus (kWh)—a plant that produces a large biomass increase in a relatively short time, suitable mainly for combustion;
- x_{18}: size of crops for biomass burning—poplar (kWh)—a species of tree belonging to the willow family, it is perfectly suited for energy use;
- x_{19}: volume of raw materials for biomass burning—sidaz (kWh)—perennial plant from North America, growing in the form of clumps composed of several stems with a diameter of up to 25–35 mm and a height of 3.0–3.5 m, suitable for energy use;
- x_{20}: volume of biomass raw material crops—topinambur (kWh)—perennial plant originating from North America; utility crop-dried stems with a diameter of 2–3 cm and a height of 2–3 m and a tuber, suitable for energy use;
- x_{21}: volume of raw material crops for biofuel combustion—oilseed rape (kWh);
- x_{22}: size of crops for biofuel raw materials—cereals (kWh);
- x_{23}: volume of raw material crops for biogas combustion—maize (kWh); and
- x_{24}: volume of raw material crops for biogas combustion—beets (kWh);

In the model, the purpose function consisted of production costs; costs of certificates; costs of EUA allowances; ecological costs for each type of energy (variables from x_1 to x_{14}); and loss of soil fertility due to their exploitation in the production of raw materials for biomass, biogas of biofuels and commodity production agricultural (variables from x_{16} to x_{24}).

The objective function (minimized) consisted of four components:

- costs related to production,
- costs related to certificates,
- costs of EUA allowances, and
- ecological costs due to loss of soil fertility.

In the optimization model, only one function (L (x)), which was a component of the above components, was minimized.

6. Discussion of Power Planning Scenario Development Results for West Pomeranian Region in 2021–2030

Two scenarios (for 2021 and 2030) were developed for the analysis of EUA price impact on the penetration of renewable energy sources in West Pomeranian region assuming different electricity production and EUA price forecasts. The West Pomeranian Region, which is the object of research, is particularly predestined for the production of renewable energy sources, especially wind energy and energy from biomass. The area of the West Pomeranian Region is characterized by low stocking of animals and surpluses of unused agricultural biomass (hay—straw). The largest biomass boiler in the country is located in the studied area (Szczecin Power Plant). The boiler burns 80% of the forest biomass, that is branches, wood chips or sawdust, the remaining 20% is biomass of agricultural origin. The Szczecin power plant, due to the price of biomass, imports “green coal” from other regions of the world, without using the surplus of agricultural biomass located in the West Pomeranian Region [49]. According to the statistics kept by the Energy Regulatory Office, the installed capacity of electricity as at 31 December 2017 in the West Pomeranian Region was 2778.8 MW, of which renewable energy sources accounted for 825,107 MW. The total energy production in the region was 8877.5 GWh, of which 7425.8 GWh was from conventional sources and 1451.7 GWh from renewable sources. The current energy mix of West Pomeranian region is presented in detail in reference [49].

In scenario I, it was assumed that according to the "Program for the development of the power sector in the West Pomeranian Region until 2015 with a prospect until 2030", the installed capacity of wind energy in 2015 will increase to 1000 MW, and small hydropower plants will grow by 1 MW. In this scenario, it was also assumed that the EUA allowance prices would be EUR 23.7 or 0.16 gr per kWh. Electricity production forecast in the West Pomeranian Region in 2021 according to scenario I is presented in Table 7.

Table 7. Electricity production forecast in the West Pomeranian Region in 2021 according scenario I.

Electricity Production in 2006 in the West Pomeranian Region [GWh]	Electricity Production in 2018 in the West Pomeranian Region [GWh]	Electricity Production in 2021 in the West Pomeranian Region [GWh]
7713.6	9333.45	8877.5

Source: Ref. [47].

Therefore, total power production in the region in 2021 will be 8877.5 GWh. Data from the statistical office shows that over the last 10 years (2009–2019), the production price of kWh of conventional electricity has increased by 100%. Based on the data from the static office, we can estimate the cost of production kWh of electricity in 2021, compared to 2019. This means an increase in the price of kWh of conventional power by 20% compared to 2019. Considering the costs of generating electricity, we can estimate the cost parameters. The appropriate cost factors for each type of energy are presented in Table 8.

Table 8. Cost factors for each type of energy source (in PLN/kWh) according to scenario I.

Types of Energy	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}
Costs of production	0.33	0.43	0.70	0.70	1.10	0.65	0.65	0.65	0.70	0.65	1.39	1.10	0.45	0.45
The cost of EUA	0.16	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
The cost of the certificate	0.01	0.01	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.2	0.12	0.12	0.20
Ecological costs	0.032	0.025	0.001	0.001	0.001	0.001	0.001	0.001	0.011	0.011	0.012	0.012	0.0004	0.0004
Total costs	0.46	0.56	0.57	0.57	0.98	0.53	0.53	0.45	0.57	0.52	1.18	0.97	0.33	0.25

Source: Own study based on the model.

The loss of soil fertility caused by the production of energy resources is presented in Table 9.

Table 9. Loss of soil fertility caused by the production of energy resources (in t/ha) according to scenario I.

Energy Resources	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}
Loss of soil fertility	1.4	1.4	1.4	1.4	1.4	0.53	0.53	1.15	1.15

Source: Own study based on the model.

The next parameters are the average costs of generating kWh of power from particular energy resources. They are presented in Table 10.

Table 10. Cost of power production from energy plants (in kWh / ha) according to scenario I.

Energy Resources	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}
Manufacturing cost	0.18	0.35	0.17	0.07	0.04	0.5	0.34	0.5	0.21

Source: Own study based on the model.

The purpose function of the decision model is as follows:

$$L(x) = 0.46x_1 + 0.56x_2 + 0.057x_3 + 0.57x_4 + 0.97x_5 + 0.52x_6 + 0.52x_7 + 0.44x_8 + 0.56x_9 + 0.51x_{10} + 1.17x_{11} + 0.96x_{12} + 0.32x_{13} + 0.24x_{14} + 1.4x_{16} + 1.4x_{17} + 1.4x_{18} + 1.4x_{19} + 1.4x_{20} + 0.53x_{21} + 0.53x_{22} + 1.15x_{23} + 1.15x_{24} \rightarrow \min \quad (1)$$

The side conditions are as follows:
Total power production:

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} = x_{15} \quad (2)$$

Electricity production for the region:

$$x_{15} = 8{,}877{,}500{,}000 \text{ kWh} \quad (3)$$

Renewable energy must account for 20% of the total electricity production:

$$x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} = 0.20x_{15} \quad (4)$$

Windmills must produce at least 1,452,858,000 kWh of electricity:

$$x_6 + x_7 + x_8 \geq 2{,}181{,}980{,}000 \text{ kWh} \quad (5)$$

Biogas combustion must produce at least 53,041,000 kWh of electricity:

$$x_9 + x_{10} \geq 53{,}041{,}000 \text{ kWh} \quad (6)$$

Biomass combustion must produce at least 416,515,000 kWh of electricity:

$$x_{13} + x_{14} \geq 416{,}515{,}000 \text{ kWh} \quad (7)$$

Electricity production from biogas combustion:

$$x_9 + x_{10} = 105{,}000x_{23} + 36{,}000x_{24} \quad (8)$$

Production of electricity from biofuel combustion:

$$x_{11} + x_{12} = 10{,}500x_{21} + 15{,}000x_{22} \quad (9)$$

Electricity production from biomass burning:

$$x_{13} + x_{14} = 47{,}226x_{16} + 39{,}197x_{17} + 47{,}226x_{18} + 39197x_{19} + 47{,}462x_{20} \quad (10)$$

Production of conventional electricity:

$$x_1 = 0 \text{ kWh} \quad (11)$$

Maximum energy production from co-firing:

$$x_2 \leq 7{,}274{,}158{,}000 \text{ kWh} \quad (12)$$

Production of hydropower:

$$x_3 \geq 61{,}798{,}000 \text{ kWh} \quad (13)$$

Production of new hydropower:

$$x_4 \geq 1 \text{ million kWh} \quad (14)$$

Minimum solar production:

$$x_5 \geq 34{,}803{,}000 \text{ kWh} \quad (15)$$

The boundary conditions assume that all variables must be non-negative. Optimizing the model with this objective function mentioned above provides for the solutions given in Table 11.

Table 11. Results of scenario I run for 2021.

Types of Energy	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
Electricity production (GWh)	0	3769.0	44.2	0.7	41.6	0	1071.7	316.4	25.2	13.9	0	0	173.2	3421.6	8877.5
Energy, raw materials	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}						
Crop size (t/ha)	0	0	0	0	0	0	0	0.042	0						

Source: Own study based on the model.

Analyzing the above data, it can be seen that the total power production in 2021 will amount to 8877.5 GWh (i.e., we assume demand in the region), of which 3769.04 GWh is electricity production from co-firing, 44.2 GWh is hydropower created in hydropower plants created for on 31 December 2018, and 0.7 GWh is electricity produced in new hydropower plants. It is foreseen to produce 41.6 gigawatt hours by solar in old installations, 1071.7 GWh is wind electricity created in wind farms, 25.2 GWh were generated by installations producing electricity from agricultural biogas, and 13.9 GWh is power generated from biogas installations with sewage treatment plant and landfill biogas. In addition, (3594.7 GWh of electricity has been produced in existing biomass-burning boilers. The average construction cost of 1 MW of electricity generation capacity will amount to PLN 5455.979. Analyzing the obtained structure of soil fertility, it is stated that the loss of soil fertility will amount to 0.059 t/ha.

In scenario II, it was assumed that according to the "Program for the development of the power sector in the West Pomeranian Region until 2015 with a prospect until 2030", in 2030 the installed capacity of wind energy will increase to 1500 MW. It is assumed to increase the use of biomass in municipal waste and increase the capacity of biogas installations at wastewater treatment plants by 1 MW. It is also assumed to increase the production of agricultural biogas by 50% and install photovoltaic cells at the level of 1 MW. In the forecasted period, production and demand for electricity in 2030, compared to 2006, will increase by approx. 55% (Table 12). The cost of EUA allowances in 2030 will be EUR 26.20 or 0.18 PLN per kWh.

Table 12. Electricity production forecast in the West Pomeranian Region in 2030 according to scenario II.

Electricity Production in 2006 in the West Pomeranian Region [GWh]	Electricity Production in 2030 in the West Pomeranian Region [GWh]
7713.60	11,956.08

Source: [47].

In Table 13, the increase of new installed renewable energy capacity in the West Pomeranian Region in 2012–2030 is provided.

Table 13. Increase of new installed renewable electricity capacities in the West Pomeranian Region in 2012–2030 according scenario II.

The Type of Renewable Electricity	Installed Power Capacities on 31.12. 2012 in [MW]	The Amount of Installed Power as of 31.11. 2030 in [MW]	Increase in New Capacity in Relation to the Previous Period [MW]	Production of New Power in the Period [GWh]
Wind farms	726.429	1500	773.571	1547.142
Installations producing power from biogas from wastewater treatment	1.478	2.478	1.0	5.5
Plants installations producing power from agricultural	3.913	5.869	1.956	10.758
Biogas installations generating electricity from solar energy	3.867	4.867	1.0	9.0

Source: Ref. [47].

In scenario II, the production cost of a kWh of electricity in 2030 was assumed in relation to 2019. This means an increase in the price of a kWh of conventional electricity by 160% in relation to 2019. Considering the costs of generating electricity, we can estimate the cost parameters. The appropriate cost factors for each type of energy source are presented in Table 14.

Table 14. Cost factors for each type of energy source (in PLN/kWh) according to scenario II.

Types of Energy	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}
Costs of production	0.33	0.43	0.70	0.7	1.10	0.65	0.65	0.65	0.70	0.65	1.39	1.10	0.45	0.45
The cost of the certificate	0.0039	0.0039	0.1239	0.1239	0.1239	0.1239	0.1239	0.2012	0.1239	0.1239	0.2012	0.1239	0.1239	0.2012
Ecological costs	0.032	0.025	0.005	0.005	0.001	0.001	0.001	0.001	0.011	0.011	0.012	0.012	0.0004	0.0004
The cost of EUA	0.18	0.18	0	0	0	0	0	0	0	0	0	0	0	0
Total costs	0.48	0.58	0.58	0.58	0.98	0.53	0.53	0.45	0.55	0.52	1.18	0.98	0.38	0.28

Source: Own study for the needs of the model.

In this scenario, it was assumed that the remaining parameters of the model will be the same as in Scenario I.

The purpose function of the decision model is as follows:

$$\begin{gathered} L(x) = 0.48x_1 + 0.58x_2 + 0.57x_3 + 0.57x_4 + 0.97x_5 + 0.52x_6 + 0.52x_7 + 0.44x_8 + 0.56x_9 \\ + 0.51x_{10} + 1.17x_{11} + 0.96x_{12} + 0.32x_{13} + 0.24x_{14} + 1.4x_{16} + 1.4x_{17} + 1.4x_{18} + 1.4x_{19} + 1.4x_{20} \\ + 0.53x_{21} + 0.53x_{22} + 1.15x_{23} + 1.15x_{24} \to \min \end{gathered} \tag{16}$$

The side conditions are as follows:

The boundary conditions assume that all variables must be non-negative.

Total energy production:

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} = x_{15} \tag{17}$$

Electricity production for the region:

$$x_{15} \geq 11{,}956{,}080{,}000 \text{ kWh} \quad (18)$$

Renewable energy must represent 30% of the total electricity production:

$$x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} = 0.30\, x_{15} \quad (19)$$

Windmills must produce at least 3,011,640,000 kWh of energy:

$$x_6 + x_7 + x_8 \geq 3{,}011{,}640{,}000 \text{ kWh} \quad (20)$$

Biogas combustion must produce at least 60,850,000 kWh of electricity:

$$x_9 + x_{10} \geq 60{,}850{,}000 \text{ kWh} \quad (21)$$

Biomass combustion must produce at least 416,515,000 kWh of electricity:

$$x_{13} + x_{14} \geq 416{,}515{,}000 \text{ kWh} \quad (22)$$

Power production from biogas combustion:

$$x_9 + x_{10} = 105{,}000x_{23} + 36{,}000x_{24} \quad (23)$$

Production of electricity from biofuel combustion:

$$x_{11} + x_{12} = 10{,}500x_{21} + 15{,}000x_{22} \quad (24)$$

Electricity production from biomass burning:

$$x_{13} + x_{14} = 47{,}226x_{16} + 39{,}197x_{17} + 47{,}226x_{18} + 39{,}197x_{19}\ 47{,}462x_{20} \quad (25)$$

Maximum production of conventional electricity:

$$x_1 = 0 \text{ kWh} \quad (26)$$

Maximum electricity production from co-firing:

$$x_2 \leq 8{,}174{,}880{,}000 \text{ kWh} \quad (27)$$

Production of hydropower:

$$x_3 = 61.798 \text{ GWh} \quad (28)$$

Production of new hydropower:

$$x_4 \geq 0 \text{ kWh} \quad (29)$$

Minimal solar electricity production:

$$x_5 \geq 43{,}803{,}000 \text{ kWh} \quad (30)$$

Optimizing the model with this objective function gives the solutions for Scenario II in West-Pomeranian region presented in Table 15.

Table 15. Results of scenario II run for 2030.

Types of Energy Sources	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
Electricity roduction	0	8074.3	61.79	0	43.9	0	1564.5	1717.9	39.3	21.5	16.2	0	416.5	0	11,956.1
Energy raw materials	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}						
Crop size	0	0	0	0	0	0	0	0.0423	0						

Source: Own study for the needs of the model.

Analyzing the above data, it can be seen that the total electricity production in 2030 will be 11,956.1 GWh (i.e., we assume demand in the region), of which 8074.39 GWh is the electricity production from co-firing and 61.79 GWh is the hydropower created in hydroelectric plants created by 31.12.2018. It is foreseen that 34.8 GWh will be generated in solar installations up to 2018, and 9.13 GWh is electricity produced after 2018. One thousand five hundred and sixty four point seven gigawatt hours (1564.7 GWh) is wind-power created in wind farms created until 31 December 2018, and 1717.99 GWh is produced electricity in new wind farms established until the end of 2030. There are 60.85 GWh of installations producing electricity from agricultural biogas, and 16.25 GWh is new power generated from biogas installations in sewage treatment plants and landfill biogas; 416.55 GWh of electricity were generated in existing biomass burning boilers. The average construction cost of 1 MW of electricity will amount to PLN 9122.015. Analyzing the obtained structure of soil fertility, it is stated that the loss of soil fertility will amount to 0.059 t/ha.

In the West Pomeranian region, currently the main energy supplier is coal power. The constructed biomass power plant in Szczecin uses local energy resources to a small extent, increasing the risk of growing biomass from wasteland and permanent herbage. The increase in CO_2 emission allowances will cause the structure of the energy mix to look completely different. The burden of CO_2 on coal-fired power plants may put the profitability of renewable energy in a different light.

Therefore, the results of two regional power sector development scenarios run for 2021 and 2030 indicate the change in the structure of renewables in West-Pomeranian region. In addition, the increase of EUA price (from EUR 23.7 to 26.20 euros) has a significant impact on increase of the costs of electricity production and increase of unit cost of installed 1 GWh (by 70%). The forecasted EUA price in 2031 lower by 3% has an impact on the increased share of electricity produced by co-firing biomass with other fossil fuels. According to scenario I, the total electricity production in 2021 will amount to 8877.5 GWh of which about 60% will be produced by renewable electricity sources and the rest 42% from co-firing biomass with other fuels (3769 GWh). The 40% or 3594.7 GWh of electricity produced in 2021 will come existing biomass burning boilers. Hydropower plants will produce 0.5% or 44.9 GWh, solar installations will produce also 0.5% or 41.6 GWh; and wind farms 12.1% or 1071.7 GWh. The agricultural biomass will contribute to 0.3% or 25.2 GWh and biogas installations will produce 0.2% or 13.9 GWh. The average construction cost of 1 MW of electricity will amount to PLN 5455.979.

According scenario II, the total electricity production in 2030 will be 11,956.1 GWh. The share of co-firing biomass with other fuels will increase to 67% (8074.3 GWh), and the share of renewables will reduce to 30%. The 3.4% of electricity or 416.5 GWh of electricity were generated in existing biomass burning boilers. Hydropower plants will produce 0.5% or 61.79 GWh, solar installations will produce 0.3% or 34.8 GWh, and wind mills 15% or 1564.5 GWh. The agricultural biogas will contribute to 0.5% or 60.8 GWh and other biogas installations will produce 0.1% or 16.25 GWh. The average construction cost of 1 MW of electricity will amount to PLN 9122.015. The loss of soil fertility will amount to 0.059 t/ha for both scenarios.

The results of scenarios run for renewable electricity development in West-Pomeranian region by analyzing the impact of forecasted EUA price for 2021–2030 can be applied for the preparation of regional power sector development programs and assessment of costs for achieving deep decarbonisation in the region. Therefore, the forecast of EUA estimates for 2021–2030 allows to have more viable representation of renewable electricity development and costs associated with this development for selected regions within the EU.

7. Conclusions

According to the European Commission, the oversupply of carbon dioxide emission allowances at the market ranges from 1.5 to 1.7 billion, causing a market imbalance [54,56,57,66]. Reforms launched by the European Union are aimed at achieving the expected reduction of the surplus of carbon allowances available at the market. At present, 31 countries (28 EU countries and Iceland, Liechtenstein and Norway) are participating in the EU ETS; their total demand for carbon dioxide emissions is about 1.5 billion Mg/CO_2. At present, it should be underlined that in the European Union, there is a claim that the prices for carbon dioxide emission allowances, at the levels observed in the recent years, are too low [55,64,68].

Current low prices for carbon dioxide emission rights do not encourage the reduction of greenhouse gas emissions and fast penetration of renewables. The launch of the IAS mechanism in 2019 may bring measurable benefits in the form of a significant increase in the prices for carbon dioxide emission allowances and will have a positive impact on the penetration of renewables as well.

The assessment of the forecasted EUA price impact on the penetration of renewable energy sources and associated costs with this penetration in the selected West-Pomeranian region of Poland demonstrates the significant impact of EUA price on the structure of electricity generation in the region in question.

Results of two regional power sector development scenarios run for 2021 and 2030 indicate the change in the structure of renewables in West-Pomeranian region. The increase of EUA price (from EUR 23.7 to EUR 26.20) has a significant impact on the increase of costs for electricity production and increase of unit cost of the installed 1 GWh (by 70%). The forecasted EUA price in 2030, being lower by 3% as compared to 2021, has its impact on the increased share of electricity produced by co-firing biomass with other fossil fuels—from 42% to 68% in electricity generation structure, or 26%.

Our results that include several scenarios for the renewable energy development in West Pomeranian can be applied for the preparation of regional energy development programs and assessment of costs for achieving deep decarbonisation in the region as forecasted EUA prices for 2021–2030 allow to have more reliable representation of the renewable energy sector development paths and costs associated with this development for the selected regions within the EU.

More reliable paths for renewable energy development can be proposed based on the results of the scenarios run as policy makers of the regional level, which can develop more realistic regional energy plans and allocate investments in renewables taking into account the EU support from structural funds and other policy measures promoting renewable energy sources (e.g., green certificates, feed-in prices for renewables etc.). Other policy measures supporting renewables can also be integrated in the proposed model.

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