International Days of Statistics and Economics, Prague, September 22-23, 2011

ELECTRICITY SYSTEM OPTIMIZATION: A CASE OF THE CZECH ELECTRICITY SYSTEM – APPLICATION OF MODEL MESSAGE

Lukáš Rečka

Abstract

The aim of the paper is to show a complex picture of energy system modeling with focus on partial equilibrium energy models and on specific conditions in the Czech Republic and to develop an optimization model of Czech electric sector allowing to analyze impacts of environmental regulations. We briefly discuss the advantages and drawbacks of partial equilibrium models, where we show that PE modes allow developing a model with a higher degree of detail of the one selected industry and also are more appropriate for technological change modeling. We employ the model MESSAGE to construct a model of the Czech electric system and analyze the possible future development of the Czech electric system. By creation and evaluation of our scenarios we focus on impacts of EU ETS on the Czech electricity system as a whole; on optimal fuel mix; costs of electricity and on the amount of CO2 during the years 2006 – 2030. Our model covers 81 % of electricity gross production and 95 % of electricity gross consumption in the Czech Republic in 2006. Based on our results, the implementation of EU ETS causes the total reduction of 238 million tons of CO2 during the years 2006 – 2030

Key words: electricity system, Message, emissions, environmental regulation

JEL Code: C61, Q40, Q53

Introduction

If we want to assess the impacts of environmental regulation, we need a tool for it. Economic models give us such a tool. Generally, we have two broad groups of energy models. 1) Top-down models are structural economic models covering the whole economy. They are highly aggregated but they take into account the feedbacks and interactions between economic sectors. They provide better understanding of economy as a complex. Their main drawback is the high aggregation of the concerned sector. Most of these models don't include detailed technology set. Computable General Equilibrium and econometric models belong to this group. 2) Bottom-up models concentrate on one selected sector – let say energy. They include detailed description of the selected sector with a large amount of detail of the technologies. Therefore they model the selected sector into more details including choice of various constrains which make the model closer to the reality. Their drawback is that they lack the interactions and feedbacks with the rest of the economy. Partial equilibrium (PE) and dynamic linear optimization models come under this group. PE models usually include interactions between the output and price through demand elasticities and are able to find the optimum in the modeled sector. On the contrary to PE models, the optimization models usually don't include any interaction between output and prices. Usually the output is given exogenously and the model minimizes the cost needed to produce the desired amount of output. The exogenous output doesn't mean any serious imperfection by electricity sector modeling because the electricity demand is very inelastic in the short-run.

In the Czech Republic, there were applied only several energy models until today. Ščasný, et al. (2009) describes the structural models employed in the case of Czech Republic. Dynamic linear optimization model EFOM-ENV has been regularly developed by Enviros and Bízek (2009) applies the GAINS model being developed by IIASA[1]. Now, we are developing optimization model MESSAGE for Czech electricity system. Its main advantages are very detailed structure of the model and ability to model emission trading.

The aim of this paper is to construct a model of Czech electricity system and illustrate its serviceability on examples of environmental regulation impacts evaluation. We will use the implementation of Emission trading scheme for this illustration.[2]

Model MESSAGE

MESSAGE is a dynamic linear model developed by IIASA. "MESSAGE is designed to formulate and evaluate alternative energy supply strategies consonant with the user-defined constraints such as limits on new investment, fuel availability and trade, environmental regulations and market penetration rates for new technologies" IAEA (2002 pp. I-3). The model is able to calculate the load curve and optimize the power plant's inventory on this base. Our model includes also for emission trading mechanism for each power plant (PP)

---

[1] International Institute for Applied Systems Analysis

[2] Other scenarios and evaluations, you can find in Rečka (2010).

separately. More detailed description of the model and its structure you can find in Rečka (2009 and 2010).

The model is not able to forecast the future. It compares the modeled future state without any change of condition and the state after some change. In both cases the model takes into account the assumption about the parameters (e.g. efficiency of the PP or emission factors) and development of the variables included in the model (e.g. fuels and allowances prices).

Generally, the emission can be reduced on four ways: A) installation of end-of-pipe technology; B) change of the fuel mix; C) change of technology (its efficiency) and D) reduction of the output. As mentioned above, the output is given exogenously in optimization models, so reduction of the output isn't available as a possible way of emission reduction in the optimization process but it is also given exogenously. Our model doesn't include the possibility of installation of new end-of-pipe technology because this technology is already installed on all power plants in the model. The change of technology is included in the model only on a limited way - the model includes a set of new technologies which can replace the old power plants at the end of their lifetime. But the old PPs cannot be upgraded. However, the strength of the model is the modeling of impacts of the regulation on the fuel mix.

Application of MESSAGE in the Czech Republic

The base year of our simulation is 2006 and all data relate to this or followings years. The end year of the study is 2030[3]. The input data into the model MESSAGE were scooped from a few sources: The Czech Hydrometeorological Institute, Energy Regulatory Office's statistics and from annual reports or web pages of the Czech energy producers (mainly from ČEZ, a.s.). The PPs included in the model and their electricity production in 2006 cover 81 % of electricity gross production and 95 % of electricity gross consumption in the Czech Republic in 2006 and also approximately 25 % of district heat. The Czech electricity consumption assumed in the model is depicted on Figure 1. Out model includes 23 new technologies including water PPs, wind PPs, solar PPs and CCS technologies by brown- and hard-coal (BC and HC) PPs. Biomass is in the model mainly in form of co-burning with BC in PPs, where this co-burning takes already place. The main extension of the model is incorporation of electricity demand

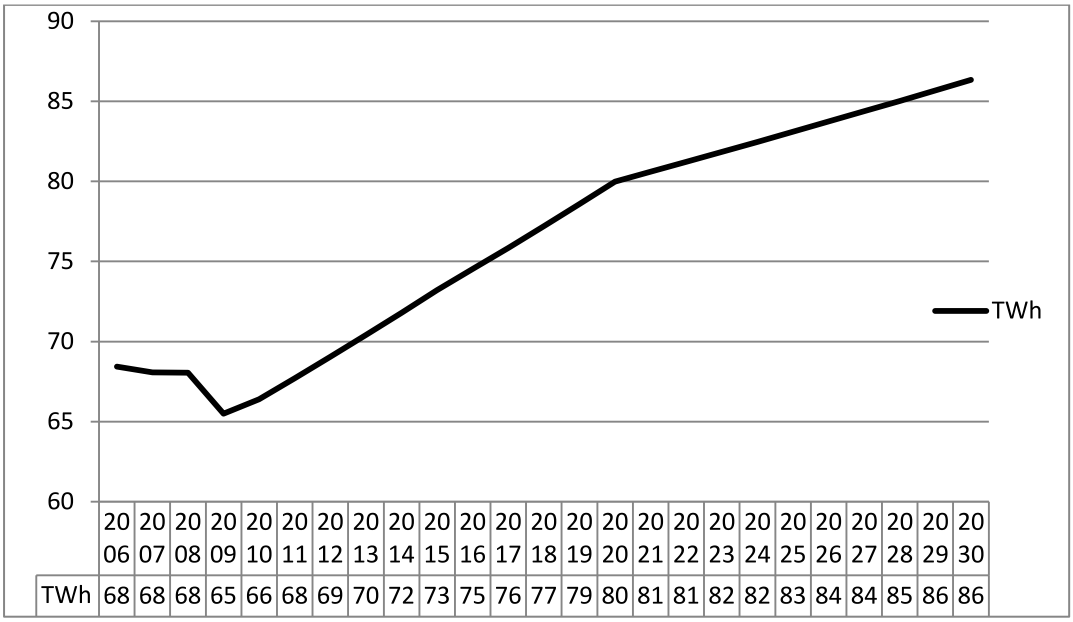
---

[3] All prices in this case study are in Euro 2007 and there was used the exchange rate 25 CZK/€ in all conversions. The discount rate is 5 %.

load curve and supply load curves by RES[4]. More detail about the data and model construction, you can find in Rečka (2009 & 2010).

The electricity demand, fuel prices are common for all scenarios. The maximal share of electricity from nuclear power plants on total electricity production is bounded on 60 % in all scenarios.

Figure 1: Electricity demand development



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
TWh	68	68	68	65	66	68	69	70	72	73	75	76	77	79	80	81	81	82	82	83	84	84	85	86	86

Source: OTE (2009) estimate – decreased by 5 %

Base Line (*BL*) scenario assumes no emission trading and no payment for emissions and no ETS. There is a subsidy for RES in form on feeding tariffs. There are only three types of constrains: a) based on current development, there is no construction of nuclear PP till 2030; b) potentials of RES and; c) the availability of BC within the ecological territorial limits.

The scenario *ETS* follows the *BL* with one modification – the ETS is considered here. The emission trading with CO2 follow the pattern of NAP I and NAP II till 2012. Since 2013

---

[4] The ecological territorial limits for BC mining and the availability of BC in the Czech Republic are also included in the model. In order to maintain the current share of BC consumption in heating and power sector, approximately 15 % of the available BC is reserved for a part of heating sector, which is not included in the model. By this amount of BC the total BC reserves in the model are reduced.

there is a switch to auctioning, where all permits must be purchased for a given price. Table 1 shows the emission permits prices used in the model.

Table 1: The allowance price (€2007/tCO2)

€/tCO$_2$	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	15.8	2	17.1	18.2	19.4	20.5	22.2	23	23.6	24.3	25.1	25.7	26.3
€/tCO$_2$	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
	26.8	27.2	27.8	28.4	29.1	29.7	30.3	31.1	31.8	32.6	33.3	33.8	

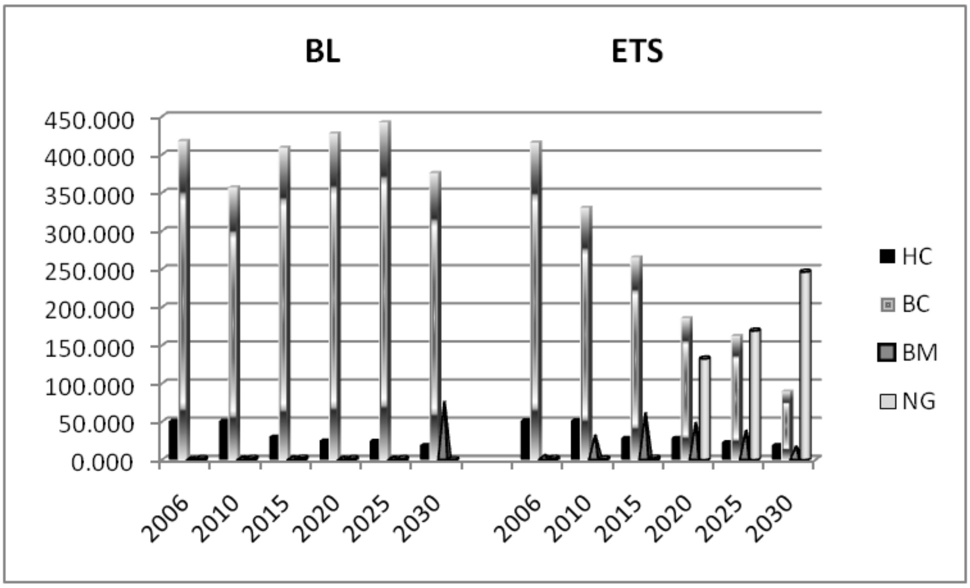
Source: E3ME model version 4.1

Scenario results

We focus on three aspects in the results evaluation. 1) Change of fuel mix indicates change in emitted emission and it is also important from the strategically point of view. 2) Our main interest is the impact of ETS introduction on emission development. 3) We show also the impact on production costs.

In the *BL* scenario, the fuel consumption decreases during the economic recession in 2009 – 2010 and increases again. The consumption of BC increases till 2027 in scenario *BL*. In 2027 one of BC mine is closed and new extraction encounter the ecological territorial limits, therefore the BC is replaced with biomass. There is almost no consumption of natural gas (NG) and till 2027 also very limited consumption of biomass. In the *ETS* scenario, the consumption of BC decreases instantly during the whole study period. The share of biomass on fuel mix is the biggest in 2019 and then decreases with share of BC. Since 2020, the NG rises rapidly, because new NG PPs are installed instead of new BC PPs. Figure 2 shows the development of fuel consumption in both scenarios.

Figure 2 Fuel consumption



Source: model MESSAGE

In Table 2, you can see differences of total emissions between the scenarios for the whole study period. The biggest reduction is by CO_2 – 22 %. The cumulative sum of NO_x is only about 6 % lower in *ETS* than in *BL*. Figure 3 depicts the development of CO_2 (right axis), SO_2, NO_x and PM[5]. We can see a significant drop of all emission in both scenarios in 2020. In this year, a big part of old BC PPs are shut down and replaced with new BC PPs with higher efficiency in scenario *BL* or with new NG PPs in scenario *ETS*. Due to this modernization, the emissions have overall declining trend also in *BL*. The second significant decrease of CO_2 and SO_2 is caused by the lack of available Czech BC and its substitution with biomass as described above.

Table 2 Cumulative Sum of emissions (tons)

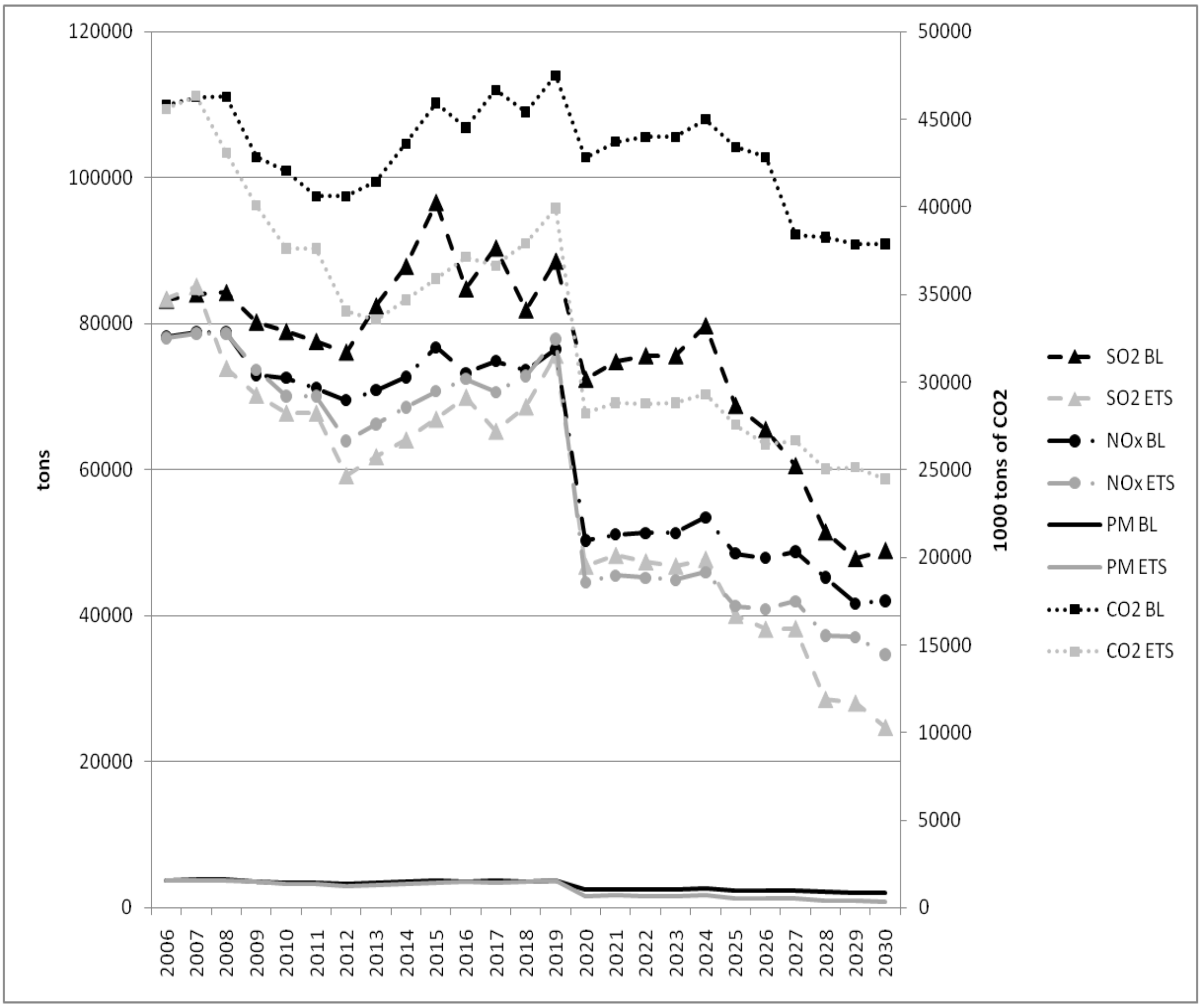
	CO2	SO2	NOx	PM	VOC
BL	1 077 851 535	1 898 843	1 572 671	76 152	118 057
ETS	839 533 784	1 415 023	1 472 004	62 937	108 438
%	78 %	75 %	94 %	83%	92 %

Source: model MESSAGE

---

[5] The black curves are for scenario *BL* and the gray one for *ETS*.

Figure 3 Emissions



Source: model MESSAGE

The presented production costs serve mainly for the evaluation of impacts of *ETS* introduction in given circumstances. Table 2 provides comparison of overall production costs of heat and electricity in the model from producer point of view. Therefore, the feeding tariffs have negative sign. The investment cost are lower in *ETS* because there are installed NG PPs with lower investment cost instead of BC PPs in *BL*. This difference overlays also the higher investments into RES in *ETS.*

Table 2 Production Costs

mil. €	Investment	Fuel	ETS	Feeding Tariffs	**Total**
BL	31 495	26 532	-	-5 150	**52 877**
ETS	29 190	34 960	13 091	-8 380	**68 861**

Source: model MESSAGE

Conclusions

The implementation of EU ETS causes the total reduction of 238 million tons of CO2 during the years 2006 – 2030. The total investments into new capacities decrease from 31 495 millions € in *BL* scenario to 29 190 millions € in *ETS*. The producers must purchase CO_2 allowances in value of 13 091 millions € in scenario *ETS*. The share of biomass stays almost insignificant until 2027 in scenario BL but in the second scenario, this share rises up to the technically possible maximum. So we can conclude that the biomass share in fuel mix is strongly dependent on the implementation of ETS and on the price of the emission allowances. It is question how the share of biomass would develop if we include also some pure biomass technology into the model because now the biomass is only co-combusted in some brown coal PPs up to 30 % of fuel input in our simulation. Although some simplification, the developed model MESSAGE gives us a good tool to evaluation of environmental policies.

We have removed the simplification of load curve, which has significant impact on the role of natural gas in scenario *ETS*. There are massive installations of NG PPs after 2020. The introduction of EU ETS has positive effect also on RES, mainly on wind PPs.

Based on our assumptions, from producer point of view the introduction of EU ETS increase the total production cost by 16 billions € during the years 2006 – 2030. If we consider the payments for CO_2 allowances and feeding tariffs as taxes and transfers and the income from EU ETS would have been again redistributed back to the society, the direct social cost would even decreased by 3.7 billions €. The benefits from emission reduction should be added to this cost reduction.

There are further challenges for future research. Incorporation heating sector as separate sector with regional demands is the most challenges. This would allow also incorporation of cogeneration technologies on pure biomass, which is another issue. We will focus on these challenges in the next version of our model.

Acknowledgment

The research has been supported by Ministry of the Environment of the Czech Republic, R&D Grant No. SPII/4i1/52/07 MODEDR „Modelling of Environmental Tax Reform Impacts: The Czech ETR Stage II". The support is gratefully acknowledged. Responsibility for any errors remains with the author.

References

Bízek, Jan. "Integrated Approach to Climate Change Mitigation and Air Quality Protection." *Bachelor Thesis. Charles University Prague, Faculty of Social Science, Institute of Economic Studies*, 2009.

IAEA. "Model for Energy Supply Strategy Alternatives - User Manual." 2002.

Rečka, Lukáš. "Optimisation of the Czech energy system." *Bachelor thesis. Charles University Prague, Faculty of Social Science, Institute of Economic Studies*, 2009.

Rečka, Lukáš. "Sestavení modelu a aplikace optimalizacního modelu MESSAGE pro posouzení dopadu environmentální daňové reformy." al., Ščasný et. "Modelování dopadu environmentální danové reformy: II.etapa EDR. Zpráva pro rok 2010 projektu vedy a výzkumu SPII/4i1/52/07 financovaného MŽP." *COŽP UK & IEEP VŠE*, 2010.

Ščasný, Milan, et al. "Analyzing Macroeconomic Effects of Environmental Taxation in the Czech Republic with the Econometric E3ME Model." *Czech Journal of Economics and Finance* 2009: 460-491.

Contact

Lukáš Rečka
Institute of Economic Studies - Faculty of Social Sciences - Charles University in Prague &
Charles University Environment Center
José Martího 2, Praha, Czech Republic
lukasrecka@gmail.com