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Impacts of Reclassified Brown Coal Reserves on the Energy System and Deep Decarbonisation Target in the Czech Republic

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Abstract: In 2015, a 24-year-long prohibition of coal mining within some territories in the North Bohemia coal basin was lifted and as a consequence mining a part of the brown coal reserves might well be resumed. This paper analyses the impacts of maintaining the ban versus three options for a less environmentally stringent policy on the Czech energy system; fuel- and technology-mix, the costs of generating energy, emissions and related external costs up to 2050. We find that overall the effect of lifting the ban, on coal usage, air pollutant emissions and hence externalities is rather small, up to 1–2% compared to the level of keeping the ban. The small difference in the impacts remains even if changes in the prices of fossil fuels and European Emission Allowances or different development in nuclear power usage are assumed. In fact, changing these assumptions will result in more pronounced differences in the impacts than the four policy options might deliver. Maintaining the ban would not achieve the European Energy Roadmap 2050 target and the newly adopted policy and the other two counter-environmental proposals would miss the 80% reduction target to an even greater degree. The environmental and external health costs attributable to emissions of local air pollutants stemming from power generation are in a range of €26–32 billion over the whole period and decline from about 0.5% of gross domestic product in 2015 to 0.1% in 2050.

Keywords: brown coal reserves; energy system modelling; TIMES model; carbon reduction targets; environmental benefits

1. Introduction

In response to the massive destruction of the landscape and air pollution resulting from brown coal mining in North Bohemia and its combustion in nearby power plants [1], in 1991 the Czech Government decided to restrict brown coal mining to specified 'Territorial Environmental Limits' (TEL) in the North Bohemia coal basin (the limits define the areas where open-pit mining is allowed and where it is not, and are legally binding according to Decrees No. 331 and 444 on Territorial Environmental Limits on Mining passed in 1991, and further re-confirmed by Decree 1176/2008, by the Government of the Czech Republic). Since then, a number of parties have called for the re-opening of the brown coal pits most affected by the restriction—Bílina and ČSA—on the basis of social concerns (to ensure the delivery of cheap coal for central heating), regional employment or energy security (domestic coal supply). Despite this pressure the Czech Government re-confirmed the ban in 2008.

A change came in October 2015 when the Czech Government lifted the TEL. The Government had taken into consideration four variants of retaining or abandoning the TEL. The Government did not decide to retain the brown coal mining limits unchanged (TEL1 variant), but in order to ensure a supply of high quality domestic brown coal, particularly to supply Czech heating plants, it revoked its past binding decision and voted in favour of lifting the brown coal mining limits at the Bílina open pit (TEL2). An additional two options concerning the TEL—a partial lifting of the restrictions (TEL3) or even completely abandoning the mining limits regarding the second open pit (ČSA) (TEL4)—remain in the game, as the Czech Government has stated that lifting the mining limits at the ČSA pit might be re-considered as part of the next revision(s) of the Czech State Energy Policy (SEP).

The ratified lifting of the brown coal mining limits of the Bílina pit (TEL2) may unfasten approximately 123 Mt (1795 PJ) of newly accessible brown coal over the period 2016–2050. The other two considered TEL variants would constitute a total of 167 Mt (2540 PJ) or even 269 Mt (4280 PJ) of newly accessible brown coal under TEL3 and TEL4, respectively; see Figure 1, more details in [2]. The use of newly accessible brown coal reserves may result not only in a higher share of brown coal in the fossil fuel mix, but it could also have an impact on the deployment of renewable resources and other non-fossil technologies. This would be in sharp contrast with the current EU energy-climate policy, which calls for a reduction in greenhouse gas (GHG) emissions and coal usage, and an increase in the share of renewable energy sources (RES) in final energy consumption (The 20-20-20 target to be achieved at the EU level by 2020 has been updated by setting the EU commitment at 40-27-27 target by 2030 [3], which was integrated into the EU 2050 Roadmap for moving to a competitive low-carbon economy [4] which requires reducing greenhouse gases emissions to 80% below the 1990 level by 2050. The 40-27-27 target specifically includes: (1) reduction of the EU's GHG emissions by at least 40% relative to the 1990 level; (2) an increase in the share of renewables to at least 27% of the EU's final energy consumption; and (3) an increase in energy efficiency by at least 27%. These new 2030 EU targets will be accompanied by the reform of the EU Emission Trading System and by a package of measures to achieve a competitive, affordable, secure, and sustainable energy supply for the EU [5]). It is worth noting that hand-in-hand with the discussion on the Territorial Ecological Limits on brown coal mining, the political debate over the building of new nuclear reactors in the Czech Republic has been revived. The new SEP [6] adopted in 2015 assumes that one or two new nuclear reactors might be built around 2035, although a public tender on building two new nuclear reactors was cancelled in 2014 due to the unwillingness of the Government to guarantee a contract for a difference in power price.

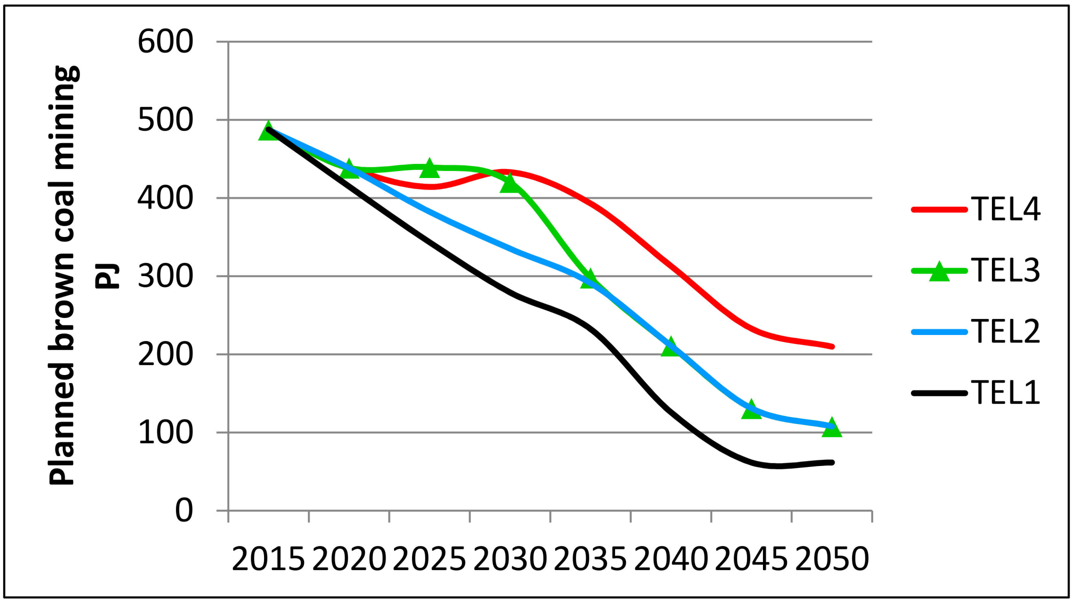

Figure 1. Planned brown coal mining in the four Territorial Environmental Limits variants (5-year averages). Source: own compilation based on [7].

Our paper contributes to energy system modelling in a threefold manner. First, while most modelling work has targeted policies aimed at improving welfare (that will reduce energy use or emissions), our study presents the opposite case. We model the impacts of re-opening brown coal mines that differ in the scope of lifting the territorial ecological limits for mining. We specifically assess the impacts of brown coal availability on the Czech energy system and on the possibilities of achieving carbon reduction and renewable energy targets. More generally, we examine whether new domestic brown coal reserves will be needed to satisfy the predicted domestic demand on energy services. Second, we perform a sensitivity analysis based on several assumptions concerning fossil fuel prices, the European Emission Allowances (EUA) price, and nuclear power usage. Specifically, we assume three sets of the baseline scenario that only differ in the usage of nuclear power, while the remaining six scenarios assume a higher or lower fuel and EUA prices with various combinations of nuclear power. We find that it is the lower price of EUA and/or higher price of fuels—rather than the expansion of brown coal mining—that differentiates the impacts. Third, in addition to the impacts on the energy system we also quantify the impacts in terms of policy indicators—the share of RES technologies in the energy mix, to what degree each scenario and policy will miss the 2030 or the 2050 carbon emission reduction targets, and what the environmental damage and health external costs will be. We find that the damage might be around 1% of GDP over the whole analysed period and thanks to the new policy that expands brown coal mining, no policy targets will be reached.

The previous analyses of the impact of brown coal availability on the Czech energy either address two policy options only [8] or assume one set of EUA and fossil fuels prices only [9]. Máca and Melichar [2] quantified the health effects of airborne emissions from coal mining and the use of extracted coal in all TEL variants, as assumed by the Czech Government, but they did not analyse the impacts on the energy system and hence emissions attributable to optimized energy mix. This paper applies a new extended Integrated Markal Efom System of the Czech Republic (TIMES-CZ) covering the whole energy sector to assess the impacts of all four policy options in question. Moreover, this paper enhances the previous analyses by performing sensitivity analyses built on various assumptions of fuel costs and the CO_2 allowance price, including three possible pathways of nuclear energy in the Czech Republic. Specifically, we are interested in whether the impacts of the newly adopted policy and the other two counter-environmental policy proposals will be weakened or strengthened if different fuel and EUA prices or different development in nuclear power usage are assumed.

Our results show the ratified lifting of the Territorial Environmental Limits—as agreed in 2015 (TEL2)—may induce a higher use of brown coal between 400 PJ and 1317 PJ in the Czech energy system over the period 2015–2050 when this range depends on future fuel and EUA prices and/or nuclear power deployment after 2035. It would imply 37–99 Mt GHGs of released emissions compared to the TEL remained unchanged (TEL1). However, the impacts of an additional revocation of Territorial Environmental Limits under variants TEL3 and TEL4 are very small, since the additional available brown coal reserves exceed domestic demand for brown coal. The 2030 carbon targets will be achieved under all three policy variants that may revoke the coal mining restrictions. According to our assumptions, this target will of course also be achieved by the more stringent policy, TEL1. However, not even the TEL1 restrictive policy variant would achieve the Roadmap 80% target in 2050 and additional measures in both the ETS and non-ETS sectors would be needed to achieve this target. The new coal mining policy as agreed in 2015 and the two alternative options would miss the 80% reduction target by an even larger amount.

In short, the lifting of the brown coal limits as such would not have a significant impact on the deployment of renewable energy sources as they do not compete directly with brown coal but instead compete with more expensive and advanced technologies. Only the use of biomass would be affected, since biomass is co-fired in brown coal power plants. Technology investment costs and fossil fuel prices are in fact the decisive factors for the wider deployment of renewable energy rather than the availability of brown coal. Nevertheless, the share of renewable energy sources per total gross energy consumption may reach 17–24 percent in 2030 and 23–47 percent in 2050. In general, a reduction of nuclear power in the fuel mix will imply a higher share of renewable energy in the energy mix, whereas an increase in the availability of brown coal will lower the share of renewables.

Additional adverse effects of lifting the brown coal limits are the increased environmental and health damages associated with the production of heat and power from coal [10]. Our analysis indicates that the newly implemented policy (TEL2) may result in up to €619 million of additional adverse impacts up to 2050; lifting the brown coal limits further would even increase these external costs by further up to €190 million, depending on the modelling assumptions.

The remainder of this paper is organized as follows: the following section provides a literature review of recent research in energy system modelling. Section 3 describes the TIMES-CZ model and data sources. Section 4 introduces our key modelling assumptions, including assumptions on fuel and EUA prices, costs of new technologies, and the shape of nuclear power development. Section 5 summarizes the impacts of the reference policy and three revocation policies for the baseline scenario. A sensitivity analysis of the impacts for each of the four policy variants, assuming various fuel and EUA prices and nuclear power deployment follows. Section 6 discusses policy implications and the last section concludes.

2. Literature Review

The Integrated Markal Efom System (TIMES) model generator, developed within the "Energy Technology Systems Analysis Program" (ETSAP) of the IEA (see Loulou et al. [11–13]), is a well-established tool for creation of energy models. TIMES has been widely used to assess the decarbonisation pathways and strategies on global [14], European [15], and country level [16,17]. Timmerman et al. [18] classify the TIMES model—alongside MARKAL [19], ETEM [20], and OSeMOSYS [21]—as an evolved energy system model. The flexibility of TIMES allows it to extend its structure and explore the energy system in more detail as needed.

In the last decade the standard structure of the model has been extended or detailed in several ways. The TIMES model, in the same way as any other similar energy system optimization tool, may be extended beyond the power sector towards to newly added sectors or towards more detail of up stream (fuel) processes. For instance, Zhang et al. [22] extend the TIMES model to accommodate the transport sector with biofuel demand, Seixas et al. [23] add electric vehicles, and Daly et al. [24] incorporate additionally travel behavior through the cost of time. A model may be then further detailed in several ways. One possible way of extending the model is to descend from national level to *regional model* in order to better reflect regional diversity in the particular energy market, such as better representation of the heating sector that allows making better links to localized heat demand or inclusion of regionally specific biomass supply and hence region-specific costs [16,22,25]. Another stream of the model extension aims at *temporal* and/or *operational* detail of the model. As found, for instance, by Poncelet et al. [26] in the case of modelling the penetration of intermittent renewable energy sources, improving the temporal representation of their TIMES model may actually outweigh the gains obtained thanks to detailing techno-economic operational constraints. The last possible extension may be based on adding a new impact category, such as GHG and local air pollutants or even adding environmental benefits associated with emissions of these pollutants [8].

Improving the model detail in any of its parts (with respect to region, time, operation, or technology set) may affect the results and yield considerable uncertainty. Price and Keppo [14] distinguish two sources of uncertainty in the energy models: the one related to model structure and its assumptions, including the level of detail embodied in its structure, as discussed above; and another related to input parameter and data used. They focus on the model structural assumptions and suggest so-called 'modelling to generate alternatives methodology' that allows exploring the near cost optimal solution space by scaling up of the total system cost of the previous standard formulation.

Uncertainty stemming from the latter is most frequently addressed through a sensitivity analysis applied mainly for fuel prices [23], capital costs [27] or availability of technologies [28], or magnitude of the discount rates [29]. Nevertheless, the most common approach being followed in the literature (e.g., [16,22,25]) relies on one set of fuel prices and technology costs that are both exogenous parameters of the model.

This paper extends the TIMES model structure with respect to usage of detailed operational data and linking technology operation to emissions and the damage they cause. It also addresses uncertainty by two means, covering both its sources. First, the simplified structure of the TIMES-PanEu model that is based on aggregated technology data is detailed through the provision of plant level data for the heat and power sector. Second, a sensitivity analysis is performed to investigate the impacts of various assumptions on fuel and EUA price trajectories, including three possible patterns of nuclear energy deployment in the Czech energy system.

3. Methods

3.1. The TIMES-CZ Model

TIMES-CZ is a technology rich, bottom-up, cost-optimising integrated assessment model built within the generic and flexible TIMES model generator's General Algebraic Modelling System (GAMS) code. TIMES searches for an optimal solution for an overall energy mix that will satisfy pre-defined (exogenous) aggregated energy demand with the least total discounted costs summed over the analysed period.

TIMES-CZ is based on the Czech region of the Pan-European TIMES-PanEu model developed by the Institute of Energy Economics and Rational Energy Use at the University of Stuttgart [15] that was originally built on the basis of Eurostat energy balances for 2010. TIMES-CZ is, however, updated to account for 2012 individual- and sector-level data and the base year is calibrated according to the Eurostat energy balance. The TIMES-CZ model covers the entire energy balance of the Czech Republic from primary energy sources to final energy consumption as depicted in Figure A1 in the Appendix A.

Compared to the original TIMES-PanEu model, the structure of the TIMES-CZ is considerably extended through the following three ways. First, all sectors included in the EU Emission Trading System (ETS) are disaggregated up to individual plants (except the iron and steel industry), while the non-ETS part follows the original structure as defined by the TIMES-PanEu model. Unique multi-fuel mixes are created for the individual ETS sources according their real consumption based on data from EU ETS emission reports. Other input data for individual ETS sources are obtained from the Register of Emission and Air Pollution Sources (REZZO database) regularly compiled by the Czech Hydrometeorological Institute and the energy register maintained by the Energy Regulatory Office. Second, emission trading is adjusted to take into account the transition to auctioning and derogation (The Czech Republic has made use of the derogation under Article 10c of the EU ETS Directive which allows it to give a decreasing number of free allowances to existing power plants for a transitional period until 2019.). Third, district heating demand and supply are both regionalized into 36 regions according to postal codes.

Emissions of greenhouse gases (GHG) attributable to the country-wide energy balance are linked to the TIMES-CZ model. The model includes all GHG emissions stemming from combustion and technological processes, based on emission reports from EU ETS or emission fuel and activity coefficients. GHG emissions from agriculture and Land Use and Land Use Change and Forestry Use (LULUCF) are not included into the model. It is expected that the GHG emission increase from agriculture will be compensated by GHG emission reduction though LULUCF (based on consultations with the Ministry of the Environment of the Czech Republic). This means the GHG emissions in the model equal to the GHG emission balance with LULUCF.

Plant-level emissions of nitrogen oxides (NO_x) sulphur dioxide (SO_2), and particulate matter (PM) stemming from heat and electricity production in the power sector are also included in the model for the reference year. Emission coefficients for later years, as well as emission intensities of new technologies reflect requirements (Best available technologies—BAT) set by the adopted regulation, as well as a new regulation on emission concentration limits for industrial emissions (Directive 2010/75/EU on industrial emissions).

The technical and economic characteristics of new technologies are taken from TIMES-PanEu [15]. In order to better reflect the newest information on current costs and development of prospective technologies, investment, fixed and variable costs of power generation technologies are updated according to [30].

3.2. Quantification of Damage

We estimate the impact of energy scenarios on the environment and health that are attributable to air quality pollutants using the ExternE (Externalities of Energy) Impact Pathway Analysis (IPA) (an internet accessible version of EcoSense (EcoSenseWeb1.3) was developed within the NEEDS project [31]. See [10,32] for the details). The IPA is an analytical procedure examining the sequence of processes through which polluting emissions result in damages. The IPA comprises four basic steps: (i) selection of the reference power plant and determination of harmful emissions releases; (ii) calculation of changes in pollutant concentrations for all affected regions using atmospheric dispersion models; (iii) estimation of physical impacts from exposure using concentration-response functions; and (iv) economic valuation of impacts. The IPA covers a range of impacts on human health, buildings and materials, biodiversity, and crop yields (see [33] for a detailed description).

In the benefit assessment, we include the most common air pollutants (SO_2, NO_x, PM2.5, PM10) to derive the external cost associated with the releases of these pollutants from district heat and power generation, as endogenously determined by our TIMES-CZ model.

Two approaches may be followed to quantify the external costs over long period in future. First, the same value of damage over the entire period is assumed. Alternatively, the willingness to pay values for avoiding the adverse effects and hence value of damage may be time variant and likely grow over time as real consumption will grow, as assumed, for instance, in Ščasný et al. [33] (following the approach described in [33] and assuming 3, 2, and 1 per cent growth in real consumption before 2015, during 2015–2030, and after 2030, respectively, we get qualitatively similar results as when no price adjustment is made. In absolute terms, cumulative value of the external costs is about 45% higher with the adjustments. This result is available from the authors on request). In this study we follow the former approach. The magnitude of damage corresponds to the pollutant-specific damage factor that was derived within the EU funded NEEDS project [31].

The ExternE's IPA quantifies the impacts of local air pollutants on human health, biodiversity, crop yield, materials that appear mostly in the EU, and also considers health impacts coming from the Northern hemispheric modelling. The damage factors per ton of pollutant used in this study are as follows: €8371 per ton of SO_2, €9359 per ton of NO_x, €25,366 per ton of $PM_{2.5}$, and €1011 per t of PM_{coarse} (all expressed in EUR 2012 using HICP) and these values cover impacts of all the above impact categories. A major part of damage for each of the four pollutant categories is responsible for adverse health impacts, 90% SO_2, 79% for NO_x, 99% for $PM_{2.5}$ and PM_{coarse}. Impacts on biodiversity contribute by 5%, 15%, for SO_2 and NO_x, respectively, and materials effects comprise 6%, 1%, for SO_2 and NO_x, respectively.

4. Scenarios and Assumptions

The impacts on the energy system and costs are analysed for all three policy variants for lifting the Territorial Environmental Limits. TEL2 is currently a binding policy that revoked the past binding decision about the Territorial Environmental Limits on brown coal mining and allowed the revocation of the brown coal mining limits in one of the two regulated open pits (Bílina). In 2015, The Czech Government also considered partially (TEL3) or even completely (TEL4) lifting the mining limits in the second open pit (ČSA). Although the last two policy variants have not been implemented—as stated by the Czech Government—lifting the mining limits at the second pit might be re-considered in the next revision(s) of the State Energy Policy. The impacts of three revocation policies (TEL2, TEL3 and TEL4) are compared to the effects of a reference policy variant (TEL1) that assumes the Territorial Environmental Limits in the two open pits, as agreed in 1991 and revoked in 2015, would be untouched.

Further, we perform a sensitivity analysis to investigate the impacts of various assumptions on fuel and EUA price trajectories and for three possible patterns of nuclear energy deployment on the energy system, emissions, cost and benefits.

Considering the actual costs and power market situation, any decision on building new nuclear reactors is conditional on public support and hence policy decisions. In fact, as revealed in our previous modelling [8,34], no nuclear power plant would be built within the Czech energy system as a result of a free market decision. Despite this fact, the new State Energy Policy [6] assumes one or two nuclear reactors will be built around the year 2035. Our modelling therefore assumes three possible pathways in developing new nuclear power plants within the Czech energy mix, as depicted in Figure 2. The first pathway ('SEP') reflects the 2015 State Energy Policy when new nuclear blocks are constructed around the year 2035, the operational nuclear power plant in Temelín will operate at least until 2050, and the second nuclear power plant in Dukovany may operate until 2035.

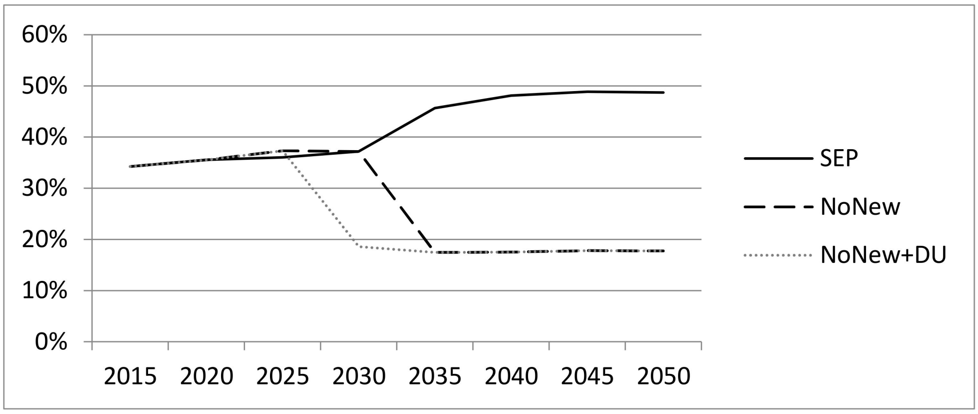

Figure 2. Three assumptions on development pathways for nuclear energy, share of electricity production.

The next two nuclear energy pathways assume no new nuclear power plant construction. While "NoNew" assumes the same operation lifetime for the two current operating nuclear power plants as in "SEP", "NoNew+DU" assumes that the second nuclear power plant in Dukovany will be phased out earlier while the current operation permits are still valid (two out of four blocks at the Dukovany power plant are permitted to operate till 2025, the other two blocks may obtain operational permission till 2027 in 2017. The extension of operations till 2035 and 2037 should be technologically possible, but may not be politically acceptable due to political pressures from the EU (and Austria especially), calling for the shut-down of the Dukovany power plant before 2027).

We note that the share of nuclear power in electricity generation, as described in Figure 2, is given by the three assumptions on nuclear power deployment and is hence exogenous in the TIMES-CZ model. It implies that other technologies are chosen on the basis of cost optimisation to complete (exogenous) aggregate electricity demand and generate all (exogenously given) heat.

The following three different assumptions on fuel prices are considered (see Table 1). The first and the last fuel price sets are based on the World Energy Outlook [35]. While the first one represents WEO *450 Scenario* that may achieve the 450 ppm carbon concentration target, the last one follows WEO *Current Policies Scenario*. The second (Middle) price set is defined as the average of more than ten price scenarios taken from several studies, including [30,35–38]. The highest fuel prices are assumed in WEO-CP. Achieving the 450 ppm target will drastically lower demand for fossil fuels which consequently implies the lowest prices for fossil fuels. The price of other fuels, including biomass, biofuels and nuclear fuel, are assumed to be the same across all assumption sets.

Table 1. Fuel prices as assumed in the TIMES-CZ model (€/GJ).

Assumption	Fuel	2015	2020	2025	2030	2035	2040	2045	2050
WEO-450	Hard coal	2.3	2.4	2.2	2.1	2.1	2.1	2.0	2.0
	Natural gas	7.9	7.8	7.6	7.4	7.1	6.8	6.5	6.3
	Oil	13.0	12.9	12.7	12.5	12.4	12.3	12.1	12.0
	Brown coal—Czech	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
	Brown coal—import	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Middle	Hard coal	2.6	2.9	3.0	3.1	3.2	3.3	3.4	3.5
	Natural gas	8.2	8.5	8.3	7.8	7.6	7.3	7.8	8.4
	Oil	13.0	12.9	12.7	12.5	12.4	12.3	12.1	12.0
	Brown coal—Czech	1.6	1.6	1.6	1.7	1.7	1.7	1.8	1.8
	Brown coal—import	1.8	1.8	1.8	1.9	1.9	1.9	2.0	2.0
WEO-CP	Hard coal	2.3	2.9	3.0	3.1	3.2	3.3	3.4	3.5
	Natural gas	8.2	8.5	9.2	9.8	10.1	10.4	11.2	12.0
	Oil	13.0	13.7	14.4	15.1	15.6	16.2	16.8	17.4
	Brown coal—Czech	1.6	1.6	1.6	1.7	1.7	1.7	1.8	1.8
	Brown coal—import	1.8	1.8	1.8	1.9	1.9	1.9	2.0	2.0

Four different patterns of the future market price of GHG emissions allowances (EUA) are assumed, as depicted in Table 2. Both the SEP and WEO Current Policy Scenario assume EUA at about €40 in 2050, with different paths for reaching this level. The highest EUA price is determined by achieving the 450 target. The lowest EUA price is assumed to reach about €28 in 2050 only and reflects the potential failure of the structural reform of the EU ETS.

Table 2. EUA price assumptions (€2012/t CO_2).

EUA Price Assumptions	2015	2020	2025	2030	2035	2040	2045	2050
SEP	7.5	9.0	23.0	33.0	34.7	36.5	40.0	40.0
WEO-CP	7.5	15.4	19.2	23.1	26.9	30.8	35.2	40.2
WEO-450	7.5	16.9	47.0	77.0	92.4	107.8	125.8	146.7
Low	7.5	8.6	10.4	12.7	17.3	20.7	23.0	27.6

Note: The EUA prices in SEP are in accordance with the Czech SEP [6]. The next two follow EUA prices as predicted by Current Policy or the 450 ppm scenario in WEO [31]. The last EUA price pattern assumes the structural reforms of the EU ETS [39] will fail and the EUA price would increase gradually up to €27.6 in 2050 only.

Combinations of nuclear energy pathways, fuel price sets and EUA prices define our assumption sets to be used in the sensitivity analysis. For the sake of clarity, however, for each of the four policy variants (TEL1–TEL4) we analyse only nine out of all 36 possible assumption sets considered, as depicted in Table 3.

The baseline assumption set (BL) is in accordance with the 2015 SEP; it assumes the Middle fuel prices of the middle high EUA price trajectory (SEP), reaching €40 in 2050, and the building of two new nuclear reactors. Impacts for all remaining scenarios are evaluated relative to the impacts of the respective policy variant with the baseline assumption set.

Half of the remaining assumption sets assume new installations of nuclear power plants according to the 2015 SEP, while no new nuclear reactor will be built in the last four assumption sets.

Two out of the remaining eight assumption sets are the same as the BL, although in contrast to the BL, no nuclear power plant will be built (BL-N) and the Dukovany nuclear power plant will be decommissioned in 2027 (BL-N+D) already. The next three sets (CP, CP-N, and CP-N+D) have the same scenarios as (BL, BL-N, and BL-N+D), but the fuel price set follows the WEO's Current Policy Scenario rather than the Middle fuel price set.

Table 3. Assumption sets for each of the TEL variants.

Parameter	Assumption Set	BL	BL-N	BL-N+D	CP	CP-N	CP-N+D	EUAlow-Faver	EUAlow-Fhigh	450 ppm
Fossil fuel price	WEO-450 (low)									x
	Middle	x	x	x				x		
	WEO-CP (high)				x	x	x		x	
EUA price	SEP	x	x	x						
	WEO-Cur-pol				x	x	x			
	WEO-450									x
	Low							x	x	
Nuclear power	SEP	x			x			x	x	x
	NoNew		x			x				
	NoNew+DU			x			x			

The next two assumption sets represent a very conservative scenario as both assume a low EUA price, always below €28 per ton of CO_2, new nuclear plants, and Middle fuel prices (EUAlow-Faver), or high fuel prices (EUAlow-Fhigh), respectively.

The 450 ppm assumption set is the only one that addresses the 450 ppm target. We note that while the (market) prices of fossil fuels are the smallest in this scenario, the expected (regulated) price of EUA is the highest among all four assumption sets. This set also assumes new nuclear plants will be installed.

Overall, combinations of four TEL variants and nine assumption sets define our 36 scenarios (named by variant and assumption set, i.e., TEL1 CP) for which the impacts are quantified.

Aggregate electricity production and heat consumption are exogenous in accordance with the 2015 SEP and the same in all scenarios. Namely the gross electricity production decreases slightly from 92 TWh in 2015 to 89 TWh in 2050 (domestic consumption increase but net exports drop from 21 TWh in 2015 to 2.5 TWh in 2050). Since we are interested in the net effect of various brown coal availability scenarios, no public support provided for renewable energy or for other alternative or efficient energy technologies is considered in any of the presented scenarios.

5. Results

5.1. Baseline Assumption Set

The baseline assumption set (BL) is in line with the Czech State Energy Policy agreed in May 2015. A new nuclear power plant is built around the year 2035. Its new capacity exceeds the capacity of the Dukovany nuclear power plant which is due to expire. As a result, the share of nuclear energy in electricity production increases from 34% in 2015 to 37% in 2030 and to 45% in 2045–2050. This trend holds for all four TEL policy variants for the BL assumption set.

Usage of brown coal to generate electricity and heat is limited by brown coal availability in TEL1 that keeps the ban on brown coal reserves. Consequently, the share of brown coal in power generation will decrease by 80% from 42% in 2015 to 7% in 2050. Brown coal is replaced by an increase in nuclear power generation and natural gas in particular, followed by greater use of all renewable energy (biomass and bio gas, photovoltaics, with a minor increase in wind energy). This trend is displayed in Figure 3.

Whether a new nuclear power plant will be built or not considerably affects the future fuel mix for power generation. Figure 3 compares the fuel shares for TEL1 with new nuclear power (BL, left panel), with no new nuclear power plant and the Dukovany nuclear plant phasing out around 2035 (BL-N, middle panel), or with faster expiration of Dukovany in 2025 (BL-N+D, right panel).

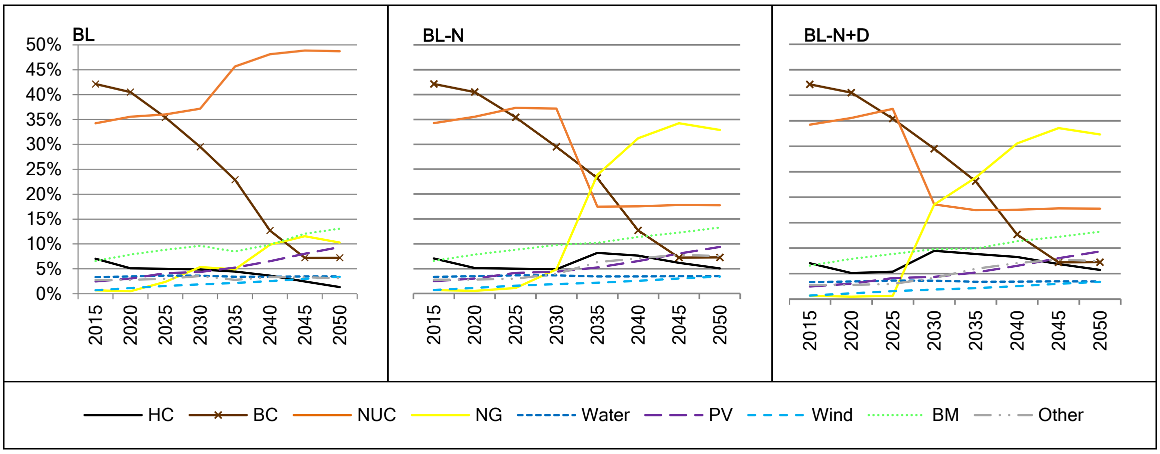

Figure 3. Fuel shares in power generation in the TEL1 variant for the three baseline assumption sets defined by a decision on a new nuclear power plant. Note: HC—hard coal, BC—brown coal, NUC—nuclear, NG—natural gas, PV—photovoltaics, BM—biomass & biogas.

Without new nuclear reactors, nuclear power will fall to 18% (as exogenously given) when natural gas will mainly compensate for this decline (with 34% of power generation), followed by more extensive hard coal usage in existing technologies. Without additional policy measures, nuclear energy will be predominantly substituted by fossil technologies—natural gas and hard coal mainly. The price ratio between natural gas and hard coal plays a decisive role whether natural gas or hard coal power plants will be installed. Specifically, if the price of natural gas increases to 12 €/GJ and the price of hard coal only increases to 3.5 €/GJ, then natural gas technologies will no longer be able to compete with hard coal and no new natural gas power plants will be built. This is the result we observe in CP, EUAlow-Fhigh, CP-N and CP-N+D scenarios (see Figure 7).

A decision on building a new nuclear power plant will have no considerably large effect on renewable energy. In fact, the share of biomass will remain the same across all three baseline assumption sets for TEL1, reaching 10% in 2030 and 13% in 2050. The share of renewable energy sources for power generation will also be same, amounting to 20% in 2030 and 29% in 2050. Due to the relatively high investment costs of renewable energy and the lack of public support assumed in this study, brown coal availability does not affect the share of wind and solar energy—this result is robust as it holds for all three baseline sets and across all four policy scenarios (TEL1–4), (see Figure 7 or Figure S2 in Supplementary Materials).

As a consequence of declining coal usage, total Czech GHGs emissions would decline in TEL1 by almost 50% from 108 Mt in 2015 to 56.5 Mt in 2050. If no nuclear power plant is built (TEL1 BL-N), total GHG emissions would be 10% larger by about 5.6 Mt in 2050, corresponding to about 3% of the 1990 benchmark level (see Figure 12). The effect of the phasing out of the Dukovany nuclear power plant earlier would increase GHG emissions by an additional 4.3 Mt of GHG a year, but only in a 5-year span around 2030 (compared to BL-N). The 2050 carbon target will be missed in any case, reducing GHG emissions by 68–71% in 2050.

Total annualized costs of the whole energy system across all industries will double from €26bn in 2015 to €52bn in 2050. Investments are the main driver of this cost increase. This is partly due to the fact that the current level of investment in the energy sector is very low while the technology portfolio to generate electricity and heat is getting older, partly due to capital-intensive new technologies (the model assumes complete replacement of transport fleet by 2025). Fixed operational & maintenance costs will increase over time as well, but at a much lower pace, by 20% from €2bn in 2015 to €2.4bn in 2050, and variable costs will range between €2.4bn and €2.9bn. On the other hand, fuel cost will decline from €11bn to €8.5bn in 2050 as a result of the increasing share of renewable energy and lower primary energy consumption. Costs for purchasing the EUA will only represent a small share—€0.5bn in 2015–2020—and then will rise to €1.5bn in 2030 and decline to €0.8bn in 2050 despite the increase in the EUA price.

Partial revocation of the coal limits (TEL2, TEL3) only slightly increases GHG emissions compared with TEL1 BL scenario, mainly between the years 2020 and 2035. Lifting the limits completely (TEL4) increases GHG emissions from 2040 by about 10 Mt each year (this is the equivalent of about 5% of the 1990 level) (see Figure 4). This can be translated as a 66 to 70% GHG emission reduction in 2050.

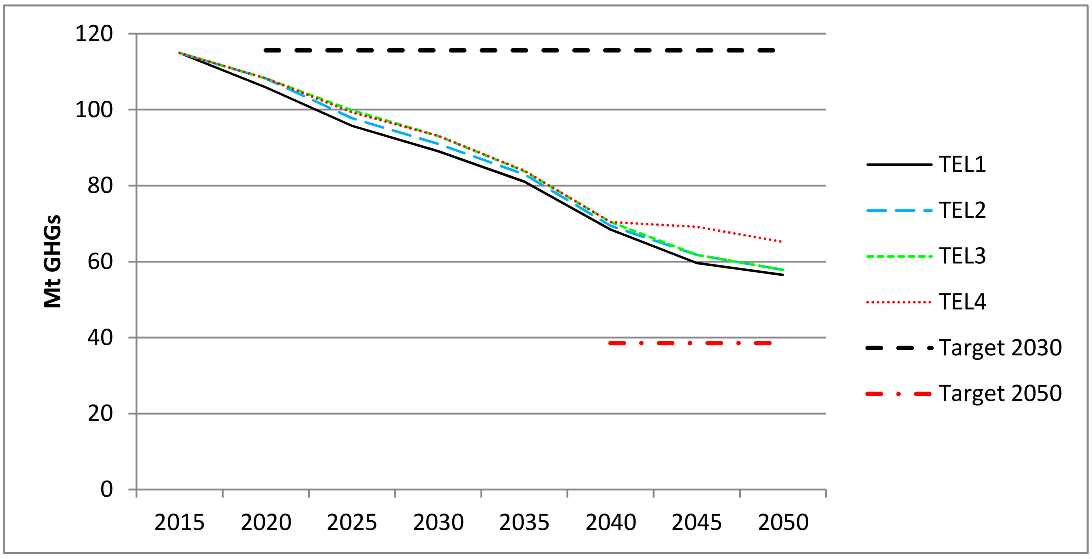

Figure 4. GHG emissions in assumption set BL until 2050 in all 4 TEL variants.

5.2. *Sensitivity Analysis*

The sensitivity analysis evaluates the variance in the impacts on the Czech energy system for four variants of TEL policies, assuming various fuel and EUA prices.

5.2.1. Brown Coal

Total consumption of brown coal in all Czech sectors declines in all scenarios between 2015 and 2050, see Figure 5. The ban on brown coal mining in TEL1 effectively restricts brown coal consumption. Over time, brown coal use will decrease from 501 PJ in 2015 to 90–93 PJ in 2050, with the lowest volume under the 450 ppm assumption set. The TEL1 variant will also yield the lowest cumulative aggregate brown coal consumption over 2015–2050, which is around 10,000 PJ for all nine assumption sets. The adopted policy (TEL2) will result in slightly larger cumulative brown coal use, with the highest volume around 11,317 PJ under the EUAlow-Fhigh assumption set that is still 478 PJ below the economically and technically available reserves to be mined in TEL2.

At the beginning of the analysed period (2015–2020), lifting the limits will increase brown coal consumption by only about 23 PJ per annum (by 5%) in all three TEL2–4 variants under all assumption sets (and domestic brown coal will replace imported brown coal). After 2020, however, fuel and EUA prices and whether new nuclear power will be used or not will start to affect brown coal consumption in TEL2–4 more than the availability of brown coal. This can be seen in Figure 5, which shows a minimal difference in brown coal consumption among the three TEL2–4 variants for 450 ppm or BL-N assumption sets during the whole period. From 2040 onwards, the high price of EUA and the relatively low price of natural gas may lead to the same or even a slightly lower volume of brown coal usage in TEL2-4 than in TEL1 with the ban This is a consequence of the need to install new capacities in TEL1 sooner than in TEL2–TEL4, where it is optimal to install more advanced technologies later.

Additional lifting of the limits above the present status in TEL3 and TEL4 increases the brown coal usage only, compared to TEL2, when a low EUA price or a high price of natural gas are assumed

(EUAlow-Faver, EUAlow-Fhigh or BL, BL-N+D, CP, CP-N, CP-N+D). TEL3 makes available the highest volume of brown coal among all TEL variants during 2025-2035. In this period, TEL3 with high prices of natural gas and hard coal, or a low price of EUA (CP, CP-N, CP-N+D or EUAlow-Fhigh) would lead to the highest brown coal usage. At the end of the period, in 20045-50, TEL4 may lead to the highest brown coal mining in BL, BL-N+D and EUAlow-Faver.

When the limits are lifted, the costs of fuel, EUA prices, and development of nuclear energy actually affect brown coal consumption to a greater degree than the availability of brown coal. For instance, under the 450 ppm assumption set, the cumulative consumption of brown coal equates to 10,400 PJ in all three revocation policies (TEL2–TEL4), which is the lowest volume among all assumption sets. This volume is only 400 PJ or 4% larger than the volume involved in the TEL1 prohibition policy. The BL-N assumption set has the same effect on brown coal use in all three TEL2–TEL4 policies, leading to the cumulative consumption of 10,900 PJ. Besides these two assumption sets, the cumulative use of brown coal in TEL2 is always smaller than under the policies that would lift the mining limits in the ČSA pit as well (eitherTEL3, or TEL4 or both). The high price of natural gas relative to other fossil fuels (CP, EUAlow-Fhigh, CP-N and CP-N+D) and the higher availability of brown coal around 2030 in TEL3 lead to higher cumulative brown coal use in TEL3 compared with TEL2 and even TEL4. In the case of TEL4 when the mining limits will be completely lifted in both mines, we found an additional increase in brown coal consumption compared to TEL2 only in assumption sets BL, BL-N+D and EUAlow-Faver. In these cases, brown coal use will cumulatively reach at least 12,000 PJ, which is at least 20% more than when the limits were in place (TEL1).

5.2.2. Power Generation Fuel Mix

In the next step, our sensitivity analysis aims at the fuel mix for power generation in two ways. First, the influence of different EUA and fossil fuels prices as well as different developments of nuclear power are examined on the agreed policy (TEL2). Figure 6 presents the percentage point (pp) differences in power generation fuel mix under specific assumption sets compared to scenario TEL2 BL. Second, all scenarios are analysed together in order to identify the most important drivers influencing the power generation fuel mix (Figure 7).

In analysing TEL2, we find almost insignificant differences in the power generation fuel mix between BL and the 450 ppm scenario. The high price of natural gas relative to other fuels (CP and EUAlow-Fhigh) involves a substitution of natural gas by hard coal (up to 10 pp). A low EUA price (EUAlow-Faver) may lead to higher shares of hard and brown coal (by 4 and 3 pp in 2040 and 2045, respectively) and lower shares of natural gas (up to -4 pp), biomass & biogas and the other resources. The ban on new nuclear reactors makes a significant difference in the power generation structure: hard coal and partly natural gas replace the drop in nuclear energy (CP-N and CP-N+D sets with high price of natural gas); but in BL-N and BL-N+D, replacement of reduced nuclear energy follows the reverse order—natural gas is followed by hard coal and other sources as the price of natural gas is lower than in the previous case.

The first strong finding resulting from the analysis of all scenarios is that the four TEL policy variants affect the fuel mix much less than the assumptions on different fuel prices or the development of nuclear energy. In general, the greater availability of cheap brown coal under TEL2, TEL3 and TEL4 policies implies that the brown coal substitutes hard coal or natural gas (if the EUA price is low) in the fuel mix.

TEL3 maintains a large number of brown coal power plants still operating up to 2035 and thus results in the highest share of brown coal use for all assumption sets. There is only one case when TEL4 will use more brown coal during 2030–2035 and that is for BL-N+D (see Figure S2 in the Supplementary Material). Figure 7 presents the fuel shares for TEL1, TEL2, and TEL4 under various price assumptions and when the new nuclear blocks will be installed (upper panel) and when these blocks will not be installed (the lower panel).

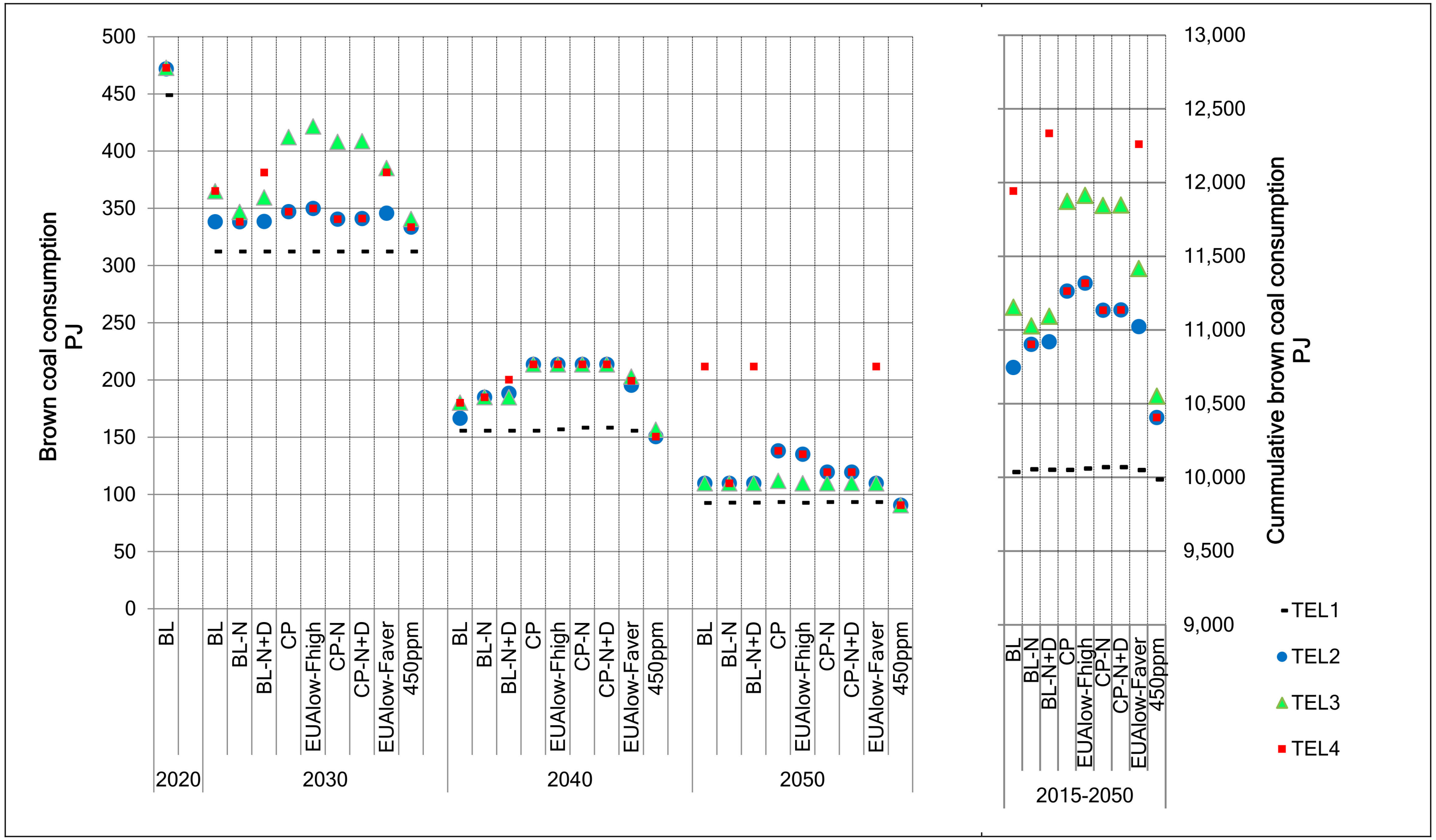

Figure 5. Brown coal consumption in 2020, 2030, 2040, 2050 and cumulatively 2015–2050. Note: The level of brown coal consumption is the same for all assumption sets in 2020.

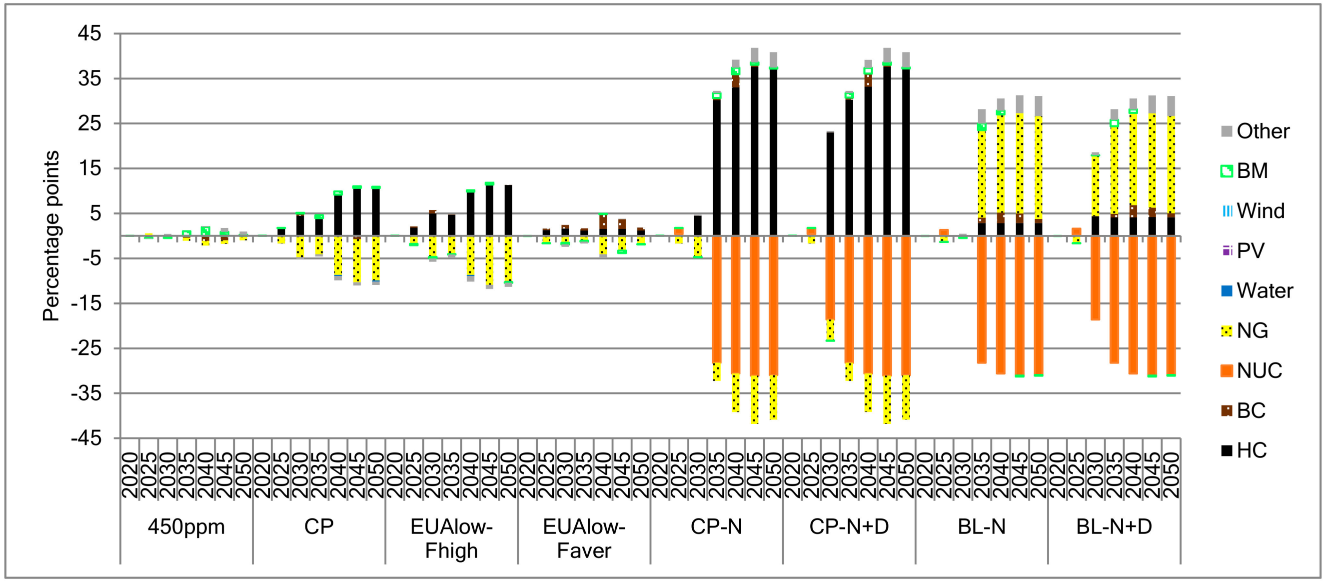

Figure 6. Fuel mix for electricity production in TEL2's scenarios compared to TEL2 BL, percentage point difference. Note: HC—hard coal, BC—brown coal, NUC—nuclear, NG—natural gas, BM—biomass and biogas.

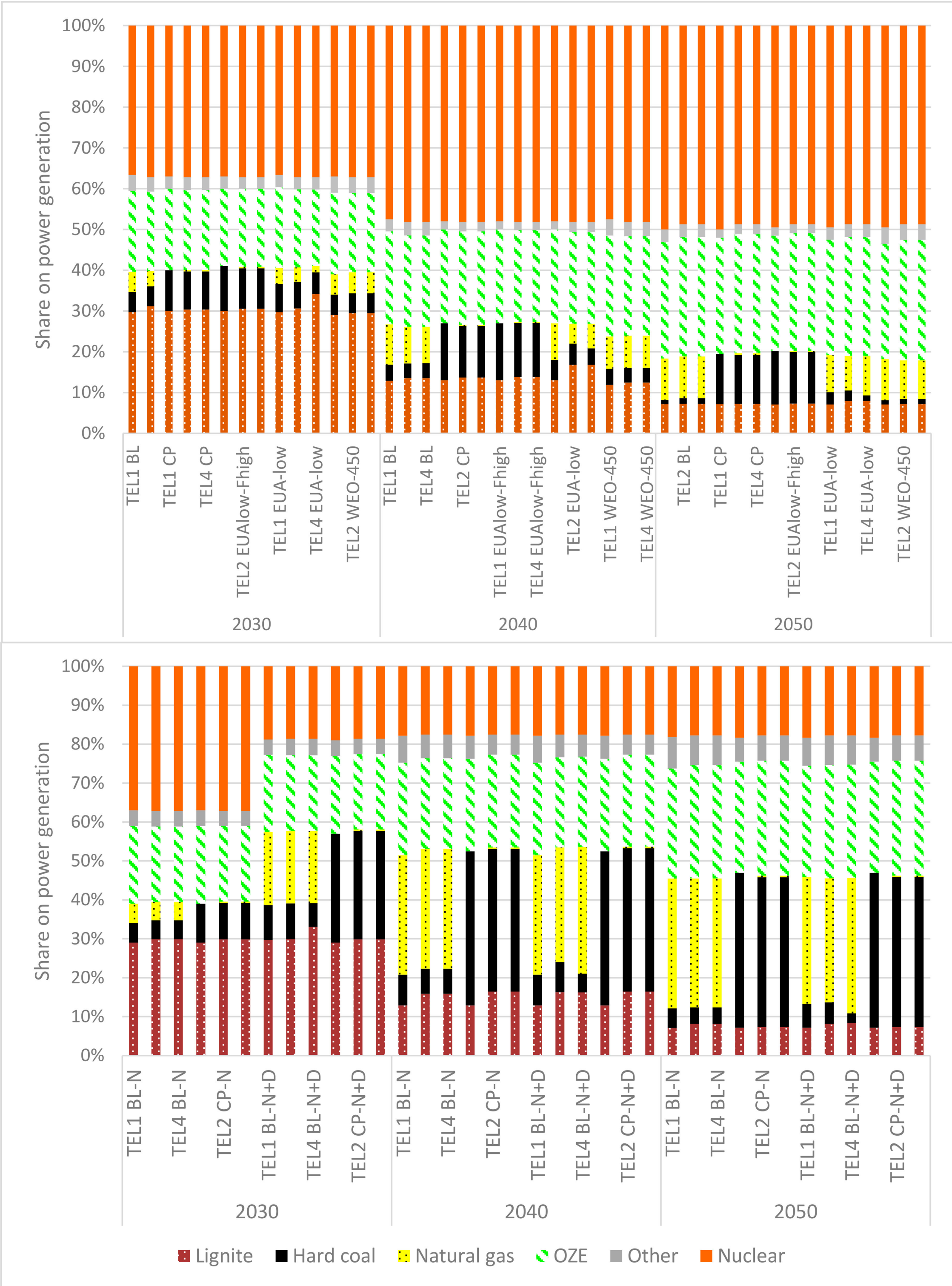

Figure 7. Shares of fuels on power generation in selected years and scenarios.

As expected, the future development of nuclear power is the most influential factor for determining what the Czech power system will look like. The policy that lifts the ban and price of EUA and fuels might have a significant impact on the fuel mix only if no new nuclear blocks are be installed. The higher price of natural gas will make natural gas uncompetitive and as a consequence its share will remain very small throughout the entire period and the share of hard coal will increase significantly. The increased availability of brown coal will only be relevant if the price of EUA is be low or if no new nuclear blocks are installed. In other words, a high EUA price will stimulate cleaner sources, such as gas, and new nuclear power will make new supply of domestic brown coal obsolete.

5.2.3. Annualized Costs

The total costs consist of investment costs, fuel, fixed operational & maintenance, and variable costs, and expenditure on EUA purchases. All costs are annualized taking into consideration the lifetime of each asset, and are expressed in real (not discounted) values. We find that the four policy variants on brown coal mining involve almost same total annualized costs with negligible difference among them, which is up to 0.5% of total costs (in range of −0.03 and 0.27 billion of euro). Different assumption sets involve, however, a larger cost difference as shown in Figure 8 for the TEL2 policy. Compared to the TEL2 BL reference case, the difference in the cumulative sum of total annual annualized costs from 2020 to 2050 resulting from assumption sets covers a range between −27 billion euro and +48 billion euro, when the scenarios without new nuclear reactors (BL-N, BL-N+D) result in the lowest cumulative costs and the 450 ppm set yields the highest sum.

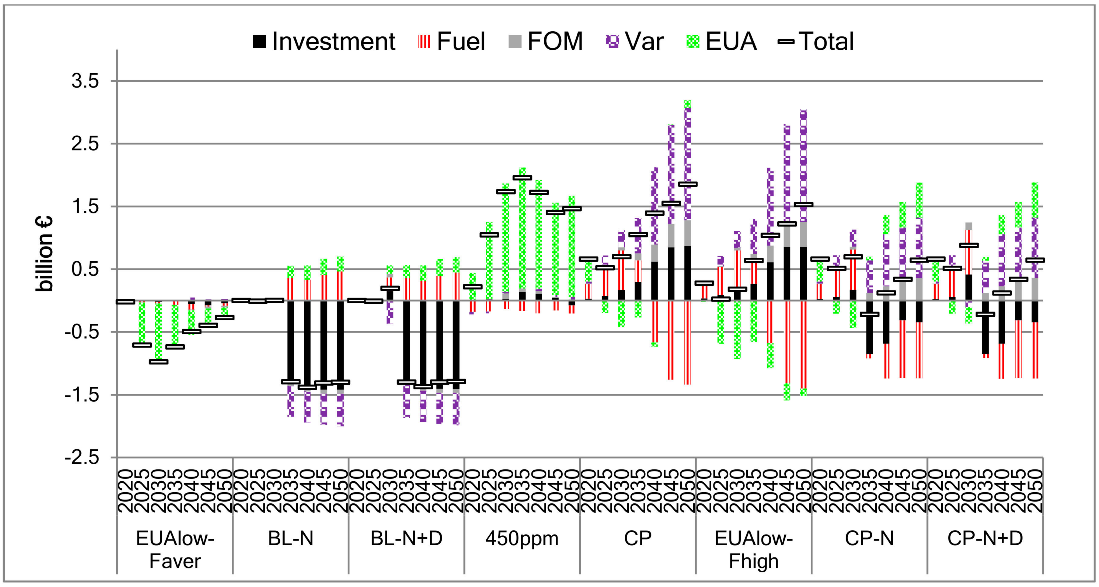

Figure 8. Total annualized costs for TEL2 policy, cost difference compared to TEL2 BL reference case. Note: Average over 5-year time span of annualized cost over (for instance, the 2020 value corresponds to the average of annual annualized cost from 2018 to 2022). The difference in the cumulative sum of total annual annualized costs from 2020 to 2050 is −€26.5bn (BL-N), −€25.4bn (BL-N+D), −€18bn (EUAlow-Faver), +€13.6bn (CP-N), +€14.6bn (CP-N+D), +€24.4bn (EUAlow-Fhigh), +€38.5bn (CP), and +€47.6bn (450 ppm), compared to the TEL2 BL reference case. For a comparison, 1 bln. € in 2020 corresponds to about 0.5% GDP predicted for the same year.

The low price of EUA reduces the total costs by up to €1bn in 2030 (compare EUAlow-Faver and BL). With higher fuel prices (EUAlow-Fhigh), a lower EUA price decreases the payments for emission allowances, but other costs remain unchanged. A very progressive EUA price in the 450 ppm set may increase total costs by €1bn to €2bn between 2025 and 2050, but also lead to savings in fuel costs (compared with the BL set).

The high price of oil may involve a technological shift in the transport sector and as a result this scenario will have the highest impact outside of the EU ETS sectors; it may lead to savings in fuel costs of more than €1bn over 2045-2050 due to partial switch to electrical vehicles, more advanced technologies with higher efficiency, but it may also increase all other costs different than the costs to buy EUA. As a result, the total costs increase by almost €2bn in 2050 under the CP set compared to BL assumptions.

As nuclear technology has the highest investment cost by far, a decision to not build any new nuclear power plants may decrease investment and variable costs in 2035–2050 by €1.4bn and €0.5bn per annum (BL-N and BL-N+D), and the total costs are also lower with no nuclear reactors as a result of lower investment costs for the CP sets (compare CP with CP-N and CP-N+D). Higher fuel and EUA costs may add €0.4bn, or €0.3bn, respectively, to the cost level when low or medium high levels are assumed.

5.2.4. Greenhouse Gas Emissions

Figure 9 shows the cumulative GHG emissions over 2015–2050 in all scenarios. TEL1 results in the lowest magnitude of cumulative GHG emissions across all assumption sets, and they are smaller by 37 to 99 Mt GHGs compared with the TEL2 counterparts depending on the assumption set. The new policy has only a negligible effect on annual GHG emissions. In relative terms, annual GHG emissions with the ban on coal mining are only 0.2 to 6% smaller than the GHG emissions involved with TEL2.

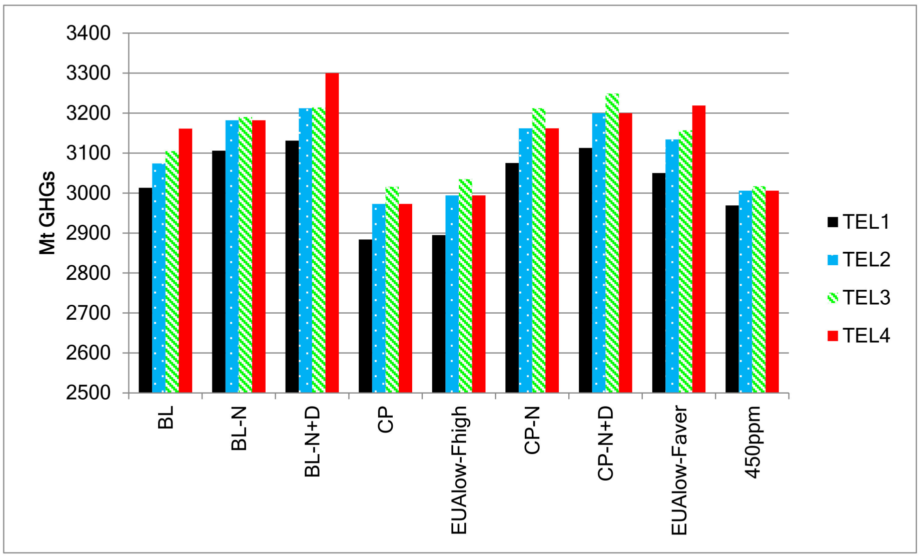

Figure 9. Cumulative GHGs emissions, Czech Republic, 2015–2050.

There are minimal differences in the magnitude of the cumulative GHG emissions among the three policies that (may) revoke the mining limits (TEL2, TEL3 and TEL4) in scenarios without new nuclear reactors (BL-N) and with very high EUA prices (450 ppm) that may likely achieve the 450 ppm target. TEL2 and TEL4 will result in the same level of cumulative GHG emissions as well, when the price of fossil fuels will be high (CP, CP-N, CP_N+D and EUAlow-Fhigh). It means that the complete revocation of the Territorial Environmental Limits (TEL4) will not affect GHG emissions if a strict climate mitigation policy is implemented or fossil fuel prices are high; that is, if coal use responds to higher prices.

Lifting the coal mining limits more in TEL3 will yield higher cumulative GHG emissions than lifting the limits partially (TEL2) across all assumption sets, from 2 Mt in BL-N+D up to 50 Mt in CP-N. Lifting the limits completely (TEL4) will result in the highest GHG emissions among all TEL variants when EUA and fuel prices will be low (EUAlow-Faver) or if the lifetime of the Dukovany nuclear power plant is not prolonged (BL-N+D)—by 85–88 Mt compared to TEL2. Despite the higher usage of brown coal, cumulative GHG emissions are also lower with a high price of fossil fuels (CP and EUAlow-Fhigh) compared to other assumption sets, especially due to lower emissions from transport after 2030 (the energy sector is responsible for less than 70% of GHG emissions in the Czech Republic).

5.2.5. External Costs

Using the ExternE's Impact Pathway Analysis, we quantify the external costs attributable to air quality pollutant emissions. These emissions are associated with adverse health impacts, such as respiratory and cardiovascular illnesses, cancers or premature mortality [40], impacts on buildings and materials, crops or ecosystems [31,33]. In this study, however, only emissions of SO_2, NO_x and particulate matters released from district heat and power generation are considered. The presented results are based on one (constant) damage factor value, regardless of when emissions will be avoided. Human health effects account for approximately 85% of total external costs. Biodiversity impacts, impact on crops and materials account for 9, 2, and 4 percent, respectively. Climate change impacts due to greenhouse gasses are quantified through the social costs of carbon (SCC), using a value of €19 per ton CO_2, similarly as in [10] (Tol [41] provides an exhaustive survey of the literature on the damages of climate change, analysing over 588 estimates from 75 published studies. The author finds the mean estimate of the social cost of carbon to be about $196 per metric ton of carbon (63 2012 EUR per ton CO_2), with the modal estimate at $49per ton of carbon (16 2012 EUR per ton CO_2); see more in [42]).

Due to already tight air quality concentration limits that are expected to be enforced as of 2020, the effect of the three TEL policies on the external costs will not be very large. Thanks to policies already implemented, the magnitude of the external costs is in fact decreasing over time in all scenarios, starting at the level of approximately €900 million a year in 2020 and reaching €300–535 million a year in 2050.

Compared to the damage caused by TEL1 baseline policy, the largest magnitude of the effect can be expected for TEL3 policy if low EUA and fuel prices are anticipated (EUAlowFaver)—under these assumptions TEL3 policy will deliver €808 million of damage more than TEL1. This effect will however appear over the entire period and so in relative terms the cumulative value corresponds to only 0.5% of yearly GDP in 2015. Keeping the ban in place (TEL1) would avoid damage up to €619 million (0.4% of 2015 GDP) over the entire period if TEL2 was not adopted and the largest magnitude of the benefits would be generated when medium prices of fuels and low EUA prices are assumed (EAUlow-Faver).

The magnitude of external costs varies across the assumption sets. In absolute terms, cumulative aggregate over 2015–2050 is within a range of €26 billion (450 ppm) to €31.6 billion (CP-N+D and CP-N), see Figure 10.

These values correspond to 16 and 20 per cent, respectively, of 2015 GDP or they may represent 0.1–0.5 per cent of annual GDP over the period. The 450 ppm set largely affects the power sector, implying the lowest magnitude of external costs and hence the largest value of environmental benefits for all four TEL's policies. On the other hand, scenarios without new nuclear reactors and with high prices of natural gas (CP-N, CP-N+D) result in the lowest avoided external costs and hence generate the lowest magnitude of benefits as nuclear energy is replaced mainly by coal.

The next figure displays climate change impacts attributable to the whole energy balance. We find that their cumulative magnitude varies across scenarios and assumptions more (€54.8bn to €62.7bn) than it is in the case of air quality impacts (€26bn to €31.5bn). Still, the magnitude of climate change impacts over the entire period corresponds to 34 and 39 per cent of 2015 GDP or may be in a range of 0.5–1.1 per cent of annual GDP. Energy-intensive processes other than heat and power generation contributes to this variation by one part, while the absence of any abatement technology for GHGs emissions adds the other part. In cumulative terms, climate change impacts are the lowest in TEL1 CP and the highest for TEL4 BL-N+D. On average, the restrictive policy variant TEL1 may lead to about €3bn lower impacts than the policy variant TEL4, with complete lifting of the limits.

The annual cost values have a decreasing trend from €2bn in 2020 to a range of €1bn and €1.37bn in all scenarios. They are the highest in scenarios with any new nuclear power plant. The TEL1 restrictive policy variant involves the lowest SCC across all TEL variants, both annually and cumulatively. High price of fossil fuels (in assumption sets CP, CP-N, CP-N+D and EUAlow-Fhigh) reduces GHG emissions and hence impacts. This is illustrated by the left panel in Figure 11, reporting the cumulative values.

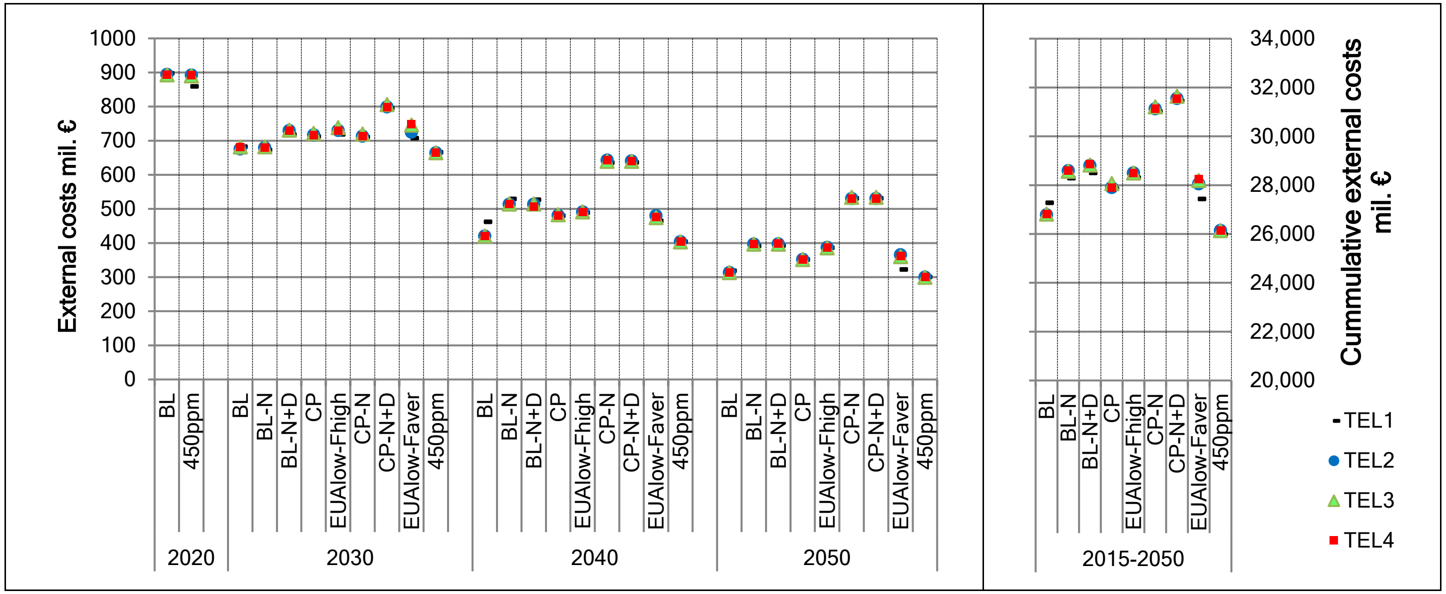

Figure 10. External costs attributable to air quality pollutants released from district heat and power generation, annual averages (**left panel**) and cumulative aggregate over 2015–2050 (**right panel**), in million euro. Note: For sake of clarity, assumption sets BL and 450 ppm in 2020 are displayed only, as the value in other assumption set is on the same level as in BL.

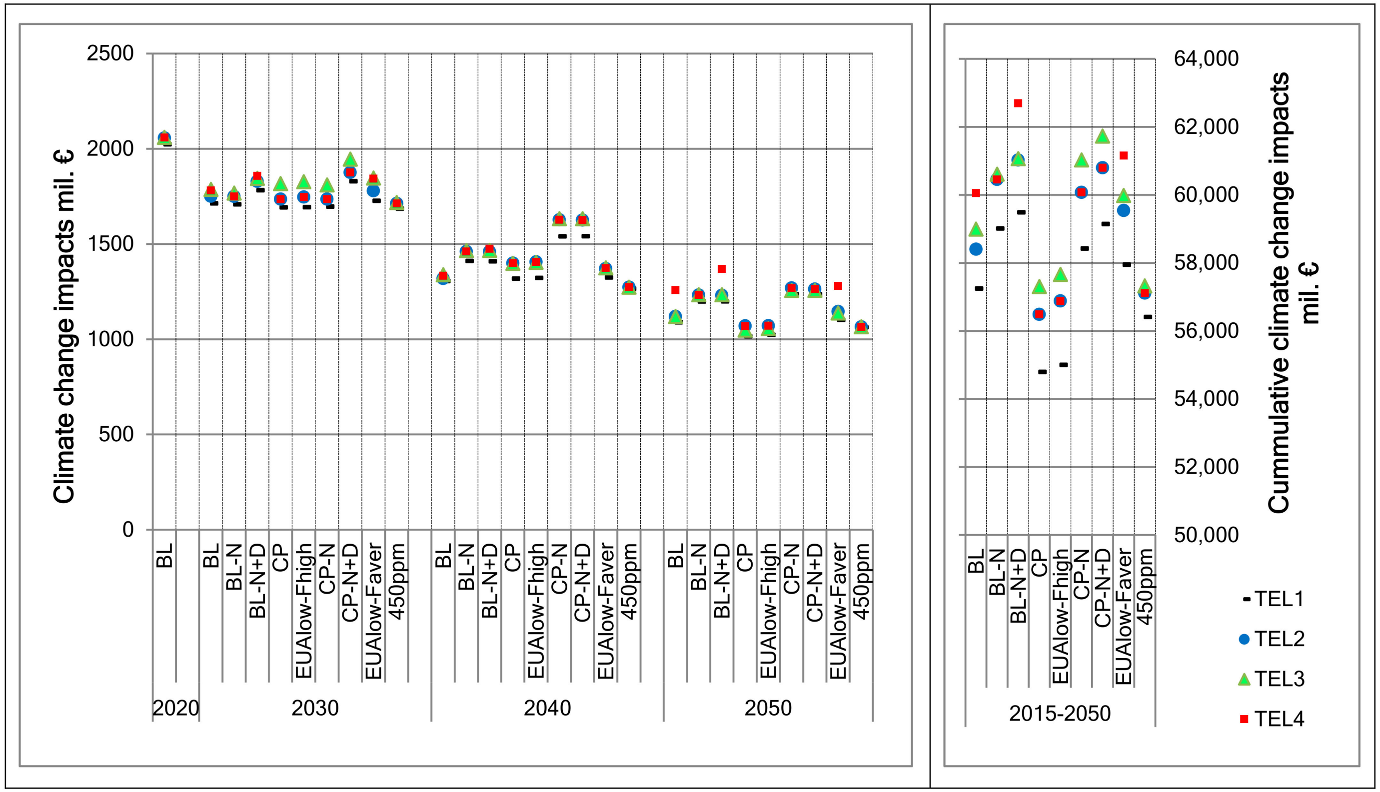

Figure 11. Impacts attributable to GHG emissions and to the whole energy balance, for selected years and cumulative figure. Note: The level of external costs is similar for all assumption sets in 2020. The share of GHG emissions from ETS sectors declines from about 60% in 2020 to a range of 30 and 55% depending on the assumption set. The climate change impacts due to GHGs are actually internalized through the EU ETS.

6. Policy Implications

There are four main policy implications resulting from our analysis:

- TEL 2 policy that was adopted by the Czech Government in September 2015 may have a more significant effect on the Czech power sector only if (1) no new nuclear power plant is built around 2035, or (2) the EUA price remains very low (<10 € up to 2025 and <27 € up to 2050) and the price of natural gas does not increase considerably at the same time (see EUAlow-Faver scenario). Recently adopted policy (TEL2) may on the other hand reduce fuel dependency and in particular import of low quality brown coal needed for the heating sector. However, the volume of brown coal imports is very small, amounting to 3 Mt a year that corresponds to 6% of total brown coal demand in 2015.
- There are two other policy options for lifting of the Territorial Environmental Limits further and beyond TEL2 that are still on the policy agenda of the current Czech government. Compared to the TEL2, both of these policy options (TEL3 and TEL4) would have a significant impact on the Czech energy system only if (1) the price of natural gas increases considerably; (2) the EUA price remains very low and the price of natural gas is not very high; and (3) no new nuclear blocks are built and the lifetime of the currently operated Dukovany nuclear power plant is not prolonged until 2035 at the same time (see BL-N+D scenario). Still, compared with the already adopted policy, the effect of the two least ecologically stringent policy proposals may change fuel mix in a magnitude of a few percentage points.
- Due to tightening air quality concentration limits in already implemented policy neither of the four TEL policies will have a significant effect on emissions of local air pollutants and hence related externalities attributable to the energy sector. However, policy that lifts the mining limits will have a considerably larger impact on GHG emissions and thus will result in adverse climate change impacts. Over the entire period, keeping the ban (TEL1) may lead to about €3bn lower damage than the policy that would lift the limits completely (TEL4). Lifting the limits on mining brown coal can be thus considered as very effective policy going against current trends in de-carbonizing the economies and energy systems in particular.
- The Czech Republic is well on the way to fulfilling the 2030 target of a 40% reduction of GHG emissions compared with the 1990 level. Based on our analysis, the GHG emission reduction should be achieved at least at the level of 47% in the worst case in the TEL3 CP scenario. If the government had agreed on keeping the TEL1 variant, the reduction potential would have been up to 55%. But even for the newly agreed policy (TEL2), the GHG emission reduction potential ranges between 50 and 54 percent in 2030 as shown in Figure 12.
- The 80% GHG emission reduction target for 2050 will not be achieved by any policy and under any assumption scenario, even if the territorial mining limits were kept (TEL1). Due to the high price of oil resulting in a high emissions reduction in the transport sector, there is the biggest GHG emission reduction potential for the CP assumption set, yielding an approximate 75% reduction in TEL1 and TEL3, or a 74% reduction in TEL2 and TEL4 policy variants. The lowest GHG emissions reduction in 2050 is achieved in scenario TEL4 BL-N+D; that is, when the mining restrictions are completely lifted, when operations at the older Dukovany nuclear power plant are not extended and no new reactors are build, with prices of fuels and EUA in the middle of the range.
- Building a new nuclear power plant would not lead to higher total annualized costs under the very high fossil fuel prices only (CP-N and CP-N+D).

As the current State Energy Policy [6] assumes installation of new blocks of a nuclear power plant, there is no need for further lifting of the Territorial Environmental Limits. Only if the European effort to mitigate climate change was unsuccessful and the EUA price was low, some of the additional brown coal outside the limits could be used.

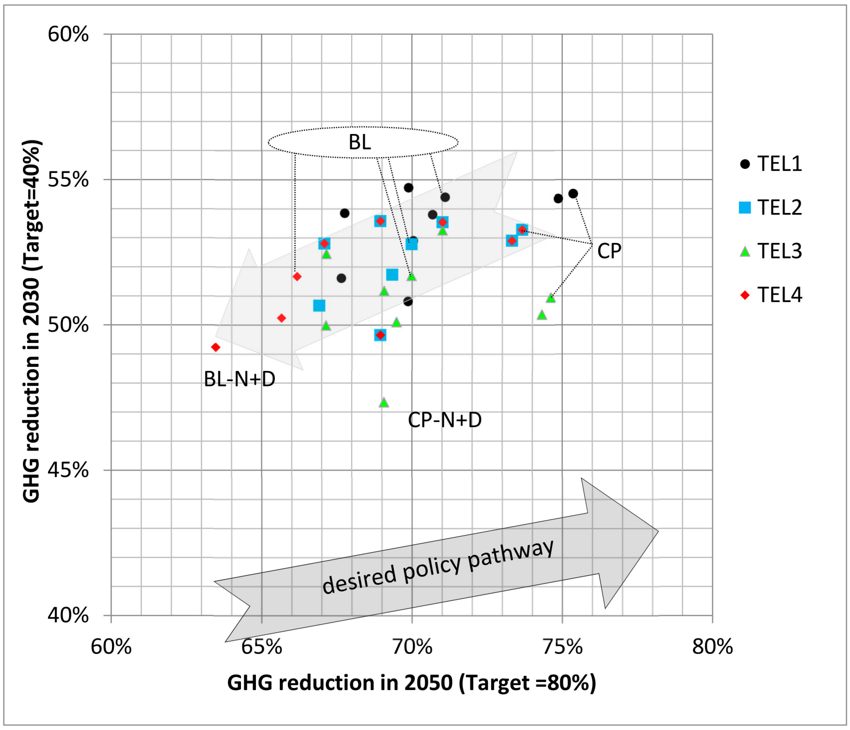

Figure 12. GHGs emissions reductions in 2030 and 2050, the 2030- and 2050-targets compared to the 1990 reference level. Note: Green triangles are always lower than blues and reds, indicating TEL3 is worse to reach the 2030 40% target than TEL2 (blue) and TEL4 (red). The reds are always more on the left (or at the same position) as green or blue, indicating missing the 2050 target most. The black circles are always on the top and on the right, showing that TEL1 has the best performance to reach both 2030 and 2050 targets.

7. Conclusions

In response to the massive destruction of the landscape and heavily polluted air due to domestic brown coal burning, in 1991 the Czech Government decided to restrict brown coal mining to specified territories in the North Bohemia coal basin, the so-called Black Triangle. Many other countries have restricted usage of coal, especially brown coal and lignite, to reduce greenhouse gasses for the last two decades, as a response to climate change impacts. The revocation of Territorial Environmental Limits on mining brown coal mines in 2015 by the Czech Government (TEL2 variant) represents an opposing policy, going against current modern policy trends. Our modelling shows that lifting the limits will lead to 400–1317 PJ higher brown coal consumption and thus to higher GHG emissions by 37–99 Mt over the period 2015–2050 compared to a policy that would maintain restrictions on the brown coal mining (TEL1). This range is quite large and stems from different assumptions concerning fuel and EUA prices and the deployment of nuclear power assumed in this paper.

The modelling results are more sensitive to price assumptions than to different deployments of nuclear power (compare with [9]). In fact, only under the highest EUA price assumption, the newly accessible brown coal—being stranded within the limits until 2015 (TEL2)—will not be domestically used completely, but the volume of imported brown coal varies. On the other hand, in the case of completely abandoning the mining limits (TE4), the share of domestic usage of newly accessible brown coal declines with increasing EUA price from 80 to 35 percent with regard to nuclear energy development.

In short, it is not lifting the Territorial Environmental Limits on brown coal reserves that will have large impact on the fuel mix of power generation. Rather it will be the (internal) decision of the Czech Government concerning nuclear energy use in the Czech Republic in the future, and even more the (external) factors, such as market prices of fossil fuels and price of EUA. The TEL lifting will also not play a significant role in determining the total costs of the Czech energy system. The lifting of the TEL will not have a large impact on the magnitude of the external costs attributable to district heat and power generation either, as strict concentration limits on air quality pollutants have been already implemented. Again, the governmental decision about development of nuclear energy and market prices of the EUA and/or fossil fuels are the key factors of the fuel mix, economic costs and health externalities.

Any of the three policy options that lift the Territorial Environmental Limits on brown coal reserves will complicate the 2050 GHG emissions reduction target to be achieved in the Czech Republic, without additional expensive measures to be implemented outside the ETS sectors. Moreover, the Czech Republic is committed to achieving a 13% share of renewable energy in total gross energy consumption in 2020 [43] and almost 20% in 2030 (indicative target [44]). In combination with the present low public support provided for renewable sources it could be also difficult to reach these targets when new brown coal reserves will be accessible (since 2014 the Czech government no longer subsidises new photovoltaic and biogas power plants with feed-in-tariffs or a quarantined price, and this subsidies to all other new renewable sources, except small hydro ceased from 2016 [45]—partly as a result of massive subsidising in 2009 and 2010 as analysed in [46]. On the other hand, an investment subsidy for photovoltaic in households was introduced in 2016).

Our analysis focuses on the period between 2015 and 2050 since very few data beyond 2050 are known or at least forecasted. In this context it is worth mentioning that the entire revocation of the Territorial Environmental Limits in variant TEL4 would increase brown coal mining even after 2050, by about 105 PJ per annum till 2074 [47]. Moreover, a more environmentally-friendly technology mix may also generate environmental benefits beyond 2050, as the technological lifetime of some technologies that will be installed up to 2050 will be longer than the period up to 2050. Neither of these effects are considered in the presented analysis.

The main limitation of our analysis is exogenous energy demand and further assumptions on the Czech energy market that follow the Czech 2015 State Energy Policy. Following the 2015 SEP allows us to better disentangle the effect of the Territorial Environmental Limits policy variants, or fuel and EUA prices from the possible effects on the supply side of the energy system that are not incorporated into the SEP. There are other important factors that may affect energy efficiency improvements, including increasing environmental awareness and concern [48] or factors that may minimise the energy efficiency gap. Energy efficiency or demand side management is not a part of the presented model. Instead, we follow the aggregate energy demand, as defined by the 2015 SEP, that also allows us to avoid double counting of energy efficiency improvements that are already accounted for in the calculations by the SEP. As a result, consumer behaviour is taken into account only implicitly through the modelling assumptions and not as a part of the model structure. We will focus on this limitation in our future research.

Supplementary Materials: The following are available online at http://www.mdpi.com/1996-1073/10/12/1947/s1, Figure S1: Undiscounted annualized costs of the whole energy system (including transport and other sectors) in TEL1 under the BL assumption set (billion €2012), Figure S2: Percentage point difference in the electricity production share between TEL2 other TEL variants in corresponding assumption sets.

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Appendix A

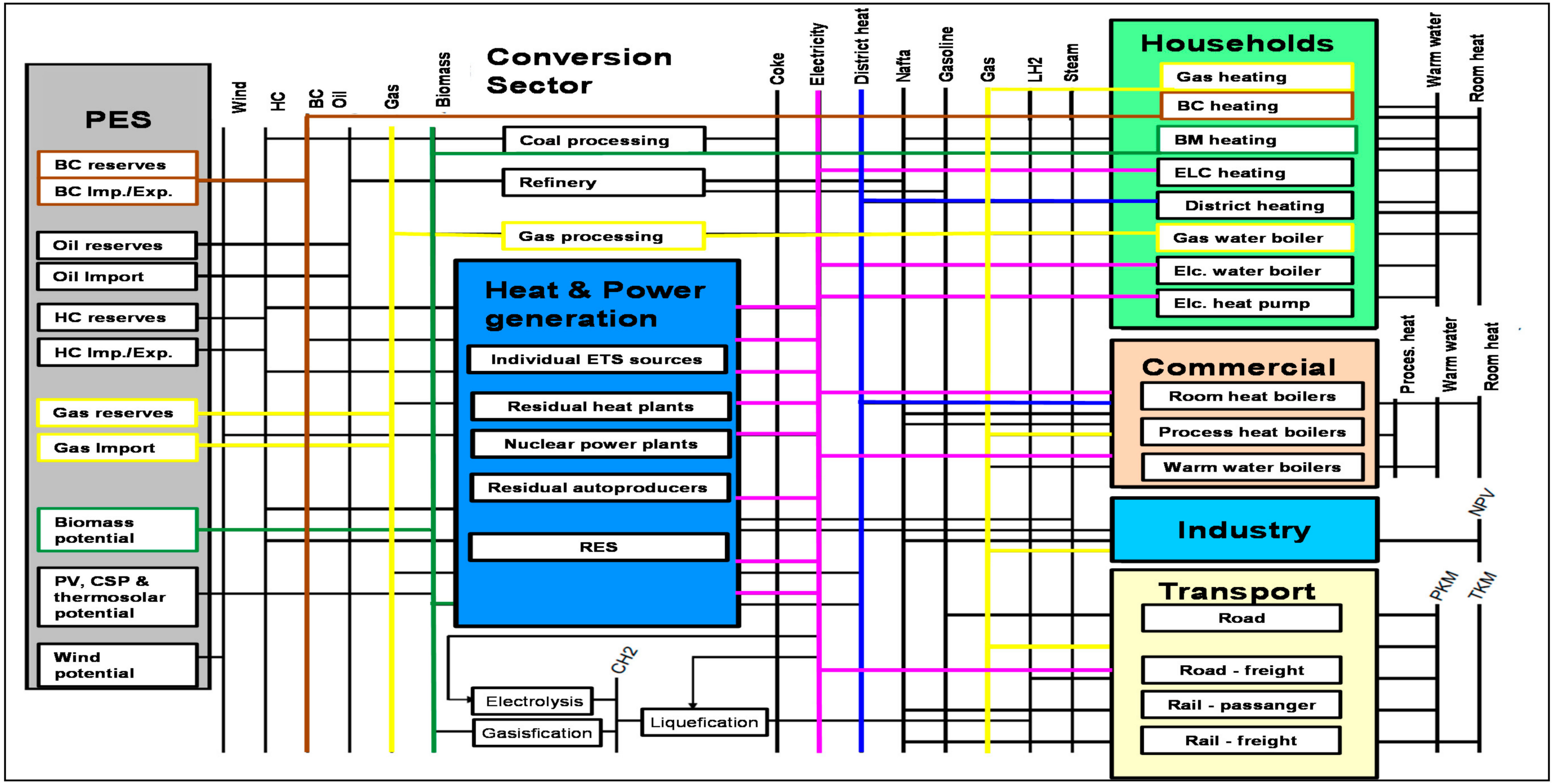

Figure A1. Model TIMES-CZ schematic structure. Note: PES—primary energy sources, BC—brown coal, Imp./Exp.—Import/Export, HC—hard coal, PV—photovoltaic, CSP—concentrated solar power, ETS—emission trading system, RES—renewable energy sources, CH2—compressed hydrogen, LH2—liquid hydrogen, BM—biomass, ELC—electrical, NPV—net present value, PKM—passenger-kilometre, TKM—ton-kilometre.

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