Modelling the mid-term development of the energy system in Poland with the use of TIMES-PL model

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Abstract

The paper presents the results of the mid-term modelling of the development of the energy system in Poland. In particular, the impact of prices of CO_2 emission allowances (EUA) on the change in the structure of generating capacity and production is analysed. Two decarbonisation scenarios are built based on the EU Energy Roadmap 2050. The first one, Diversified Supply Technologies (DST) assumes that no technology is preferred and all energy sources can compete on a market basis with no specific support measures. The second scenario, NO_NUC_CCS is similar to the Diversified Supply Technologies but assumes lack of public acceptance for both: nuclear and Carbon Capture and Storage (CCS) technologies.
The main analytical tool used in the analysis is the TIMES model generator. The analysis is carried out with the use of TIMES-PL model for the period 2008 to 2035 with five-year time steps. The structure of the Reference Energy System and main modelling assumptions are presented. The latter include: (i) prices and potentials of primary energy sources, (ii) prices of CO_2 emission allowances, (iii) the demand for electricity and (iv) the technical and economic parameters of energy technologies. The results show significant changes in the structure of the fuel and technology mix by the year 2035 caused by the decarbonisation policy. Nuclear power plants and lignite-fired power plants equipped with CCS technology dominate in the DST scenario whereas renewables and gas-fired power plants in NO_NUC_CCS scenario.

Keywords: Modelling, energy system, TIMES-PL, CO_2 emission reduction

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1. Introduction

The Polish energy sector is at crossroads. On one hand it has to meet the growing demand while most of the centralized heat and electricity production fleets have to be retrofitted. On the other hand, global and EU regulations to mitigate climate change have to be obeyed. There is lack of general consensus on what would be the best mix of fuels and energy generation technologies in Poland in the coming decades. Some experts and policy makers consider the domestic coal as the best fuel for the future, arguing that it guaranties Poland's energy security. Others favour nuclear energy and/or switching from coal to natural gas, which would, however, have to be mainly imported from abroad. Some put main emphasis on promotion of renewables and energy efficiency as clean an inexhaustible energy sources. There is also an emerging issue of exploitation of newly discovered gas shale reserves. This ongoing debate on the Polish energy policy should be supported by analytical tools that are capable to thoroughly analyse this multidimensional problem of security of fuel supply, environmental impacts, national competitiveness and social concerns [1].

2. Goal and scope of the research

The main objective of the research is to identify possible changes in the future fuel and technological mix used for power generation in Poland. The impact of the CO_2 emission allowances prices [2] on emissions reduction is examined. It is also analysed how the lack of social acceptance for nuclear and carbon capture and storage technologies will affect the results. The analysis is carried out with the use of TIMES model generator for the period 2008–2035 with five-year time steps.

3. Methodology

The main analytical tool used in the work is the TIMES model generator. TIMES (The Integrated MARKAL – EFOM System, hereinafter referred to as model) is developed by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). TIMES has been applied in several projects as a tool for the analysis of energy systems at different spatial scales (from local to global) and temporal. This, together with the well-described and verified methodology is certainly his great advantage [3]. It is a bottom–up, demand driven and technology oriented model generator in which energy economy is made up of producers and consumers of commodities such as energy carriers, materials, energy services and emissions. TIMES assumes perfect foresight and competitive markets for all commodities. It finds the optimal solution that maximizes the net total surplus (i.e. the sum of producer and consumer surplus) in order to satisfy the energy services, by simultaneously making decisions on equipment investment and operation, primary energy supply and energy commodities trade. TIMES is built based on a dynamic linear programming. The model allows for flexible division of the year into periods of time. It is also possible to take into account various constraints such as environmental, resource, technical and political.

4. Description of the model used

The model of the Polish energy system, TIMES-PL, is used in this work. This model has been developed with the use of TIMES model generator by the AGH group since the beginning of 2010. The present version of TIMES-PL model consists of: a subsystem of centralized electricity and heat generation and a subsystem covering space heating in the residential sector with the use of individual heating technologies. The simplified structure of the subsystem of centralized electricity and heat generation (only existing objects are displayed) is presented in Fig. 1. The structure consists of: technologies (representing energy processes) and goods (raw materials, energy carriers, pollutants, etc.). The important features are balances of goods that are generated for the system built and calibrated for the baseline year 2008 [4].

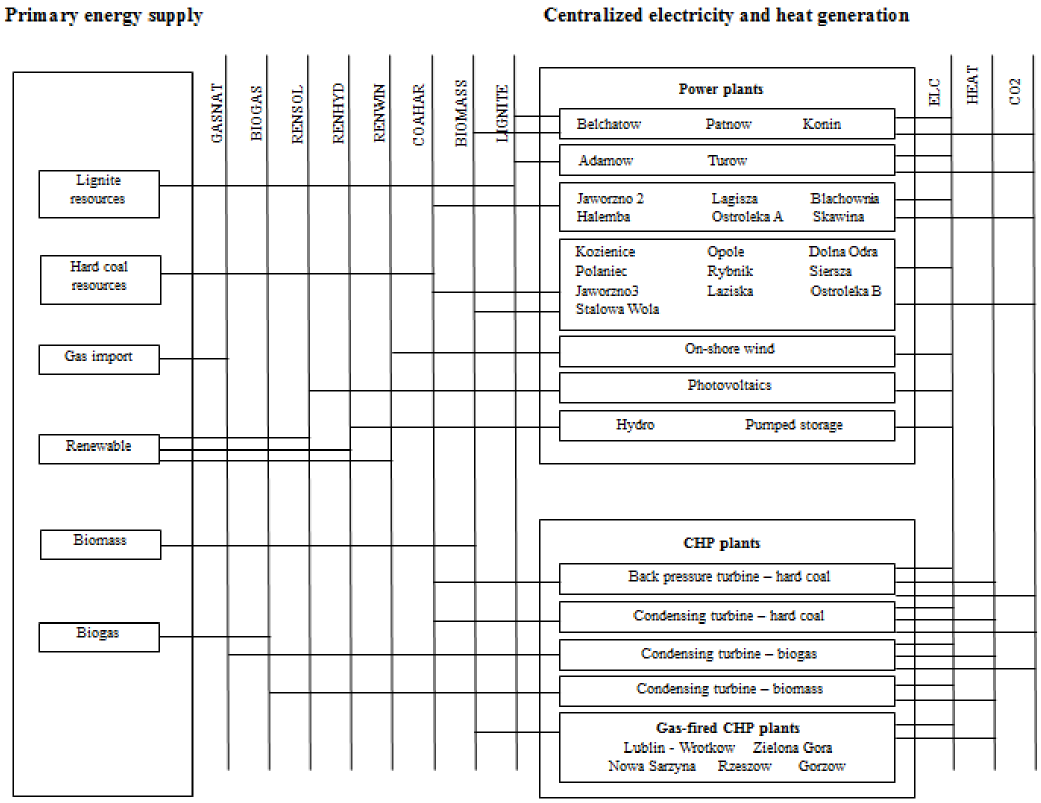


Fig. 1. Model of the subsystem of centralized electricity and heat generation.

The current version of the subsystem of centralized electricity and heat generation includes all existing thermal power plants. These are mainly hard and brown coal-fired power plants. In some of them coal is co-fired with biomass. Each of power plants is represented individually. Natural gas-fired CHP plants are also represented individually. The rest of existing CHP plants are aggregated into several categories according to the type of fuel used and installed turbine (i.e. back pressure or condensing) [5]. Besides fossil technologies also those based on renewable energy sources such as on-shore wind, photovoltaic, and hydro power units are taken into consideration. Moreover, the model takes into account the planned decommissioning of existing capacities as well as planned investments e.g. new units in Patnow, Lagisza and Belchatow. The model can also apply new energy technologies such as e.g. nuclear, CCGT or IGCC. All the technologies included in the model are characterized by various technological and economic parameters.

5. Assumptions

a) Forecast of prices and potentials of primary energy sources

Fuel prices have a large impact on the competitiveness of technologies of electricity and heat generation. The current analysis assumes that the price of hard coal, crude oil and natural gas will be at the same level to those presented in the document [2]. It is expected that the prices of crude oil and natural gas will increase in 2035 to 12.3 and 9.1 EUR'08/GJ, respectively. Prices of brown coal and uranium are taken from [6]. The rest of fuel prices including biomass are based on the information contained in [2, 7]. The projected fuel prices used in the current work are presented in Table 1.

Table 1. Forecast of fuel prices expressed in price of energy content of fuels [EUR’08/GJ].

Fuel/year	2008	2010	2015	2020	2025	2030	2035
Crude oil	10.9	9.5	9.0	9.8	11.3	11.8	12.3
Natural gas	7.1	5.9	5.5	6.9	8.2	8.6	9.1
Hard coal	3.3	2.6	2.8	3.2	3.7	3.7	3.9
Brown coal	1.6	1.6	1.6	1.6	2.4	2.4	2.4
Uranium	0.68	0.68	0.68	0.74	0.74	0.8	0.8
Biomass	7.0	7.0	7.0	7.0	7.0	7.0	7.0

Sources: [2,6,7].

The present analysis assumes that the supply of hard coal will be reduced from around 82 Mt in 2008 to approximately 50 Mt in 2035. The supply of domestic brown coal is limited to 69 Mt in 2035. These assumptions are based on [8] and [9] for hard and brown coal, respectively. The potential of renewable energy sources is adapted based on the document [10] prepared at the request of the Polish Ministry of Economy. There is no constraint on import of natural gas and crude oil. Due to large uncertainties related to the potential of shale gas in Poland and to the costs of its extraction the current analysis does not include the possibility of using this fuel in the modelling period considered.

b) Forecast of price of CO_2 emission allowances under the EU ETS

The price of CO_2 emission allowances under the EU ETS is based on the forecast resulting from the scenario Diversified Supply Technologies included in the EU Energy Roadmap 2050 (DST EU Roadmap). This projection is presented in Table 2.

Table 2. Forecast of CO_2 emission allowances under the EU ETS [EUR’08/t_{CO2}].

Scenario	2010	2015	2020	2025	2030	2035
DST EU Roadmap	10.0	17.5	25.0	38.5	52.0	73.5

Source: Own elaboration based on [2].

c) Forecast of electricity demand

The current analysis assumes that the final demand for electricity in 2035 will increase by approximately 40% compared to the electricity demand in 2008 reaching the level of 164 TWh. This modest increase is mainly due to the relatively low rate of economic development, actions aimed at improving energy efficiency of final energy consumers as well as the decreasing share of energy-intensive industries. The data on forecasts of electricity demand are prepared based on [11, 12]. It is also assumed that the net electricity import will increase in the whole modelling horizon, reaching in 2035 the value of 35 TWh as presented in Table 3 [12]. The annual demand for electricity in each modelling year is distributed into time slices based on [13].

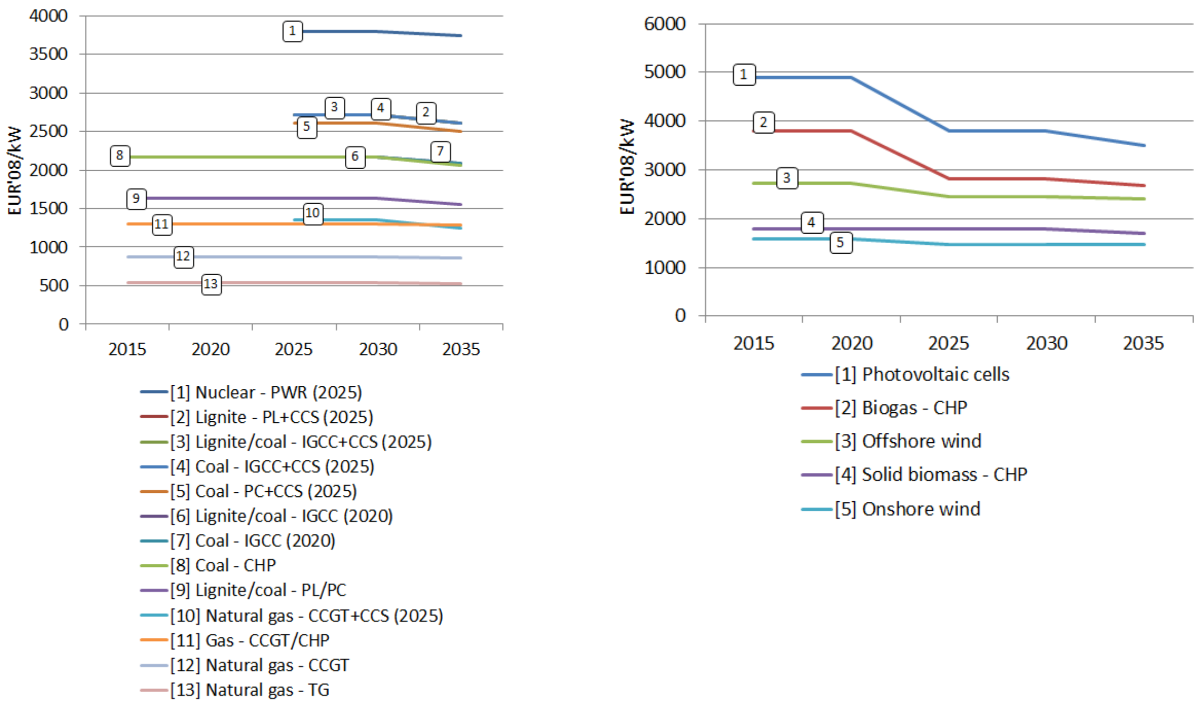
Table 3. Final electricity demand and net electricity import [TWh].

Item	2008	2010	2015	2020	2025	2030	2035
Final electricity demand	117.6	119.5	129.4	139.4	151.9	161.0	163.7
Conversion sector	9.9	9.9	10.2	10.6	11.1	11.7	9.1
Line losses	12.5	12.5	12.9	13.0	13.4	14.2	13.1
Net import	0.0	0.0	2.0	13.0	22.5	35.0	35.0

Source: Own elaboration based on [11, 12].

d) Technical and economic parameters of new energy technologies

Technical and economic parameters of energy technologies are ones of the most important factors determining the structure of generating capacity and electricity production. Among these parameters are mainly unit investment costs, operating and maintenance costs (fixed & variable), efficiency and economic lifetime of technology. Unit investment costs for new energy technologies are presented in Fig. 2. These numbers are taken from [6] and cover the period up to 2030. After this period they follow a similar trend to this shown in [2]. Discount rate of 8% is used. The analysis is carried out for the period 2008 – 2035 with five year time steps.



Source: Own elaboration based on [2, 6].

Fig. 2. Unit investment costs of new energy technologies.

6. Scenarios

Two decarbonisation scenarios are considered, i.e. Diversified Supply Technologies (DST) and No Acceptance for Nuclear and Carbon Capture and Storage technologies (NO_NUC_CCS).

a. DST scenario assumes that no technology is preferred and all energy sources can compete on a market basis with no specific support measures. There is an assumption of the public acceptance for the use of nuclear power to meet energy needs. The first block of the nuclear power plant with an electric capacity of 1.6 GWe in Poland may start operation in 2025. However, next nuclear power plants may be put into operation in five-year intervals. It is assumed that in each five-year period after 2025 the maximum value of electric capacity which can be installed in the nuclear power plants cannot exceed 1.6 GWe. This scenario also enables installation of carbon capture and storage technologies. The first CCS installations can be run in 2025. Based on the study on geological storage of CO_2 in deep geological structures in Poland presented in [14] it is assumed that the total captured gas can be stored.

b. NO_NUC_CCS scenario – this scenario is similar to DST but assumes lack of public acceptance for both: nuclear and carbon capture and storage technologies. All other energy technologies compete in the market without any specific support measures. It assumes that in each five-year period, the maximum electric capacity of wind turbines installed on land cannot exceed the value of 5 GWe.

In both analysed scenarios there is no limit on CO_2 emissions.

7. Results

The results of the study for both energy scenarios are presented in Figs. 3-5.

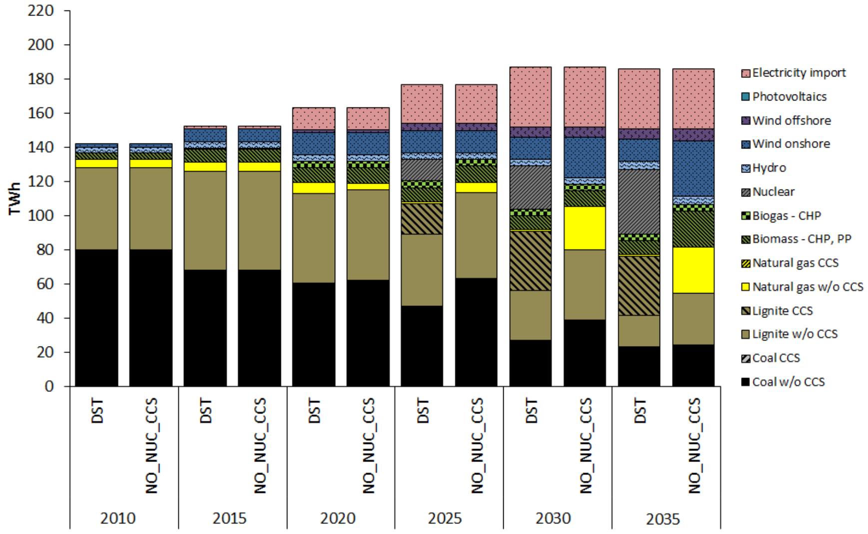


Fig. 3. The structure of the net electricity generation [TWh] split into technologies and fuels.

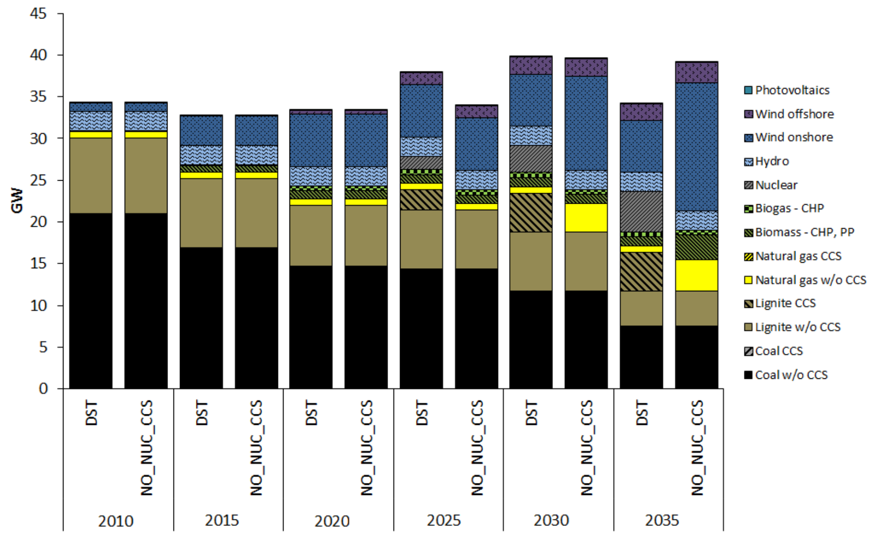


Fig. 4. The structure of the electric capacity generation [GW] split into technologies and fuels.

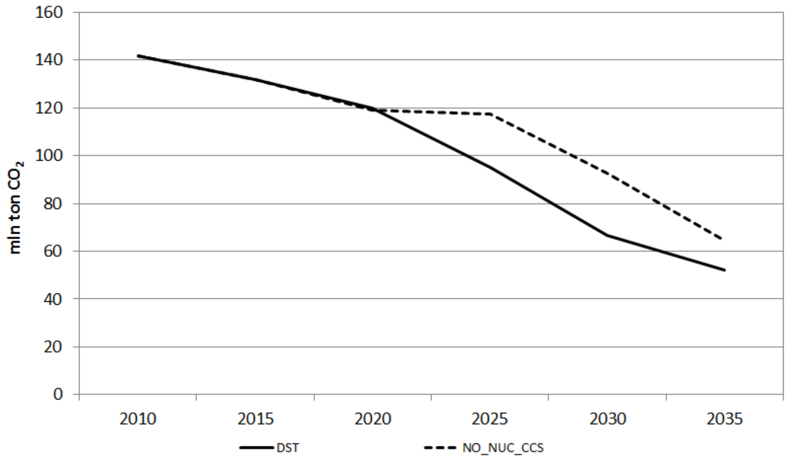


Fig. 5. CO_2 emissions for both scenarios [Mt].

8. Conclusions

The paper presents the approach in which system method was used to provide information on the future fuel and technology mix in Poland. The analysis was conducted for two scenarios and shows how scenario assumptions affect the structure of generating capacity and electricity production as well as reduction of CO_2. The results of the analysis lead to the conclusion that the assumed fuel prices and increase in prices of CO_2 emission allowances caused by EU's decarbonisation policy will have a significant impact on changes in the future structure of the Polish power system. These changes deepen with the increase of the EUA price. Depending on the analysed scenario it means: (i) the wide use of nuclear and lignite-fired power plants equipped with CCS installations in case of DST scenario and (ii) renewables together with gas-fired power plants in case of NO_NUC_CCS scenario. In fact, under given constraints DST scenario maximises the use of nuclear power plants. In case of conventional power plants, only electricity production in lignite-fired power plants is maintained or even increases after 2025 with the introduction of CCS technology. Electricity generation in hard coal power plants decreases in both scenarios, however, in case of DST this decrease is more visible. In case of renewable energy sources most investments are made in onshore wind and biomass-fired CHP plants. It should be noted, that the achievement of a significant reduction in CO_2 emissions from the national power system is achieved by 2035 in each of the analysed scenarios. However, the larger CO_2 emissions reduction is observed in DST. Further works will be focused on the analysis of the sensitivity of modelling results to changes in the technical and economic parameters of new energy technologies. Special attention will be paid to nuclear power plants.

Acknowledgments

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