Impacts of the implementation of European Union policy Emission Trading System on Polish power sector

Morgane THOMAS, Artur WYRWA

This article aims at analyzing the aftermaths of the implementation of the EU ETS system on Polish power sector. The main factors taken into account are the auctioning of CO_2 allowances and the effectuation of quotas about electricity generated from renewable energy sources. In order to model the Polish power sector and to study its evolution, the modeling system for mathematical programming and optimization GAMS was used. Results show that green technologies are widely developed with the implementation of CO_2 non free allowances. The implementation of European Union policy ETS is going to change deeply Polish power sector since the study shows that nuclear technology should be developed to provide the main part of electricity generation. The mix of green and nuclear technologies could enable to cut CO_2 emissions efficiently, reducing the high share of coal electricity generation.

Keywords: Emission Trading System, renewable energy, CO_2 emissions, modeling, Poland, power sector.

I. INTRODUCTION: EUROPEAN UNION ENERGY POLICY

The European Union is unquestionably a leader regarding efforts to mitigate climate change. Kyoto expectations are nowadays on the way of being implemented thanks to the European Climate Change Program (ECCP) which aim is to cut climate emissions. To reach this goal, EU wants to develop and increase the use of renewable energy sources. Consequently important investments on green technologies are currently done, in order to reduce greenhouse gas emissions and to reach the "20-20-20" target (20% decrease of greenhouse gas emissions, 20% of energy consumption from renewable sources, 20% decrease of primary energy use) by year 2020.

To make this goal easier to reach, the European Climate Change Program implemented a new policy called Emission Trading System (ETS). The EU ETS covers nowadays about 11 000 power stations in 30 countries. Based on a cap and trade principle, it aims at limiting the total European greenhouse gas emissions. This system is implemented in three stages:

- 1st stage: 2005-2007
  During this first stage, each country belonging to the European program had to prepare and publish a National Allocation Plan aiming at evaluating the amount of CO_2 emission allowances needed by each company.

- 2nd stage: 2008-2012
  The second stage was used to implement the system of free allowances and to publish another National Allocation Plan to assess the system efficiency.

- 3rd stage: 2013-2020
  During the last stage, contrary to the previous stages, greenhouse gas emissions are not considered independently but in a whole European way. Indeed, an EU-wide cap of emissions, instead of National Allocation Plans, is implemented. Decreasing by 1.74% per year, its goal is to globally reduce European emissions. From this moment, CO_2 allowances

are not free anymore and are reduced over time, which leads to start CO_2 allowances auctioning.

This policy could seem binding and even economically non sustainable for countries which electricity is essentially based on coal, regarding the substantial increase of production cost due to CO_2 allowances. Companies could then be tempted to relocate their production in countries outside the EU in order not to pay CO_2 allowances. To avoid this carbon leakage, a limited number of free allowances for a transitional period are granted. In addition, to promote electricity production from renewable energy sources, green certificates were implemented.

The aim of this study was to analyze the influence of European Union energy policy on Polish energy sector. For this purpose, software GAMS was used. It enabled to study under scrutiny the evolution of electricity production, greenhouse gas emissions and MWh generation cost according to different energy policy scenarios.

This article is organized as follows: a brief presentation of power sector in Poland is provided in section II. Then section III deals with the methodology used for this analysis. It is followed in section IV by the explanation of scenarios under study which lead to an analysis of the results presented in section V. Finally, section VI draws the major conclusions from this study.

II. POWER SECTOR IN POLAND

Poland is a country essentially based on coal regarding electricity production: ca. 95% of electricity generation is from hard and brown coal. Moreover, Poland is one of the main producers of coal in Europe, which has a major influence on Polish economy.

Polish electricity demand is about to increase substantially (by 2.8% between 2011 and 2020). To feed this demand and to fulfill EU renewable energy quotas, new facilities have to be built. However, since Poland electricity is essentially generated by coal, the implementation of green technologies seems to be more difficult. This is why a limited number of free allowances for a transitional period are granted.

III. METHODOLOGY

A. GAMS model

The aim of this study was to analyze the influence of the implementation of European ETS system on Poland energy sector. For this study, software GAMS (General Algebraic Modeling System) was used. This tool is a modeling system for mathematical programming and optimization, with which the user has to develop his own problem modeling, meaning implementing his own data, parameters and equations.

The developed program is a linear model, which means without nonlinear terms or discrete variables such as binary or integer variables, based on a goal function and on constraints. To solve the model optimizing the goal function and satisfying all model requests and constraints, decision variables are created. In this study, the goal function is the minimization of total costs. This objective function is modeled by the sum of different types of costs generated by electricity production which are discounted according to user base year and discount rate:

Equation 1: Goal function

$$Total\_cost = Tc = \sum_{y \in [2006;2030]} Disc(r,y). \begin{pmatrix} construction\_cost(y) + fixed\_cost(y) \\ + variable\_cost(y) + fuel\_cost(y) \\ + CO2\_cost(y) \end{pmatrix}$$

with

y: year belonging to the modeling period
r: discount rate
Disc(r,y): discount factor

$$Disc(r,y) = \frac{1}{(1+r)^{ord(y)-1}}$$

ord(y): ordinal number of year y in modeling period

Costs are discounted in order to take into account the inflation effect on money devaluation (indeed, 1000 EUR in 2010 will not have the same value as 1000 EUR in 2020, consequently this fact is considered in the model). **[1]**

B. Modeling approach of the study

1) Parameters

For this study, GAMS was used to model technology development of Polish energy system with the aim of determining its optimal configuration, depending on different EU emission policy scenarios. The analysis is run on a 25 years modeling period, from 2006 (considered as the base year) to 2030 and considers different plant technologies and types of fuel.

Table 1: Possible combinations of fuel and technology

Technology	Fuel
Pulverized Fuel	Hard coal
	Brown coal
Coal Fluidized Bed	Hard coal
	Brown coal
Combined Heat and Power	Hard coal
Power Plant	Gas
	Oil
	Wind
	Hydro
	Biomass
	Nuclear

For each plant technology, reliable data were collected to characterize the facility, such as efficiency, lifetime, emission factor or types of costs generated by electricity production. **[2] & [3]** According to the goal function defined above, the model takes into account unit cost (or investment cost) representing the costs generated by the construction of one unit of capacity (these costs are split all along plant lifetime), fixed and variable costs about operating and maintenance. Costs linked with fuel consumption or greenhouse gas emissions are also considered but they vary according to the energy market or the different EU policy scenarios.

Table 2: Characteristics of plants **[4]**

Technology	Lifetime	Investment cost [M€ per GWe]*	Fixed O&M cost [M€ per GWe]**	Variable O&M cost [M€ per GJe]***
Pulverized coal	30	921	13	0,128
Coal: atmospheric fluidized bed	30	997	19	0,128
Combined heat and power	30	900	10	0,128
Gas steam	30	399	5	0,055
Oil steam	30	798	5	0,347
Nuclear: advanced light water reactor	40	2345	36	0,16
Biomass: direct combustion	30	1359	31	0,971
Wind: centralized	20	773	13	0,069
Hydro: dam	200	1269	8	0,347

Costs were converted from USD to EUR using the conversion factor 1.4 $/ €

* base year monetary units per unit of capacity (M€ /GWe)

** base year monetary units per unit of installed capacity (M€ /GWe)

*** base year monetary units per unit of activity (M€ /GJe)

2) Equations and constraints

Using these different parameters and decision variables, equations are developed to calculate electricity and heat production, costs, fuel consumption and greenhouse gas emissions generated by electricity production. These equations, useful to optimize the goal function, are regulated by different constraints.

Electricity and heat demand: For each year of the modeling period, electricity production is calculated according to final electricity consumption and different losses in the process of electricity production and transportation.

Equation 2: Electricity demand

$$Demand(y) = \frac{Final\_consumption(y)}{1 - \frac{Transmission\_losses(y) + Plant\_requirement(y) + Net\_export(y)}{100}}$$

with

y : year belonging to the modeling period

$Final\_consumption(y)$ [TWh per year]

$Transmission\_losses(y)$ [%]

$Plant\_requirement(y)$ [%]

$Net\_export(y)$ [%]

Thus, gross electricity production is defined as below:

<u>Equation 3</u>: *Electricity production*

$$elec\_prod(y) = \sum_p \sum_f \begin{pmatrix} ex\_cap(p,f,y) * load\_factor(p,f,y) \\ + x(p,f,y) * load\_factor(p,f,y) \\ + \sum_{i<y} x(p,f,i) * load\_factor(p,f,i) \end{pmatrix} \geq Demand(y)$$

with

y : year belonging to the modeling period

p : power plant technology

f : fuel

i : year $\in$ [2006 ; y[

$elec\_prod(y)$: electricity production of year y [TWh]

$ex\_cap(p,f,y)$: remaining of existing capacity (capacity before 2006) [GWe]

$x(p,f,y)$: new capacity added to the system in year y [Gwe]

$load\_factor(p,f,y)$: hours of plant operation per year [h]

In addition, renewable energy sources production has to fulfill annual EU quotas globally increasing during the modeling period. This constraint has an important influence on new capacity implementation.
Concerning heat demand, the 2006 level is the same for the entire modeling period.

<u>Technology and capacity constraints</u>: In order to meet electricity demand, the model is able to make a choice between keeping exploiting existing capacity or reducing it and building new plants, regarding the most cost-efficient option. Nevertheless, this choice is essentially made by the assumptions of the scenario under study.
In addition, another constraint in the model is about nuclear technology: regarding the current development of this technology in Poland, nuclear plant implementation is not possible before year 2020.
Besides, analyzed costs about each technology do not take into account decommissioning costs (except for nuclear technology) nor Carbon Capture and Storage technology (CCS).

<u>Fuel constraint</u>: Even if available hard and brown coal potential in Poland is assumed to be enough, other sources such as gas are constrained by an upper limit on imports. In addition, natural constraints are potential limits for renewable energy sources.

<u>Equation 4</u>: *Fuel balance*

$$\left(\sum_p \frac{3.6 * elec\_prod(p,f,y)}{el\_efficiency(f,p)} + \sum_p \frac{h\_prod(p,f,y)}{th\_efficiency(f,p)} \right) \leq potential(f,y)$$

with

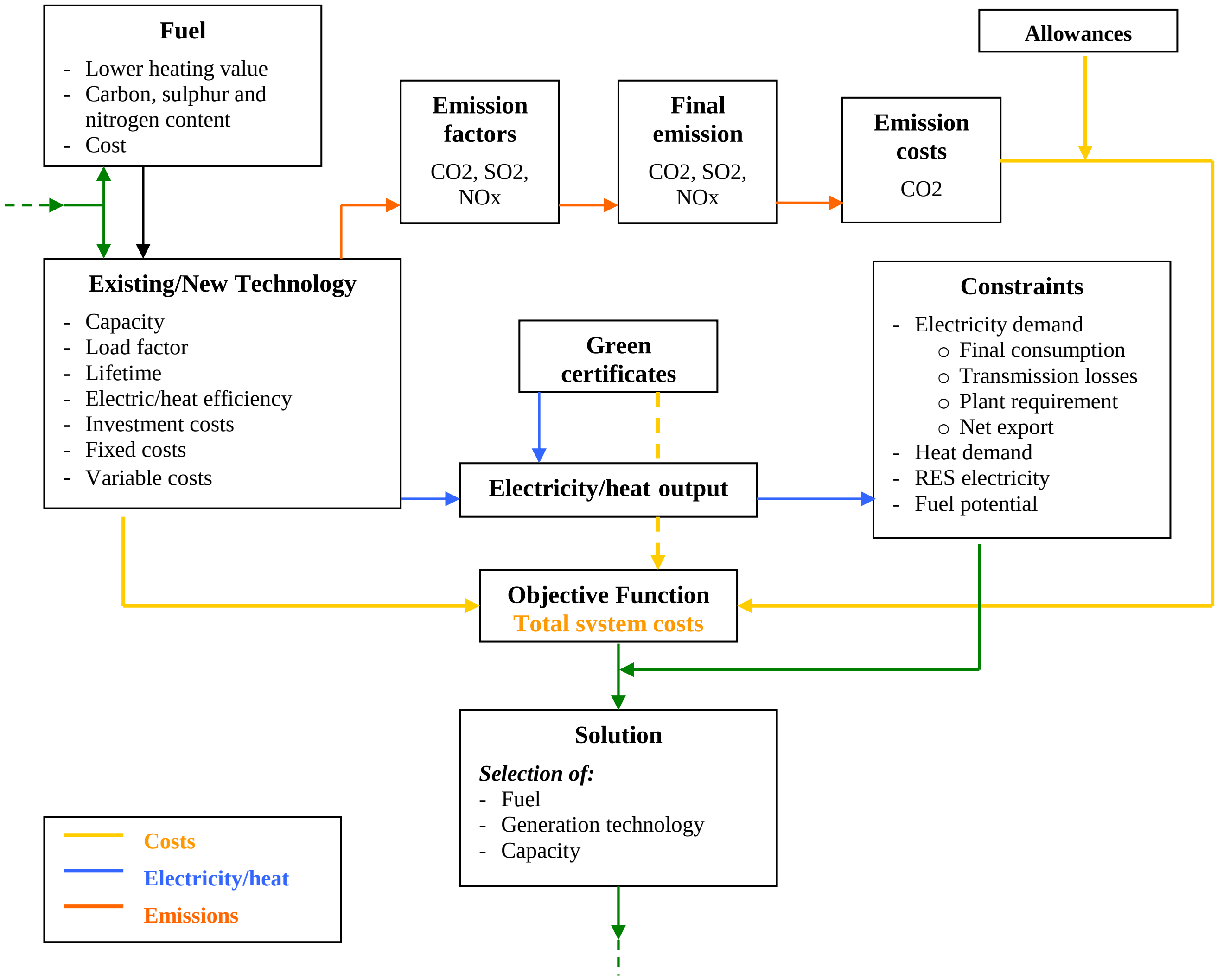
y : year belonging to the modeling period

p : power plant technology
f : fuel
$elec\_prod(y)$: electricity production of (p,f) combination for year y [TWh]
$h\_prod(y)$: heat production of (p,f) combination for year y [PJ]
$el\_efficiency(f,p)$: electrical efficiency of (f,p) combination
$th\_efficiency(f,p)$: thermal efficiency of (f,p) combination
$potential(f,y)$: upper limit for f consumption for year y

Discount rate: A discount rate of 10% is used for this analysis.

In order to visualize interactions between the different inputs, the model structure is presented below:

Figure 1: Model structure



IV. SCENARIOS

Two scenarios were defined to analyze the consequences of implementing EU ETS on Polish energy sector.

First scenario, called Reference Scenario (Ref_Sc), assumes that even after 2012, 100% of CO_2 allowances will be granted for free. There is no emission cap but quotas about electricity production from renewable sources must be provided. Nevertheless, no financial help to support renewable energy development is taken into account.

Second scenario is called CO_2 Scenario (CO2_Sc) and takes into account the price of allowances (20 € per ton between 2013 and 2020 and 50 € per ton then). To balance this substantial increase of production cost due to CO_2 allowances and to promote the use of renewable energy sources, Poland chose to implement the RPS/TGC strategy (Renewable Portfolio Standard/Tradable Green Certificates) **[5]**. To make renewable energy competitive facing cheaper fossil fuel energy sources, green certificates are granted (70 € per MWh produced from renewable sources). However, simulations are run without green certificates in order to visualize the real costs of the evolution of Polish power sector.

V. RESULTS ANALYSIS

Aiming at analyzing the influence of RPS system on Poland energy sector, the study focuses on the evolution of electricity generation, fuel consumption, gas emissions, cost distribution and the evolution of MWh generation cost.

A. *Electricity generation*

1) *Reference Scenario*

In this scenario, total installed capacity increases from 29 GWe in 2006 to 33 GWe in 2030. The details of this evolution are presented below:

Table 3: Ref_Sc Generation capacity [GWe]

Technology	Fuel	2006	2010	2015	2020	2025	2030
PF	HC	12,73	11,34	11,315	10,891	9,77	9,325
PF	BC	4,91	4,91	4,91	4,91	4,91	4,91
CFB	HC	0,81	0	0	0	0	0
CFB	BC	2,11	2,11	2,11	2,11	2,11	2,11
CHP	HC	6,944	6,944	6,944	6,944	6,944	6,944
PP	WIND	1,483	3,426	3,703	5,681	8,418	8,418
PP	HYDRO	0	0,74	1,19	1,19	1,19	1,19
SUM		**28,987**	**29,47**	**30,172**	**31,726**	**33,342**	**32,897**

The most striking result of the Reference Scenario is the constant importance of coal in electricity generation. With 97.8% of production in 2006, electricity generation from coal remains the highest share of total production (84.8% in 2030), except for hard coal which use decreases by 21.5%, and particularly for hard coal used with pulverized fuel technology (decrease of 26.8%). But this decrease is only due to quotas about renewable energy sources production (a simulation run without RES quotas shows that no investment in green technologies would be made). Thus, instead of keeping exploiting hard coal plants, small share of wind and hydro plants are developed.

Figure 2: Ref_Sc Distribution of electricity production [%]

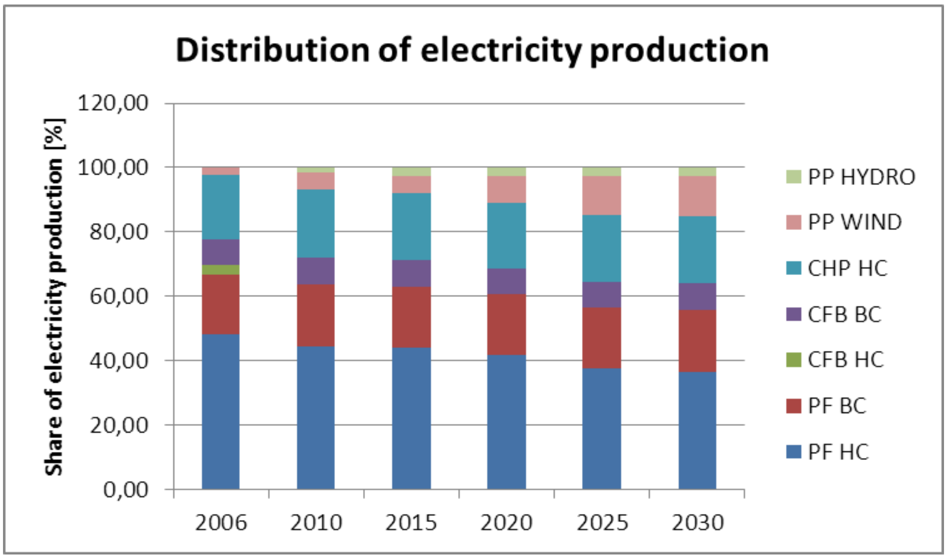
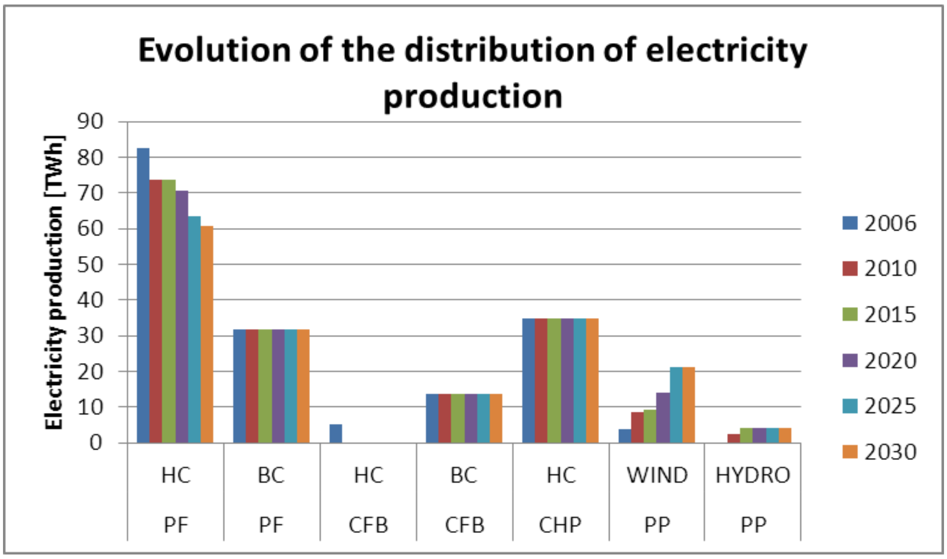


Figure 3 highlights the evolution of electricity production and the minor proportion of green production. With less than 11% in 2020, renewable energy sources production hardly increases until 15.2% in 2030.

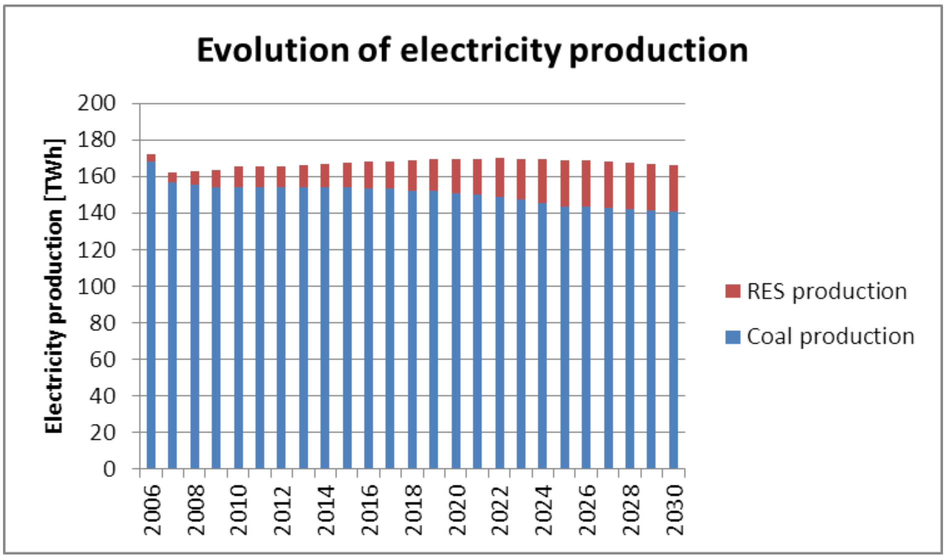
Figure 3: Ref_Sc Evolution of electricity production [TWh]



In addition, *Figure 4* presents the evolution of total electricity production. The peak in 2006 is certainly the result of the fact that existing plants are enough to provide necessary electricity. However, according to renewable energy sources quotas and the constraint about closing existing plants progressively, there is consequently a slight overproduction in 2006.

Then, electricity production is firstly rising according to electricity demand but from 2022, production is slowly decreasing whereas final consumption keeps growing. In fact, this decrease of production is linked with technology improvement which progressively limits losses in electricity generation process.

Figure 4: Ref_Sc Electricity production [TWh]



2) CO2 Scenario

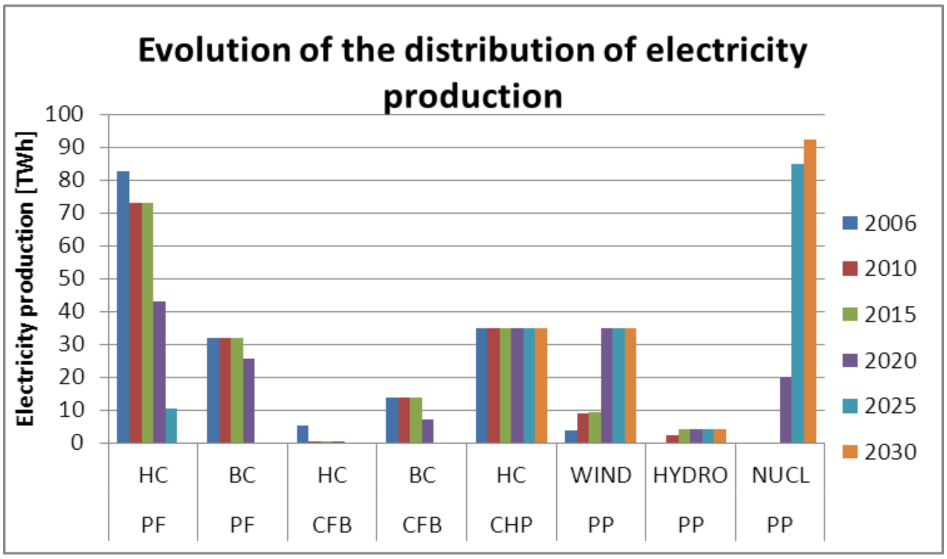
In this scenario, installed capacity remains stable all along modeling period. From 2006, maximal needed capacity is reached as shown in *Table 4*.

Table 4: CO2_Sc Generation capacity [GWe]

Technology	Fuel	2006	2010	2015	2020	2025	2030
PF	HC	12,73	11,243	11,243	6,593	1,593	0
PF	BC	4,91	4,91	4,91	3,91	0	0
CFB	HC	0,81	0,039	0,039	0,039	0	0
CFB	BC	2,11	2,11	2,11	1,11	0	0
CHP	HC	6,944	6,944	6,944	6,944	6,944	6,944
PP	WIND	1,483	3,576	3,789	14	14	14
PP	HYDRO	0	0,633	1,19	1,19	1,19	1,19
PP	NUCLEAR	0	0	0	3,059	13,05	14,198
SUM		**28,987**	**29,455**	**30,225**	**36,845**	**36,777**	**36,332**

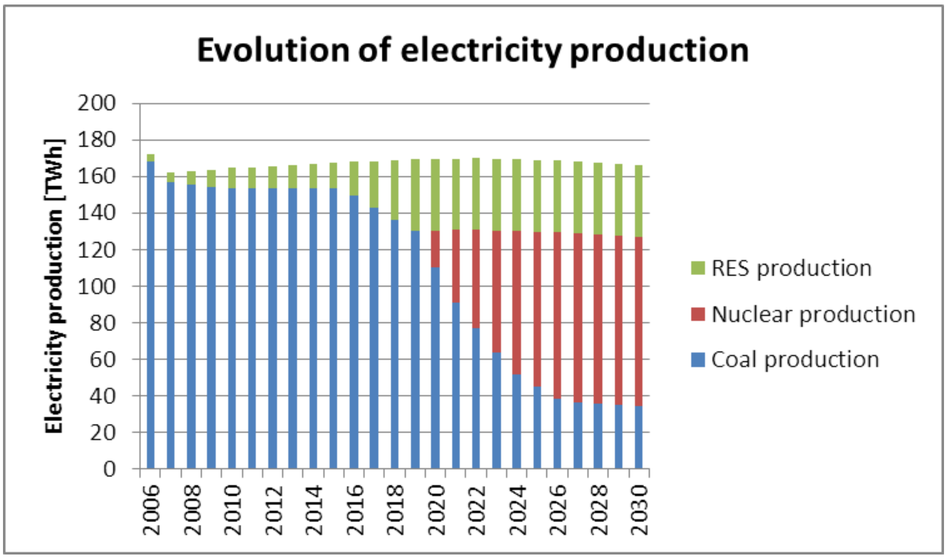
This overproduction from the beginning of the modeling period enables to close progressively existing plants in order to replace them by new technologies. Since CO_2 emissions are taxed in this simulation, renewable energy sources production are extremely developed while coal plants are closed.

Figure 5: CO2_Sc Evolution of electricity production [TWh]



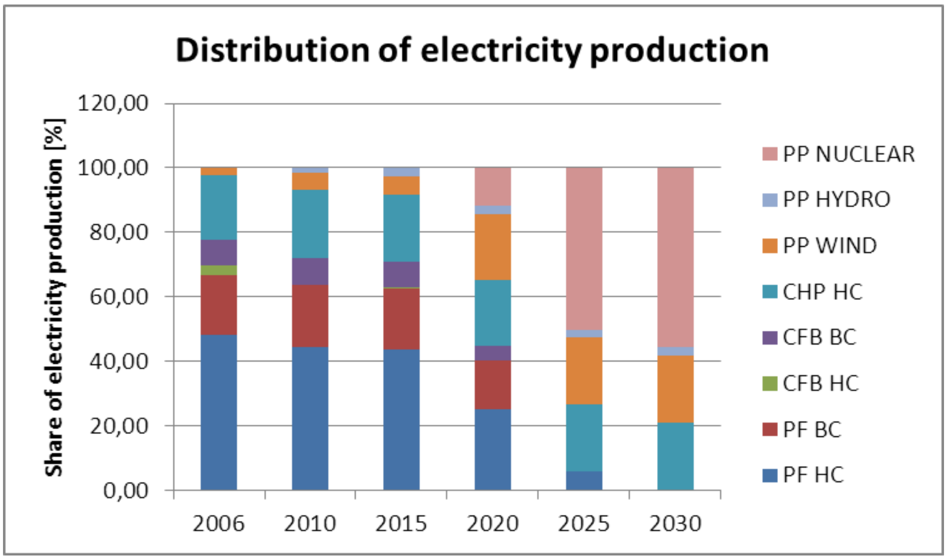
As shown in *Figure 5*, the closing of coal plants is very quick except for Combined Heat and Power plants which are needed to meet heat demand. Indeed, electricity from coal which was 97.8% of electricity generation in 2006 represents only 20.9% of electricity production in 2030. At the same time, proportion of green electricity is increasingly growing from 2.2% of electricity production in 2006 to 23.6% in 2030, with a 23.1% level in 2020 which reaches EU goals of "20-20-20" target.

Figure 6: CO2_Sc Electricity production [TWh]



In addition, wind and hydro technologies are so developed that their maximal potential is quickly reached (from 2015 for hydro and 2020 for wind). In order to provide the rest of the electricity demand, nuclear plants are built. These technologies are used instead of new coal technologies because even if major improvements have been done to limit emissions in new coal plants, CO_2 allowances remain very expensive. Since nuclear technologies do not produce greenhouse gases, they seem more interesting regarding cost-efficiency.

Figure 7: CO2_Sc Distribution of electricity production [%]



Furthermore, the development of nuclear plants is quite impressive since a 14 GWe capacity is built for only ten years. In 2030, nuclear technology provides 55.5% of electricity demand.

B. Fuel consumption and Emissions

1) Reference Scenario

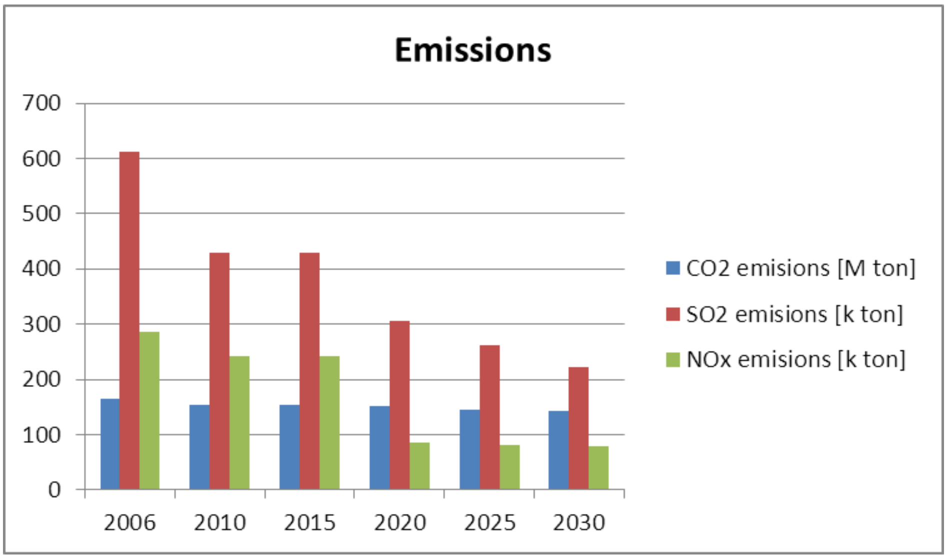
In the Reference Scenario coal remains the main fuel to produce electricity. As it provides 98% of electricity generation, coal represents 99% of total fuel consumption in 2006. This consumption decreases regularly during the modeling period (8.3% between 2006 and 2030) because of the improvement of technology efficiency and loss cutting.

Table 5: Ref_Sc Energy needs [PJ]

Fuel	2006	2010	2015	2020	2025	2030
HC	1320,75	1206,35	1205,07	1183	1124,69	1101,58
BC	365,04	365,04	365,04	365,04	365,04	365,04
GAS	0	0	0	0	0	0
OIL	0	0	0	0	0	0
WIND	13,35	30,83	33,33	51,13	75,76	75,76
HYDRO	0	9,32	15	15	15	15
BIOMASS	0	0	0	0	0	0
NUCLEAR	0	0	0	0	0	0
SUM	**1699,14**	**1611,54**	**1618,44**	**1614,17**	**1580,49**	**1557,38**

As a consequence, greenhouse gas emissions remain high. Indeed, existing capacity plants are mainly fueled with hard or brown coal and do not reach nowadays standards about greenhouse gas emissions. Nevertheless, a gentle decrease is observed for CO_2 emissions which are reduced from 164 Mton in 2006 to 143 Mton in 2030 (12.5% decrease). This level is still very high and the decrease by 8% in 2020 is far from reaching the 20% target set by EU. However SO2 and NOx emissions are cut more efficiently because existing plant level of emission is gradually improved all along modeling period.

Figure 8: Ref_Sc Gas emissions



2) CO2 Scenario

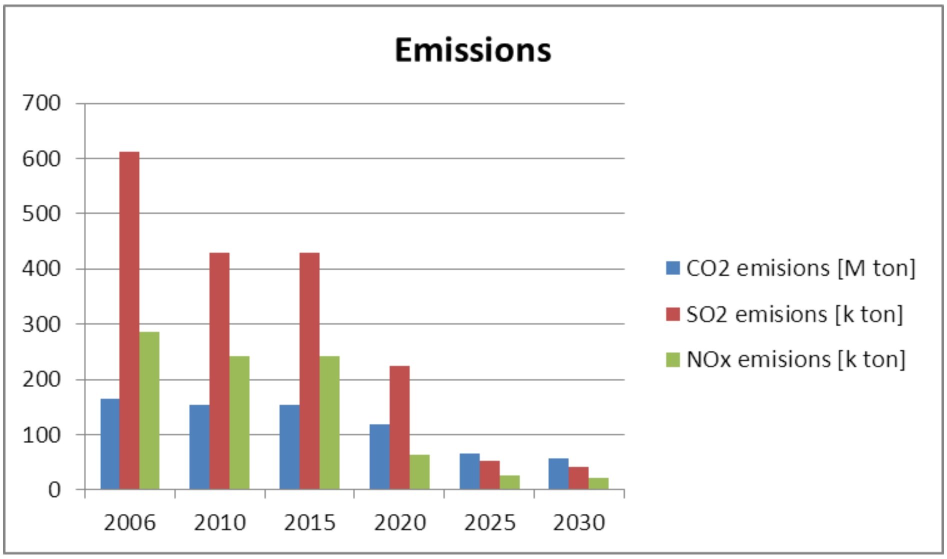
In this scenario, electricity generation from coal decreases from 97.8% in 2006 to 20.9% in 2030. This fact explains the cut of coal consumption during modeling period (from 99% in 2006 to 36.7% in 2030). Moreover, total fuel consumption is first decreasing between 2006 and 2020 by 8% because of the improvement of existing technologies and the building of green technology plants which efficiency is higher than plants fueled with coal. However, general fuel consumption increases then because of nuclear plant construction which efficiency is lower than coal and green plants.

Table 6: CO2_Sc Fuel consumption [PJ]

Fuel	2006	2010	2015	2020	2025	2030
HC	1320,75	1203,35	1203,35	961,56	699,51	616,67
BC	365,04	365,04	365,04	261,04	0	0
GAS	0	0	0	0	0	0
OIL	0	0	0	0	0	0
WIND	13,35	32,18	34,1	126	126	126
HYDRO	0	7,97	15	15	15	15
BIOMASS	0	0	0	0	0	0
NUCLEAR	0	0	0	198,82	908,42	922,89
SUM	**1699,14**	**1608,54**	**1617,49**	**1562,42**	**1748,93**	**1680,56**

Furthermore, with a highly emission-taxing scenario, existing plants are quickly closed in favored of environment-friendlier technologies. This is why CO_2 emissions are cut by 27.5% between 2006 and 2020 and by 64.8% all along modeling period. In addition, SO2 and NOx emissions are also cut drastically thanks to emission improvement and closing of existing plants which were the most polluting.

Figure 9: CO2_Sc Gas emissions

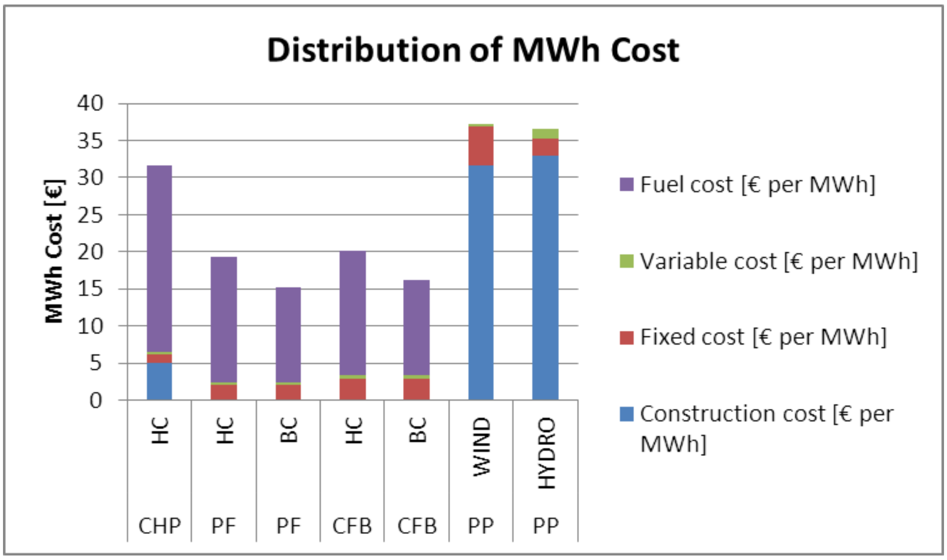


C. Cost of electricity generation

1) Reference Scenario

The total costs generated by this scenario come to 42 832 M€. This amount is essentially used to maintain existing capacity and particularly to feed them with fuel. Fuel costs represent 80.8% of total costs whereas costs for construction of new plants in order to meet RES quotas only reach 8.9% (these costs are the second higher amount). This is reflected in the MWh cost. As *Figure 10* shows it, the main part of MWh cost for coal technologies is the cost of fuel while construction costs are the most important for green technologies.

Figure 10: Ref_Sc Distribution of electricity generation costs [€]



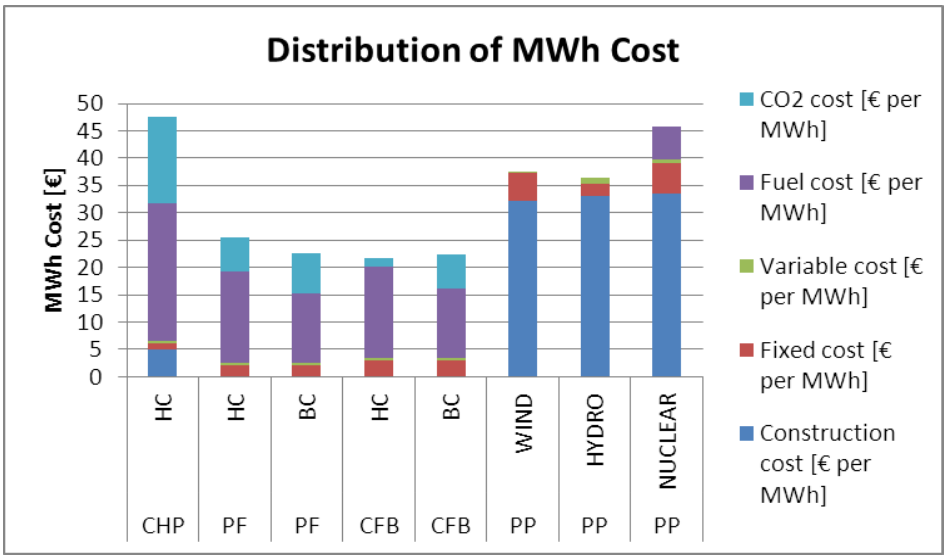
For the reference scenario, MWh cost from green technologies remains far more expensive than for coal technologies.

2) CO2 Scenario

For CO_2 Scenario, total costs generated by the evolution of Polish power sector reach 62 063 M€. This amount represents 1.45 times the total costs generated by the Reference Scenario. However, implementing green certificates of 70 € per MWh of electricity produced by renewable sources can generate subsidies reaching 12 055 M€, which makes this scenario competitive compared with Reference Scenario.

For CO_2 Scenario, three types of costs share the main part of total costs: fuel costs (34.8%), CO_2 costs (30%) and construction costs (27.5%). Important amount of fuel costs is used for the maintenance of existing coal plants but also for the consequent consumption of nuclear plants due to their major installed capacity. In addition, since existing plants are rather quickly closed to be replaced by environment-friendlier technologies, it seems normal that construction costs, which are the biggest costs for green technologies, represent an important percentage of this scenario. Finally, the elevated percentage of CO_2 costs is due to the price of allowances that remaining coal plants have to buy. These costs for CO_2 allowances accelerate impressively the closing of coal technologies.

Figure 11: CO2_Sc Distribution of electricity generation costs [€]



As it is visible in *Figure 11*, CO_2 costs become rather important with ETS system. Even if MWh cost from green technologies remains still higher, especially due to their construction costs, the implementation of not free allowances enables green technologies to be more competitive facing cheaper fossil fueled technologies.

VI. CONCLUSIONS

The aim of this study was to analyze the impacts of the implementation of European Union energy policy Emission Trading System on Polish power sector. To carry out this study, software GAMS was used to model Polish power sector, in order to optimize the development of Polish energy system regarding costs. It enabled to study the evolution of power capacity, electricity production, fuel consumption, greenhouse gas emissions and total system and electricity generation costs according to different scenarios.

The implementation of non free CO_2 allowances will lead to the major development of renewable energy sources, which whole potential would be exploited for wind and hydro power, rising green electricity generation to more than 23% in 2030. In addition, CO_2 taxes tend to reduce coal plants working as much as possible since they remain high polluting technologies in spite of important emission improvement. In order to replace coal technology, nuclear power should be used. The mix of renewable and nuclear sources should lead to a major decrease of CO_2 emissions. Even if this scenario does not seem to be efficient economically, according to huge changes it is going to generate, the implementation of green certificates will enable to balance the majority of these investments and to make these new technologies competitive compared to traditional coal technologies.]

However, it is important to keep in mind that these results are the fruits of simulations. They do not rule future development of Polish power sector, but they can give the tendency these different scenarios would lead to. It is clear that Poland will not close coal plants and build nuclear plants so easily. Nevertheless, it is very interesting to understand that Poland should move towards green and nuclear technologies in order to cut CO_2 emissions efficiently in an economically optimal way.

VII. REFERENCES

[1] International Energy Agency, Nuclear Energy Agency, Organisation for Economic Co-operation and Development, “Projected Costs of Generating Electricity”, pp. 33-35, 2010.

[2] E. Smol, R. Jeszke, P. Sikora, A. Błachowicz, “Metodyka wraz z przykładowym obliczeniem “limitu” krajowej emisji gazów cieplarnianych dla polski na lata 2013-2020 (dyrektywa eu ets i decyzja non-ets) ”, Kashue-Kobize, 2010.

[3] “Wartości opałowe (WO) i wskaźniki emisji CO2 (WE) w roku 2008 do raportowania w ramach Wspólnotowego Systemu Handlu Uprawnieniami do Emisji za rok 2011”.

[4] K. Vaillancourt, M. Labriet, R. Loulou and J.P. Waaub, “The role of nuclear energy in long-term climate scenarios: An analysis with the World-TIMES model”, Energy Policy, vol. 32, pp. 2296-2307, March 2008.

[5] Volkmar Lauber, “REFIT and RPS: options for a harmonized community framework”, Energy Policy, vol. 32, pp. 1405-1414, 2004”.