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# Modelling long-term technological transition of Polish power system using MARKAL: Emission trade impact

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## HIGHLIGHTS

- The impact of emission trade on power technology choice was studied.
- Nuclear, biomass and wind will replace coal base-load plants in Polish power system.
- Carbon Capture and Storage potentials should be recognized for coal-based production.
- High emission allowance prices will lead to decarbonization of electricity production.
- Implementation of $SO_2$ and $NO_X$ emission trading system should be reconsidered.

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## ABSTRACT

The need for technological transition of electricity production becomes a global problem. However, in coal-dominated Polish power system this need is even more crucial than anywhere, since technical lifetime of the most domestic power plants is ending. In this paper, the impact of the EU Emission Trading Scheme (EU ETS) for $CO_2$ combined with sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$) emission trading mechanism on power technology choice was studied using Market Allocation (MARKAL) model of Polish power system. Poland can contribute to achieving ambitious EU $CO_2$ emission reduction goals to 2050 by switching to diversified electricity mix of low-carbon coal technologies with CCS, and carbon-free options e.g. nuclear, biomass IGCC, wind onshore and offshore. This 'low-carbon' mix can be achieved only at high emission allowance prices, stimulated by the introduction of Market Stability Reserve to EU ETS and successive decrease in EU $CO_2$ emission cap. At high emission allowance prices, Poland's $CO_2$ emissions from ETS-participating electricity generating plants are expected to decrease in 2010–2050 period by 96–99%, depending on the projected electricity consumption. Model results prove that $SO_2$/$NO_x$ emission trading scheme, envisaged in Poland, is not effective, in view of Industrial Emission Directive implementation, and should be reconsidered.



## 1. Introduction

### *1.1. Background and motivation*

Since the contribution of fossil fuels to worldwide electricity production is approximately 66% (2013) (Energy Information Administration, 2013), there is a global need for technological transition of power systems to mitigate their environmental impact. European Union (EU) emphasized the need in decarbonization strategy drawn in EU Energy Roadmap 2050 (European Commission, 2012). To achieve the long-term goal of carbon-free power production, two instruments for emission reduction have been implemented before the publication of Energy Roadmap, i.e. Carbon Dioxide Emission Trading Scheme (EU ETS) (European Commission, 2009) and the mechanism of the integrated pollution prevention, implemented in Industrial Emission Directive (IED)

*Abbreviations:* BAU, Business As Usual case; CBM, Coal Bed Methane; CCGT, Combined Cycle Gas Turbine; CCS, Carbon Capture and Storage; CEN, baseline (central) EUA price case; CHP, Combined Heat and Power; $CO_2$-eq., equivalent of $CO_2$ emission on emission allowance; EFF, efficient (case); ETS, Emission Trading Scheme; EUA, emission allowance ($CO_2$); FBC, Fluidized Bed Combustion; FGD, Flue Gas Desulfurization; HIGH, high EUA price case; IED, Industrial Emission Directive; IGCC, Integrated Gasification Combined Cycle; LCP, Large Combustion Plants; LOW, low EUA price case; LWR, Light Water Reactor; MARKAL, Market Allocation modelling framework; MSR, Market Stability Reserve; NPP, Nuclear Power Plant; PCC, Pulverized Coal Combustion; PLN, Polish zloty (currency); PSE SA, Polskie Sieci Elektroenergetyczne Spółka Akcyjna (Polish Power Transmission System Operator); PV, Photovoltaics; REF, reference (case); RES-E, electricity from renewable sources; SC, Supercritical

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(European Commission, 2010). Investment decisions in power sector have to be in line with the EU and national energy policy goals which are: sustainability, security of energy supply, and competitiveness (European Commission, 2007; Ministry of Economy of the Republic of Poland, 2009). Simultaneous consideration of all long-term energy policy objectives in search of optimal electricity mix is a complex problem, so using decision making support tools is desired. These tools are usually simulation or optimization models of energy system, very often built with the use of energy modelling framework e.g. MARKAL (Market Allocation), EFOM (Energy Flow Optimization Model), MESSAGE (Model for Energy Supply System Alternatives and their General Environmental Impacts) or TIMES (The Integrated MARKAL-EFOM System). In such case, the research problem comes down to developing the approach to modelling energy policy instruments such as emission trading scheme and promotion mechanisms for both renewable electricity (RES-E) and high-efficiency cogeneration (Bućko, 2007). If maintained, these mechanisms are expected to have the biggest impact on the choice of electricity generating technologies within next decades.

Poland, where electricity production is dominated by coal, has rejected to adopt ERM 2050 (Reuters, 2012), expecting high costs of decarbonization, i.e. $18–22 \cdot 10^9$ EUR'05/yr after 2050 (Jankowski, 2010). However, as an EU Members State, the country implemented EU ETS in their legal framework (Ministry of the Environment of the Republic of Poland, 2011a) and proposed draft act on the trading scheme of sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$) emissions (Ministry of the Environment of the Republic of Poland, 2011b). As of 2013, almost 40% of Polish power units were over 40 years old and more than 15% were over 50 years old, and should be considered for decommissioning (Polish Information and Foreign Investment Agency, 2013). Therefore, investments in power sector are necessary in a short- and medium-term perspective to avoid power imbalance (The Energy Market Agency, 2011). This creates a chance for switching to clean electricity production. However, vast majority of large power plant projects, being in progress in Poland, are coal and natural gas power plants and combined heat and power (CHP) plants (PSE SA Polish Transmission System Operator, 2010; The Energy Market Agency, 2016), with small contribution of biomass. Failure to accomplish them by the end of this decade, increases the risk of power deficit. In search for carbon-free options in long-term perspective, Polish government has approved the nuclear power program in 2013, expecting to commission the first nuclear power plant in 2024 (Ministry of Economy of the Republic of Poland and Polish Government Commissioner for Nuclear Power, 2014). However, neither the location of the plant, nor the technology vendor is known, to date. Scientists, environmentalists and decision makers debate on whether Poland should build nuclear power plant or invest more in distributed generation based on renewable energies (Ministry of Economy of the Republic of Poland, 2012). Because of the lack of consensus on the future electricity mix, there is a need to build the methods and tools to support energy system planning, based on transparent and objective rules and incorporating emission reduction mechanisms. Recently, the draft version of Energy policy of Poland until 2050 (Ministry of Economy of the Republic of Poland, 2015a) was presented for public discussion. This paper reflects author's vision of power system development and is a counter-analysis for projections appended to the document (Ministry of Economy of the Republic of Poland, 2015b).

Bearing in mind the problems described in previous paragraphs, the modelling approach was proposed to include emission trading schemes in energy system optimization model that support investor decisions in view of EU ETS continuation and planned implementation, in Polish legal framework, of country-specific trading schemes for $NO_x$ and $SO_2$ emissions. Using Market Allocation (MARKAL) modelling framework, the model was developed to find the mix of technologies that are least-cost and in line with EU energy policy concerning renewable electricity standards and emission reduction goals. These policies were expressed in terms of indicative goals (e.g. obligatory share of renewable electricity in total electricity sales to final consumers) or emission allowance trading. As a result of the implementation of the proposed modelling approach, optimal structure of power technologies for Poland by 2050 was calculated.

### 1.2. Review of related work

Energy systems modelling and the impact of emission trade on power generation were the subjects of previous works. Agent-based modelling, in which actors (i.e. companies acting in power sector, usually power generation systems) are represented by agents living in a simulated world, was applied in (Chappin and Dijkema, 2009; Cong and Wei, 2010; Ermoliev et al., 2015; Matsumoto, 2008; Richstein et al., 2014). There was also a number of applications of energy-technology-oriented models to study the impact of emission trading on technology choice and its long-term consequences. MARKAL bottom-up partial-equilibrium model was used to analyze emission trade in (Anandarajah and Strachan, 2010; Barreto and Kypreos, 2004; McDowall et al., 2012; Victor et al., 2014). Similar model i.e. The Integrated MARKAL EFOM System (TIMES) was employed to study the cases of Finland (Kara et al., 2008), Czech Republic (Rečka and Ščasný, 2016) and Portugal (Amorim et al., 2014). A computable general equilibrium model was applied to analyze the impact of climate policy on the supply of renewable energy (Boeters and Koornneef, 2011), and to assess emission trade both in global scale (Springmann, 2012) and at national level i.e. for Romania (Loisel, 2009). A model developed using General Algebraic Modelling System (GAMS), defined as a Linear Complementarity Problem, was employed for power generation expansion planning under emission trading schemes (Linares et al., 2008). The studies concerning Polish energy system modelling include PolMark game theoretic model, applied to study the impact of different factors, among others $CO_2$ emission tax, on the market potential of coal for power generation (Kamiński, 2011, 2009). TIMES model, including the projections of $CO_2$ emission allowance prices, was used to study the long-term development of Polish power system (Pluta et al., 2012; Wyrwa et al., 2014). Previous concepts of Polish MARKAL model were presented in (Jaskólski and Bućko, 2015, 2013; Jaskólski, 2014, 2012a, 2012b).

### 1.3. Contribution of the paper

The main contribution of this paper is the modelling approach to EU ETS for $CO_2$, combined with $NO_x$ and $SO_2$ emission trading schemes ($SO_2/NO_x$ ETS) and its implementation for the case of Polish power system. MARKAL – technology-oriented optimization tool offering linear programming (LP) in its standard version (Loulou et al., 2004) – was applied to build energy system model for Poland. Reference Energy System, technology database, energy carrier price projections and electricity demand projections were improved in relation to previous Polish MARKAL studies (Jaskólski and Bućko, 2015, 2013; Jaskólski, 2014, 2012a, 2012b).

## 2. European Union emission trading scheme

EU ETS was implemented in 2005 to promote reduction of anthropogenic greenhouse gases (GHG) emissions. As the scheme