Partial equilibrium model of Czech energy sector – scenarios of future development

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Abstract
This paper constructs a partial equilibrium, Czech energy model in TIMES model generator taking into account remaining brown coal reserves in currently operating mines and in potential new brown mines and potential of renewable energy sources. The new energy and climate objectives to be met by 2030 proposed by the European Commission are taken into account. Baseline scenario assuming current and ongoing environmental regulation and six policy scenarios are analysed.
The results shows that new nuclear reactors are competitive already from 20€ per ton of CO_2. New advanced wind technologies should be competitive without subsidies but further development of photovoltaic is dependent on subsidies. Share of natural gas in the heat and power generation in the Czech Republic is highly dependent on future carbon and fuel prices. The price of CO_2 is essential for further reduction CO_2 and other emission.

Keywords: Czech, energy model, emission, partial equilibrium, TIMES

JEL Code: C61, Q40, Q42, Q48, Q53, Q54

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1 INTRODUCTION

The Europe energy system is at the crossroad and the Czech energy system as well. Besides the Europe-wide dilemma between nuclear, conventional-thermal and renewable energy sources, there is further open question in the Czech Republic – to dampen slowly the brown coal mining; or to prolong the brown coal mining by relax the local ecological limits[1] and to expand the brown coal mines into new areas. This brings additional uncertainty and instability to Czech energy policy (van Wees, Uyterlinde, & Maly, 2002). A public tender process for contractors to build two new nuclear reactors was cancelled in April 2014. But there is still a policy will to build at least one nuclear reactor in the future. Monthly average baseload power price on the Prague power exchange (PXE) is in a downward trend since June 2011 and since January 2013 it have been fluctuating between 30 and 35 €/MWh[2] and neither increasingly important role of renewables in the power mix in the EU nor the low carbon price bring incentives for significant rise of the power price in the near future. The Czech government stopped subsidies for new photovoltaic and biogas power plants since 2014 and for all other renewable sources installed in 2016 and after (*Act No. 165/2012 Coll. on supported energy sources (as amended)*, 2012).

The possible development of energy system has been modelled mainly on the EU-level (e.g. Capros et al. (2014), Blesl et al. (2010), EC (2011), Bussar et al. (2014), Spiecker & Weber (2014), Dowling (2013)) but there is only a few application of energy models directly in the Czech Republic. Linear optimization model EFOM/ENV (Energy Flow Optimisation Model) is used in some documents of Ministry of Industry and Trade or Ministry of the Environment of the Czech Republic (e.g. MPO (2004)). Rečka & Ščasný (2013) apply linear optimization model MESSAGE (Model for Energy Supply System Alternatives and their General Environmental Impacts) purely on power sector. Lechtenböhmer et al. (2009) use an expert-based model for formulation of energy savings and renewable energy scenario.

This paper enriches Czech energy modelling literature. A dynamic partial equilibrium Czech energy model in TIMES model generator is developed taking into account all the facts mentioned above. A baseline and six policy scenarios are modelled to assess the impact of policy decisions and possible fuel price development on the Czech energy system. In addition, the scenarios are evaluated also terms of external cost using the ExternE methodology (Preiss, Friedrich, & Klotz, 2008).

The paper is structured as follows: first, the Czech energy TIMES model is introduced, followed by a section describing the baseline and six policy scenarios. The section 4 presents and discusses results of the scenarios in terms of new generating capacities, cost, emissions and electricity production. The article is closed by conclusions.

2 MODEL

The energy system model generator TIMES (The Integrated Markal Efom System) is applied to construct Czech energy model. The TIMES is a further development of the two model generators MARKAL and EFOM-ENV written in GAMS. TIMES was developed within the ‘‘Energy Technology Systems Analysis Programme’’ (ETSAP) from the IEA – see Loulou et al. (2005) for documentation. The TIMES belongs in one category with the models MARKAL, EFOM or

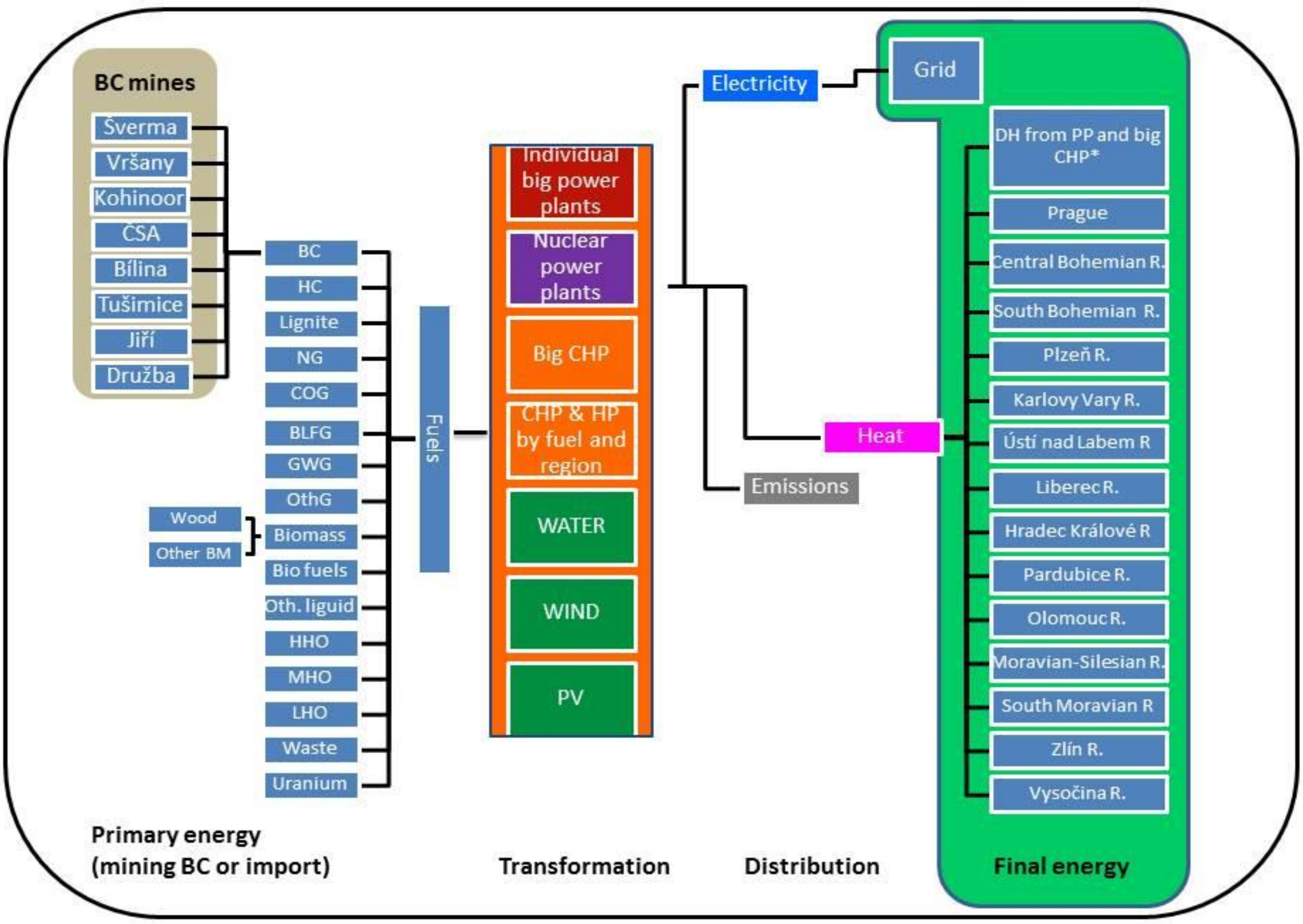
[1] Territorial limits to the mining of brown coal in North Bohemia are legally binding according to Resolution No. 444 passed in 1991 by the government of the Czech Republic. The limits define the areas where a surface mining is allowed and where not.

[2] http://www.pxe.cz/dokument.aspx?k=Statistika&language=english

MESSAGE but in contrast to them it allows the interaction between supply and demand through price elasticity of demand. It searches for a solution with the least total discounted cost over the whole period.

Our Czech energy model is built on plant level data mainly. It includes all significant power plants individually, aggregated renewable sources by type and other sources aggregated. In this detail pattern it covers 92 % of electricity gross production in the Czech Republic in 2011 and 2012. The model includes also the production of district heat. The model takes into account the obtainable potential of renewable sources, the brown coal reserves in current brown coal mines and also the reserves behind the local ecological limits. The model covers the whole energy chain from brown coal mining and other fuels import over power and heat generation, losses to final demand of electricity and heat as illustrated on Figure 1. One of the advantages of our model is the regional basis of the district heating production and demand: the heat demand and production are regionalized and the heat supplier can compete only within a given region. The regions are created according the district heating systems or Czech regions. As mentioned in the introduction, the brown coal has a special role in the Czech energy system and therefore the model is focused in this way. The brown coal mining is modelled for each mine separately and the mine-mouth power plants are linked directly to these mines.

Figure 1 Schematic structure of the model

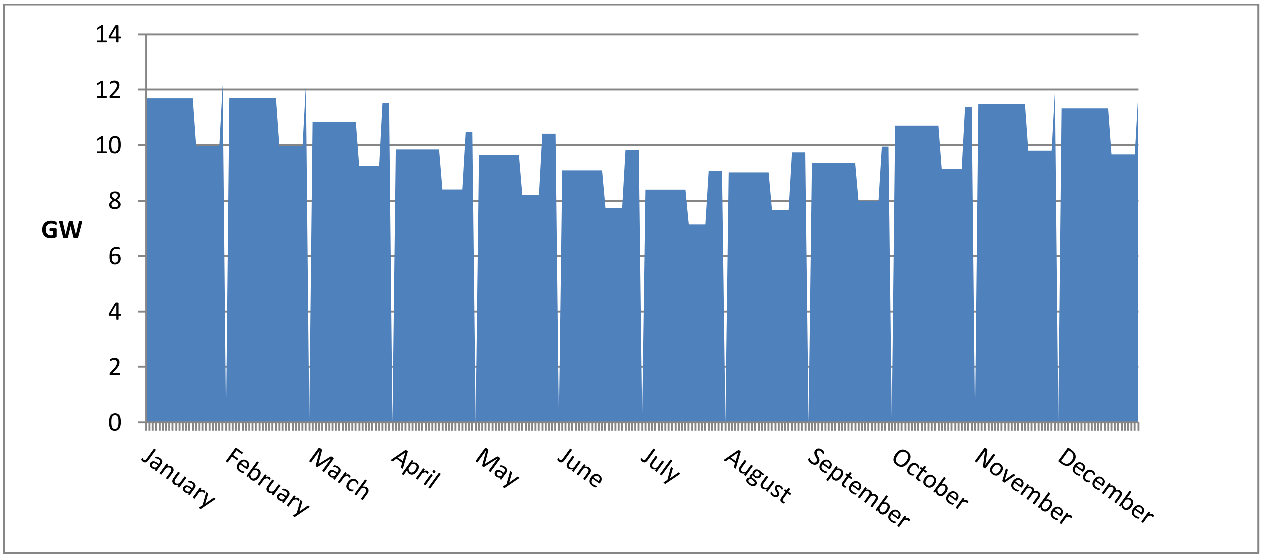


The model is calibrated on 2011 and 2012 data and the time horizon ends in 2050. Electricity production data are obtained from Czech Energy Regulatory Office (ERÚ), heat production data comes partly from ERÚ and partly from district heat producers. The fuel prices are collected from several sources: World Energy Outlook 2013 , ERÚ and Gavor (2013). Parameters and cost of new technologies are based on EPRI (2011), only the cost of nuclear power plant per kW are adjusted according to the bids in the cancelled Czech tender. Potentials for wind energy are based on estimate by Institute of Atmospheric Physics of the Czech Academy of Science (2012).

Load curves for electricity and heat demand as well as availability factors of power plants are included in the model in order to model the required installation capacity and the intermittent electricity production from renewable sources, especially wind and photovoltaic power plants. Electricity demand load curve is divided into 36 different time slices: three day phases - *day*, *night* and *peak* – are defined specific for each month based on averages of days with maximal and minimal load in years 2005 – 2012 (ERÚ, 2013). Specific profile of typical day is created for each month where the length of *day* phase varies between 13 and 15 hours, the *night* is longer in winter months (8 hours) and shorter in summer months (6 hours) and the *peak*. Figure 2 present the electricity load curve for a typical day in each month of 2012. The heat demand load curve is divided in 12 month only. The load curve's profiles are considered as fix the whole analysed period.

The conventional power plants (including nuclear power plants) are considered as flexible and the availability factors are defined on monthly basis. The renewable energy sources (water, wind, photovoltaic) have the availability factors defined for each of the 36 time slices – e.g. the photovoltaic power plants are not available during the *night* and their availability in *peak* is restricted.

Figure 2 Electricity demand profile during 1 day in each month of 2012



3 MODELLING SCENARIOS AND ASSUMPTIONS

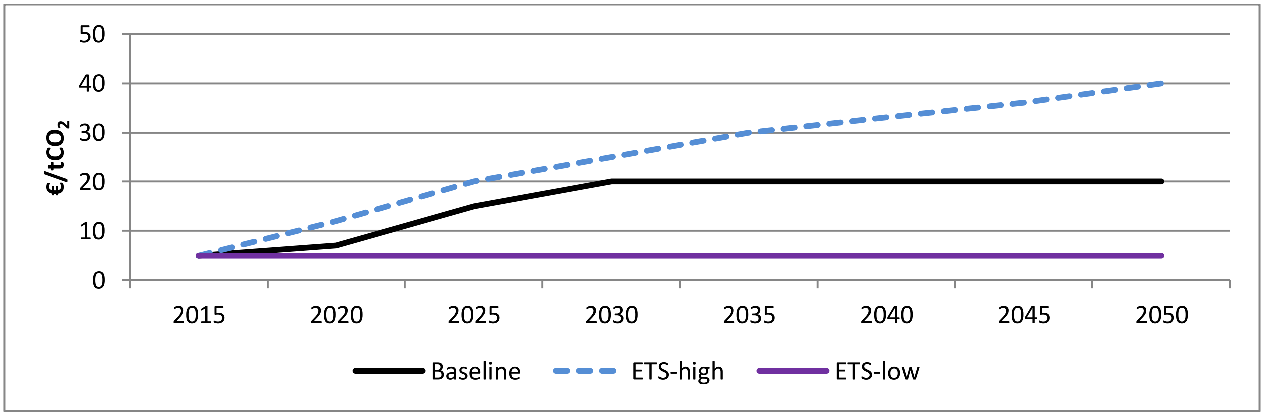
The impacts of policy measures and price development on energy system are analysed in a baseline scenario and six policy scenarios: ETS-high, ETS-low, BCmine, BCmineETS-high, BCmineETS-low and NG-low.

Discount rate assumed in the model is 5 %. Only a moderate growth in electricity consumption (up to 1 %/a) is assumed in all scenarios. Real reserves of Czech brown coal (BC) and renewable energy sources are taken into account. The maximal share of nuclear energy is set to 65 % to ensure the stability of the power system. The baseline (BL) scenario assumes current and ongoing environmental regulation, no restriction on new installation of nuclear power plants and a correction the EU Emissions Trading System (EU ETS) such as the market stability reserve (Acworth et al. 2015). Figure 3 presents the assumed CO_2 allowances' price development in three typical scenarios: BL, ETS-high and ETS-low. In all other scenarios the CO_2 allowances' prices correspond to one of these three scenarios. The baseline scenario assumes the EU policy will lead to a correction of the EU ETS so the CO_2 allowances' price will increase up to 20 € from 2030.

The ETS-high scenario is based on baseline scenario but assumes higher price of CO_2 allowances. There is a gradual increase of CO_2 allowances' price up to 40 € in 2050. The ETS-low scenario assumes that the effort to reform the EU ETS will fail and the CO_2 allowances' price will stay on the current level till 2050.

NG-low scenario is based on baseline scenario but tests the sensitivity of the energy system on significant decrease of natural gas price that might be induced by a shelf gas revolution in Europe. The natural gas price is supposed to gradually decrease from 8.6 €/GJ in 2015 over 6 €/GJ in 2025 to 4 €/GJ in 2040 where it stays till the end of the study horizon.

Figure 3 Assumed price of CO2 allowances in policy scenarios (€/tCO2)



BCmine scenario is based on baseline scenario but assumes abolition of the local ecological limits and expansion of the brown coal mines into new areas what means significant increase of brown coal reserves. The brown coal from the expanded brown mines is supposed to be 2.4 €/GJ higher than the old one due to additional mining cost.

BCmineETS-high combines the BCmine scenario with the CO_2 allowance price path from ETShigh scenario. BCmineETS-low scenario is a combination of scenarios BCmine and CO_2 allowance price path from ETS-low.

4 RESULTS

4.1 New generating capacity

The Baseline scenario supposes relative environmentally friendly price of CO_2 allowance and it is reflected also in the new installed capacities as shown in Table 1. The Baseline scenario uses the full potential of maximal feasible nuclear share in energy mix and the full realizable potential of wind technology – 2.3 GW. The Carbon Capture and Storage (CCS) technology is installed on 500 MW brown coal power plants. One of the reasons of new wind turbine installation is the lack of available brown coal, because in scenario BCmine no wind technology is installed but only brown coal with and without CCS and nuclear power plants are installed. Due to the depletion available wind potential and lack of brown coal the 4.3 GW of hard coal technology are installed. Additionally 300 MW of pure biomass technology are installed.

The higher price of CO_2 allowance in the ETS-high scenario leads to higher usage of CCS technology. The main difference between the Baseline scenario and the ETS-high scenario is the installation of CCS technology on hard coal power plants (5 GW) where in the Baseline scenario the CCS technology is used only in brown coal power plants.

The low price of CO_2 makes unprofitable to build nuclear power plants in both scenarios – ETS-low and BCmine ETS-low – where it is assumed. Installations of new capacities are split between brown coal and hard coal technologies. Due to the lack of available brown coal only 400 MG of brown coal power plants and 10.3 GW of hard coal power plants are installed in the ETS-low scenario. The opening of new brown coal mine allows building 8.6 GW of brown coal power plants and only 2.1 GW of hard coal power plants in the BCmine ETS-low scenario.

The slump in nature gas price in the NG-low scenario leads to massive installation of natural gas power plants and crowds out all other new technologies and together 10.7 GW of natural gas advanced combined cycle are installed.

Table 1 New installed capacities from 2020 to 2050 (GW)

	BL	ETS-high	ETS-low	NG-low	BCmine	BCmine ETS-high	BCmine ETS-low
BC			0.4		0.8		8.6
BC CCS	0.5	0.9			5.3	6	
BM	0.3	0.3					
HC	4.3		10.3				2.1
HC CCS		5					
NG				10.7			
NUC	4.2	4.2		0.05	4.2	4.2	
WIND	2.3	2.3					
TOTAL	11.6	12.7	10.7	10.75	10.3	10.2	10.7

Note: BC-Brown coal condensing power plants (PP), BC CCS-Brown coal condensing PP with CCS, BM-Biomass, HC-Hard coal condensing PP, HC CCS-Hard coal condensing PP with CCS, NG-Natural gas advanced combined cycle, NUC-Nuclear PP, Wind-Advanced Wind Turbine

4.2 Costs

The installation of new technologies determines the fuel consumption and together with expenditures for CO_2 allowances create the core of total production cost. Table 2 shows the total discounted system costs between years 2011 and 2050 and relate the total discounted cost to the Baseline scenario. It is shown that the availability of brown coal from the new mines is crucial for the overall costs as even the BCmineETS-high scenario has significantly lower total discounted cost than the scenario ETS-low.

Note that a discounted value for the unused portion of technical live of investments (so-called Salvage value), whose technical lives exceed the model's horizon, is subtracted from the total discounted cost. Therefore for example the NG-low scenario with relative high variable costs and lower investment costs has higher costs till 2050 than the Baseline scenario but the total costs in the objective function are lower because higher Salvage value is subtracted in the Baseline scenario.

Table 2 Total discounted system costs 2011-2050 in mil. €

	BL	ETS-high	ETS-low	NG-low	BCmine	BCmine ETS-high	BCmine ETS-low
M€	46,267	47,859	46,353	48,956	41,673	43,959	39,128
% of BL	100%	103%	100.2%	106%	90%	95%	85%

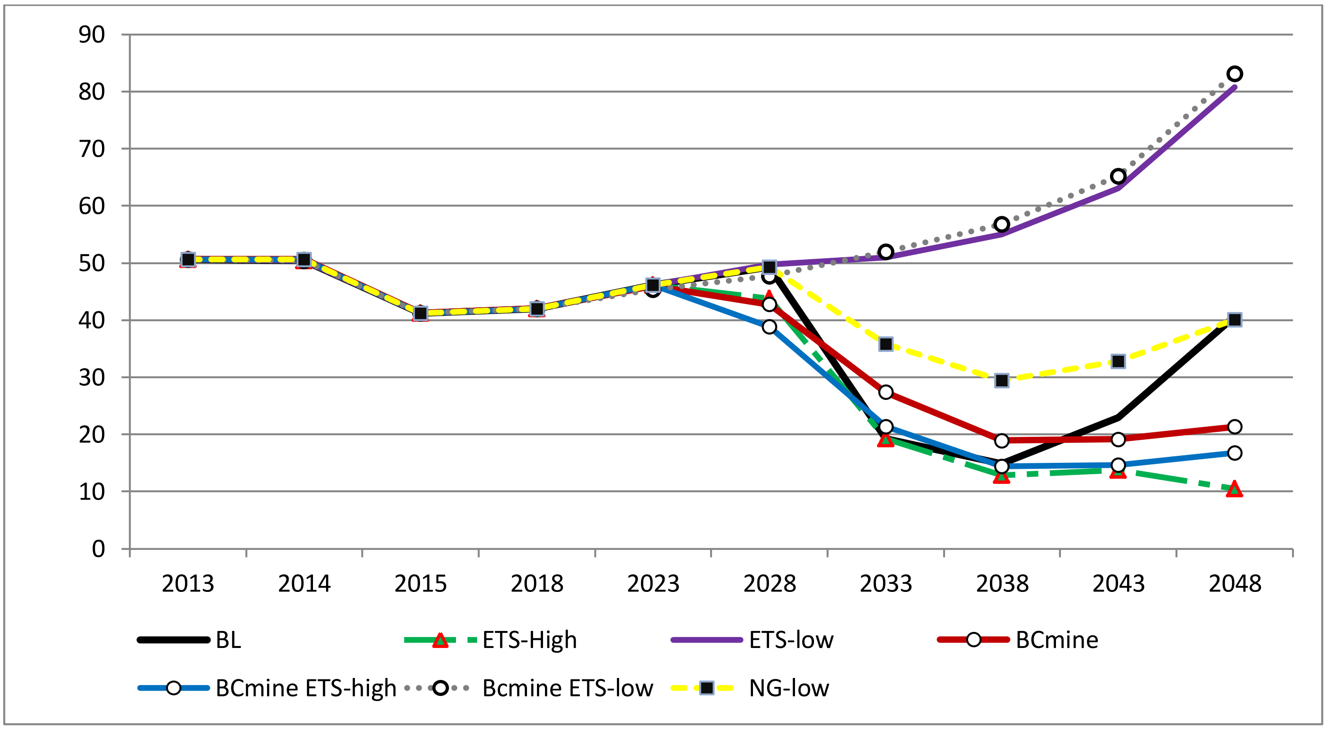
4.3 Emissions

As the electricity production is in the all scenarios the same, production of CO_2 emission and other air pollutant is determined by the fuel consumption and by the installed technologies. This section describes the development of of CO_2 emission and classical air pollutants.

4.3.1 CO_2 emission

The CO_2 price is the most important parameter for the CO_2 emission. The CO_2 emissions differ between the scenarios since 2025 when significant part of old power plants is retired and new installed capacity is needed. Figure 4 presents the CO_2 emission development in all scenarios. In scenarios ETS-low and BCmine ETS-low with low CO_2 allowance price (5€/tCO_2) the emissions increase steeply from 50 Mt in 2028 to approximately 83 Mt of CO2 in 2050. There is a decrease in CO_2 emissions from 2028 till 2050 in all other scenarios. The lowest CO_2 emissions are in scenario ETS-high followed by scenarios BCmineETS-high and BCmine. The Baseline scenario has lack of cheap brown coal and therefore it is more cost effective to construct hard coal power plants without CCS in this scenario instead of brown coal power plants with CCS technology as in BCmineETS-high and BCmine scenarios. This lead to a rapid increase in CO_2 emissions from 15 Mt in 2038 to 40 Mt of CO_2 in 2050. As mentioned above, the low price of nature gas in NG-low scenario crowds out all other new technologies including nuclear and renewables or CCS. This leads to the highs CO_2 profile among the scenarios with price of CO_2 20€/t or higher.

Figure 4 CO_2 emission developments



4.3.2 Classical air pollutants

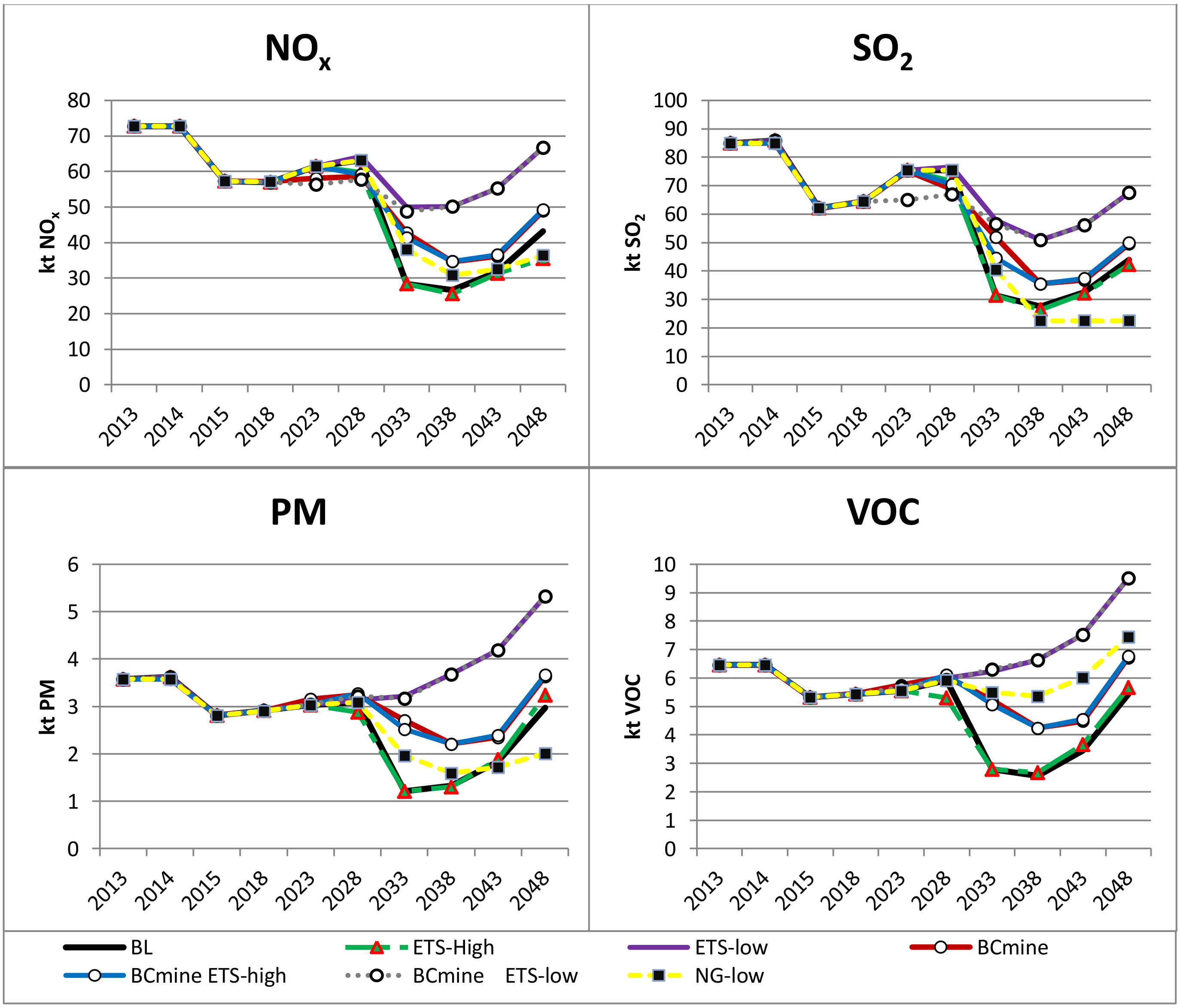
Because all new technologies are considered to fulfil the emission coefficients of classical air pollutants according to the ongoing regulation and no additional abatement technology is available, the development of emission of classical air pollutants is different from the CO_2 emission where the CCS can compensate the consumption of dirty brown coal for example. The consumption of the brown and hard coal is the main driver of all classical air pollutants analysed in this article – nitrogen oxide (NO_x) sulphur dioxide (SO_2), particular matter (PM) and volatile organic compound (VOC).

The ETS-low and BCmine ETS-low scenarios have the highest emission of all classical pollutants. Only the SO_2 emissions do not reach in 2050 a higher level than in 2030 in these two scenarios. Emissions of particulate matter and volatile organic compound increase even above their initial levels in these two scenarios.

The construction of new nuclear power plant after 2030 implies radical emission reduction of classical pollutants in all four scenarios where it takes place. Since 2040 the emissions rise again and in case of PM and VOC they attack their values in 2030 in these scenario.

The NG-low scenario differs from the other scenarios as there is a different development across the classical pollutants. SO_2 emissions drop after 2030 and continue in decrease on approximately 30% of 2030 level in 2050. NO_x emissions also decrease after 2030 stay on higher values than in scenarios Baseline and ETS-high. PM emissions decrease by half between 2030 and 2040 and increase slightly on 64% of 2030 level what still means the lowest value among all scenarios. VOC emissions have the third highest profile behind ETS-low and BCmine ETS-low and after a decrease after 2030 reach in 2050 25% higher value than in 2030.

Figure 5 Developments of clasicall air pollutants



4.4 Electricity production

The share of source type on electricity production presented in Figure 6[3] corresponds with new capacity installation and emission development but it shows better the role of renewable energy sources in the Czech energy system. No new photovoltaic system (PV) is constructed in any scenario and after the end of its lifetime it disappear form the electricity production practically.

The production from wind is significant only in scenarios BL and ETS-high since 2038. Interesting is the role of hard coal which is very low in scenarios with price of CO_2 20€/t or higher and availability of cheap fuel (brown coal or natural gas) at the same time. On the contrary, the role of hard coal increases in the other scenarios in the last periods.

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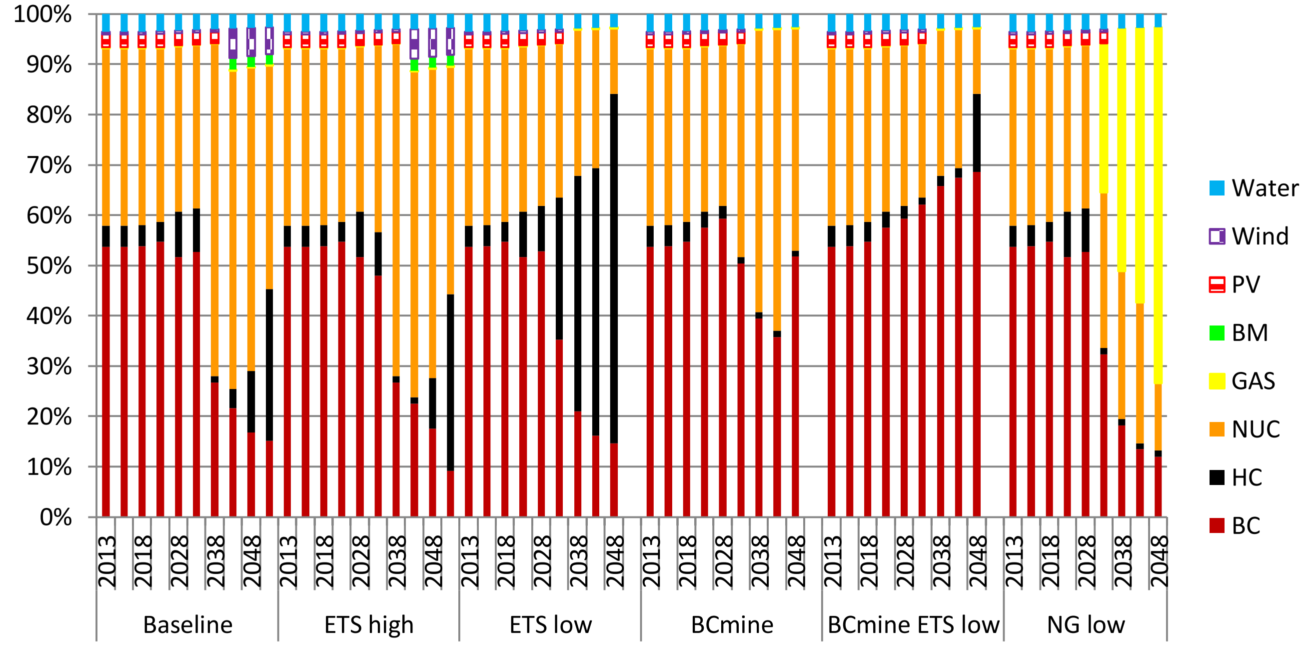
[3] The scenarios BCmine and BCmine ETS-high have almost identical structure of electricity production and only the BCmine scenario is presented in the figure.

The share of nuclear energy increases in the Baseline scenario, ETS-high, BCmine and BCmine ETS-high scenarios up to 60% around year 2045. But the low price of natural gas or low price of CO_2 allowance crowd the nuclear energy out.

The natural gas plays significant role only in NG-low scenario where its price falls to 4 €/GJ and share of the natural gas on electricity production increase up to 70% since 2045.

Figure 6 Electricity production per type of source



Note: Only main energy source is illustrated, biomass is co-combusted in some current power plants.

5 CONCLUSIONS

A Baseline and six policy scenarios are assessed in this article. Low, baseline and high patter of the CO_2 allowance price, magnitude of brown coal reserves and price of natural gas are the parameters changing in the scenarios. Based on this assessment the price of CO_2 allowance is the most important factor for the future not only CO_2 but also other classical pollutants emissions reduction. The price of 20 €/tCO_2 is sufficient for CO_2 emission reduction in all scenarios. But as the ETS-low scenario shows, the current low price of CO_2 would lead (without any additional measures) to significant CO_2 emissions increase in the long term.

Availability of brown coal determines the fuel consumption more than the price of CO2. The local ecological limits on brown coal mining are the main drivers of phasing out of brow coal from Czech energy mix. The photovoltaic systems are not competitive without subsidies and are not installed in any scenario. The wind power plants are installed in scenarios with BC constrains and price of CO_2 20 €/t and higher and the full realizable wind potential is used. Significant decrease in NG price would lead to dominance of NG combined cycle technologies in power production. It is the only one scenario where no coal technology is installed.

The whole analysis is dependent on price and technology assumptions. Although the effort in literature search there is always some degree of uncertainty about the future development of each parameter. In order to control an improbable development a scenario with very low price of natural gas was incorporated into the analysis and it shows the energy system would be changed dramatically under such conditions. Nevertheless the highest uncertainty is in the CCS technology price and availability since is still in experimental phase of development. Our results correspond with Lohwasser et. al (2012) the CCS should expand from 20 €/tCO_2 but the real availability and cost of CCS in Europe and Czech Republic remain uncertain.[4]

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[4] The first research projects focused on CCS in the Czech Republic have been launched just recently: http://www.eeagrants.cz/en/programmes/norway-grants-2009-2014/cz08-carbon-capture-and-storage/cz08-news/2015/results-of-the-first-open-call-within-th-1775

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