What Is Effect of Climate Change Mitigating Policies on Energy Sector in Slovakia?

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Abstract

We assess the impacts of more strict regulation than the EU-wide 20% CO_2 reduction target in 2020 on Slovak energy sector. Linear dynamic optimisation model MESSAGE with very detailed structure of Slovak energy sector is used for the assessment of impacts of imposing a carbon tax of €17 per tonne of CO_2 and for two emission caps on CO_2 emission that follow the EU policy to tighten the GHG target at the EU. The impacts on the fuel-mix and the technology-mix of energy sector in Slovakia, air quality and GHG emission, economic costs are assessed. Environmental benefits attributable to air pollutants and greenhouse gasses are quantified by using the ExternE impact pathway analysis. The impacts of *17€* scenario are similar to the baseline scenario. The Slovak public electricity sector achieves CO_2 emission intensity of 0.465 t CO_2 per MWh that is lower than the EC benchmark already in 2009. Maximal feasible CO_2 emission reduction in the Slovak electricity sector is 24.6 % compared to the year 2005. The average carbon intensity will decline to 0.057 tCO_2 per MWh in 2020 and result in 15.4 % reduction of CO_2 in 2020 compared to the *17€* scenario level. Total production costs are €481 million higher (18.6%) in *Cap24.6* scenario. As a consequence of the emission reduction, the externality costs are €190 million smaller in *CAP24.6* scenario than in the *17€* scenario in 2020. Our results indicate that it is feasible to reduce CO_2 emissions in the power sector in Slovakia more than the 20% reduction target set at the EU level.

Keywords: optimisation model; energy system; MESSAGE model; climate change mitigation; external costs

JEL: Q40; Q52; C61

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1. Introduction

Regulation enforced recently in Slovakia to mitigate greenhouse gasses and airborne pollution in energy sector is neither able to internalise external costs nor effective to motivate abate emissions. For instance, (Máca et al., 2012) estimate that the three instruments being enforced in Slovakia, namely charges on air quality pollutants, energy tax and cross-subsidy of renewable energy sources, altogether internalise only about 55% of the external costs attributable to air quality emissions from power sector, while the emission charges and energy tax both introduce only about 5% of damage. In 2010-2011, freely allocated EUAs to Slovak combustion installations were 64% larger than the verified CO_2 emissions and as a result Slovakia can enjoy economic benefit from the largest over-allocation of the EUAs among all EU Member States. Such instrument cannot however provide any stimuli in power sector towards resource-savings.

Coping with climate change, resource efficiency and air quality belong to the key topics in the EU agenda for environmental policy and strengthen environmental regulation might be one of the consequences of this trend. Among all intended instruments, the climate-energy package with the 20-20-20 targets is likely one of the most influential EU policy being discussed lately. Further tightening the EU GHG target from -20 to -30% was then one of the responds of EU authorities to the effect of global financial crisis on economic production and consequently on energy use and emissions that should turn the policy back to be effective. It is reasonable to assume that such policy will have large effect mainly on carbon intensive sectors and particularly power sector including economic agents in Slovakia.

Several types of energy models have been developed to furnish the policy makers by impact assessment made for intended policy and regulation. However, only very few models focusing on the energy sector have been applied in the Slovak Republic. For example, (Kouvaritakis et al., 2005) investigate the effects of implementation of the EU Energy Tax Directive (2003/96/EC), CO2 tax and climate policies also on Slovak economy by GEM-E3, a macro-sectoral general equilibrium model. The same model, but enriched by detailed technological and abatement costs information from the bottom-up GAINS model and by damage costs, is used by (Van Regemorter, 2008) and (Pye et al., 2008) to evaluate the macro-economic impacts for a revised National Emission Ceilings Directive (with and without the climate/energy package). (ENTEC, 2008) study uses the macro-econometric E3ME model to assess the impacts of revisions to the EU's Emission Trading System and Energy Taxation Directive, while the macro-econometric model GINFORS evaluates the effects of several environmental/energy policy scenarios (Meyer, Lutz and Wolter, 2005; Meyer and Lutz, 2007). However, neither of these models has evaluated the macroeconomic impacts in the Slovak Republic in great detail. Computable General

Equilibrium models developed merely for the Slovak Republic (e.g. Livermore, 2004) deal mainly with fiscal, FDI, trade and interest & exchange rates shocks and don't focus on the energy sector. As far as we know, a few predictions for Slovak power sector have been only made by means of a bottom-up energy model, MESSAGE, (e.g. ECOSYS, 2010). Projections of emissions for the National Report on Climate change, the Biennial report to the EU and other documents were obtained from this model. Neither of these applications analysed comprehensively the effect of several carbon-specific policies on power sector in Slovakia. Main contribution of our paper is to fill this gap and by means of the bottom-up energy model to assess the effect of three policy scenarios on energy, environmental and economic indicators. Specifically, we use updated version of the MESSAGE model, as in (de Bruin et al., 2011), and analyse the effect of imposing a carbon tax of €17 per tonne of CO2 and then two different caps on CO2 emission that follow last EU policy to tighten the GHG target at the EU on the fuel-mix and the technology-mix, on air quality and GHG emission, on involved economic costs and environmental benefits.

The rest of the paper is organized as follows: Section 2 introduces our model, while next section describes data, main assumptions and policy scenarios. Simulation results are presented in Section 4 and the last section concludes.

2. Method: Model Description

The energy models can be divided into two broad modelling approaches: top-down and bottom-up. The top-down models focus on the entire economy on aggregated level and do not include detail structure of the energy sector, while the bottom-up models focus on selected sector of the economy (energy) on very detail level but they lack the inter-linkages to other economic sectors usually. (Jebaraj & Iniyan, 2006) provide one of the most comprehensive reviews of energy models used worldwide.

In this paper, we use a bottom-up energy model MESSAGE, i.e. Model for Energy Supply Strategy Alternatives and their General Environmental Impacts, originally developed by International Atomic Energy Agency (IAEA). The model is a linear dynamic bottom-up optimisation model designed to simulate and optimise energy system from resource mining or import through to final demand.

The steps of energy transformation from primary energy sources to final energy demand create individual links of energy chain – co called *technology*. Particular levels of the energy chain build on each other and output from the lower level becomes input to the higher level.

The objective function minimizes the sum of all discounted costs. Below a simplified form of the function is described[1]:

$$\sum_t \left[\beta_o^t \left\{\sum_j pal_{j,t} \cdot \mu_j \cdot var_{j,t} + \sum_j \sum_{\tau=t-\tau_j}^{t} kap_{j,\tau} \cdot fix_{j,t}\right\} + \beta_i^t \left\{\sum_j \sum_{\tau=t}^{t+\tau_j} kap_{j,\tau} \cdot inv_{j,\tau} \cdot fri_j^n\right\}\right],$$

where j is technology. Technology means any link in the energy chain including primary fuel where the fuel price is the $var_{j,t}$. t is period of optimization, τ is period when new capacity is built, $t, \tau = 2009, \dots 2020$; β_i^t and β_o^t are discount coefficients for investment costs and other costs; $var_{j,t}$ is variable cost of j in t; $fix_{j,t}$ marks fix cost of of j in t; $inv_{j,\tau}$ are the specific investment cost of j in period τ (given per unit of main output); $kap_{j,\tau}$ is is the annual new built capacity of technology j in period τ; $pal_{j,t}$ is fuel consumption of j in t; μ_j is energy conversion efficiency of j; ; τ_j is plant life time of technology j;and fri_j^n is the share of this investment that has to be paid n periods before the first year of operation.

Like any linear optimisation model, MESSAGE is not able to simulate the demand response to price changes. Aggregate energy demand, or its main sub-sector components, constitute the main exogenous input to the model. The main advantage of MESSAGE model is its very detailed technology set. The model searches for the best 'technology set' that minimises total social costs subject to given prices and defined constraints. In principle, there are three types of the constraints: policy-relevant constraints (such as emission ceilings and caps, extraction limits, acceptance of nuclear power, etc.), environment-specific constraints (for instance, fossil fuel reserves, or biomass availability) and technology-specific constraints (e.g. maximum share of co-burnt biomass). For more details about the model see (Rečka (2009) or the online Annex on www.czp.cuni.cz/ekonomie/MESSAGE description_CUNI.pdf.

The structure of our MESSAGE model follows Slovak national energy balance simulation and it is broken down into several horizontal levels, which simulate the individual steps of energy conversion from primary resources to final energy use: 1) **Primary energy** calculates fuel costs as well as the scope for fuel substitution based on national resource availability and import potential; 2) **Fuel mix** contains fuel input to individual chains, characterised by emission factors as well as emission abatement technologies; 3) **Emission trading** simulates sale or purchase of CO_2 emission allowances in order to comply annual emission quota for individual or grouped emission sources within the energy chain; 4) **Energy conversion** represents conversion from fuels to energy carriers (electricity, heat, process fuels, etc.) and installations of new technologies are simulated here;5) **Losses –** simulates losses occurring during energy distribution and conversion; and 6) **Final energy** is the energy demand of

[1] Detail description of the objective function and other characteristics of MESSAGE you can find in IAEA (2002, Annex A) or in online Annex to this paper on www.czp.cuni.cz/ekonomie/MESSAGE description_CUNI.pdf.

individual energy chains including energy saving measures on the demand side of the energy balance.

The optimisation process is performed in several nodes of energy balance. Optimal technology set is chosen for electricity generation delivered to grid, industrial heat demand, and district heat demand. The model does not search for the best technology set in remaining fuel nodes. Fuel mix is in most cases given by applied technological process in these remaining nodes and can be hardly changed without changing whole technology fully.

Several vertical types of energy chains are broken down into several emission sources included or non-included in the National Allocation Plan. The model includes following four categories of the energy chains:1) Electricity generation in publicly operated power plants; all of them included in the NAP; 2) Publicly operated cogeneration plants (CHP) and heating plants; split into sources in and outside the NAP; 3) Manufacturing sectors such as metallurgy, chemistry, engineering, pulp and paper, mineral products, wood processing, mining and others; each split into NAP and non-NAP sources; and 4)Non-industrial sectors such as services, institutions and agriculture; each split into NAP and non-NAP sources. The energy conversion chains follow the final energy demand that is further divided into several categories: grid electricity, industrial heat demand, fuel use in technological processes, district heat demand and residential heating demand. Special attention is given to large energy consumers such as US steel, gas utilities and oil refinery.

Abatement of CO_2 emissions is possible only through supply side measures. Any effect of abatement measures at demand side may be included only exogenously through setting adjusting the aggregated demand of given sub-sector Specifically, we implement following five CO_2 abatement measures in the MESSAGE model: biomass and coal co-firing in energy sources included in ETS sector; new installations of biomass combustion for district and industrial heat supply in both ETS and non-ETS sector; new installations of biomass combustion for electricity supply in grid (ETS sector); and wind and photovoltaic generators. Due to the prohibitively high cost of carbon capture and storage, this technology is not included in recent version of the model.

3. Key Variables in the Model

Model Assumptions

Any prediction or scenario assessment is determined by model assumptions and data. Among the model assumptions, there are particularly three that have the key effect on the modelling results:1) energy demand; 2) fuel prices; and 3) technical and economic data of new technologies that are all exogenous in our model.

The calibration of final energy demand for the first year of the projection, the year 2009, is based on fuel consumption from the NEIS database.

We do not count for international trade explicitly while assuming exogenous energy demand, but rather we implicitly assume that any exports and imports are included in the 2009 demand level. We review several literature sources in order to set a most likely path in electricity consumption for Slovakia, particularly (SEPS, 2011b), (Resch et al., 2010), and (EC, 2010), resulting in the prediction ranging from 32 to 41 TWh in 2020. Assumption on fuel use takes also into account Slovak energy saving potential (http://www.eepotential.eu), (Fraunhofer et al., 2009) and projection on electricity demand implicitly assumes an autonomous adjustment due to electricity price increase given by elasticity of demand with respect to GDP as econometrically estimated in (de Bruyn et al., 2011) at +0.12. It gives us the value of electricity consumption around 30.4 TWh in 2020 and based on this projection we assume annual growth in electricity demand of 1.37 %. This implies electricity generation in 2020 at the level that is 16 % larger compared to the base 2009 level (26.16 TWh) (SEPS, 2011a).

Electricity generation from nuclear power plants is kept constant, i.e. we keep the 2009 level (14.081 TWh) during the whole period 2009-2020. In other words, we implicitly assume that the new nuclear blocks in PP Mochovce will replace the old blocks that are going to phase out in PP Jaslovské Bohunice. Furthermore small part of electricity produced in small privately owned plants (1.2 TWh), which use electricity mostly for their own use (and thus is not supplied to national grid), is also kept constant over the whole analysed period. Electricity generation from large hydropower-plants in the base year (4.6 TWh) is also assumed to remain constant over the whole period due to limited possibility to build new large hydro-power plant in the next 10-15 years. Last, in 2009 about 0.8% of electricity is generated from other renewable energy sources, mostly from biomass co-burnt in CHPs. This biomass is attributed to electricity generation according to the energy inputs used in combined generation.

Assumptions on fuels demands in other combustion processes and technological processes are based on autonomous saving potentials and annual production growth rates of given sector. The former assumption is based on the EU Data Base on Energy Saving Potentials as defined for its Low Policy Intensity scenario (http://www.eepotential.eu), the latter relies on Baseline PRIMES scenario as set in (EC, 2010). Combining these two pieces of information, we get a reduction in fuel use by 1.58% per annum, this means 16% reduction in 2020 related to 2009 level. Demand for fuel in gas utilities, refineries, agriculture, mining and textile sectors is assumed to remain constant over the period, whereas demand for fuel in remaining industrial sectors is assumed to rise in the range of 0.4% to 6.2% annually. Mobile sources fuel use does not enter into the model, however emissions from mobile sources directly contribute to CO_2 emission balance of our model, we assume that the 2009 level as reported in NIR-2010 is annually growing with a rate based on the assumption applied at projection for Biennial Report SR (ECOSYS, 2010) (that is +8.2% in 2010, +0.82% in 2011-15, and +0.37% in 2016-20).

Fuel prices for the base year are taken from Slovak Regulatory Office for Network Industries. Price of hard coal for the base year and fuel price trends for crude oil, hard coal and nature gas are compiled as an average from the price trends reported in (IEA, 2009), (EC, 2010), and (Jaeger et al., 2011). Price trend of brown coal folows the price for hard coal , whereas price trend of oil follows the trend in crude oil price. Trend in price of biomass is obtained as the average from the scenarios for Large Scale Solid Biomass by PRIMES model in (Nezi & Capros, 2011, p. 11). Table 5 in Annex reports the fuel prices as used in the model. All prices reported in this paper are recalculated to 2007 price level.

Technical and economic data of new technologies are taken from (EREC, 2011) and (Resch et al., 2010) and the main input data are reported in Table 3 in Annex.

Policy Scenarios

Our baseline scenario, *BL*, assumes Slovakia will comply with the Renewable Energy Directive (2009/28/EC) but other climate policies affecting industry (e.g., the EU ETS) will come to a halt. There are no other imposed restrictions in the baseline besides the assumptions as described above.

Table 1 CO_2 price and share of auctions

	CO2 price	Share of auctioned allowances (%)		
		All	Power	Industry
2009	12	0	0	0
2012	12	0	0	0
2013	17	5	100	10
2014	17	13	100	20
2015	17	21	100	30
2016	17	29	100	40
2017	17	37	100	50
2018	17	45	100	60
2019	17	53	100	70
2020	17	61	100	80

In the *17€ scenario,* we assume the price of CO_2 allowances at the level of €17 after the year 2012. This price is based on (EC, 2009) estimate for a 20% reduction target. We assume that the share of auctioned versus grandfathered allowances will vary along time and will differ across sectors as shown in Table 1.

Next two scenarios do not assume trading within the ETS scheme, but impose a cap on total CO2 emissions in Slovakia. *CAP20* reduces CO2 emission in 2020 by 20% compared to the 2005 level. This scenario follows the 20% reduction target, however, it assumes that this reduction will be made not at the EU level, but also in each Member State. Next scenario, *CAP24.6*, assumes 24.6% reduction in 2020 compared to the 2005 level. We highlight that this is the maximal feasible reduction reached by our model under the assumptions as described above. CO2 reduction beyond 24.6% can only be reached if energy demand is reduced more than we have assumed and/or if relative prices of fuels and technologies will prioritise more environmentally-friendly options.

4. Results

As highlighted above, the optimization is performed only for electricity generation delivered to grid (from public power plants and industrial CHPs), industrial heat demand, and district heat demand. Therefore also the reported results focuses more on these sectors, i.e. investment and O&M cost are realised only in these sectors. However, fuel cost and consumption are reported for all stationary sources and emissions for the whole Slovak economy including mobile sources. The impact of higher energy prices on energy demand is considered only implicitly in the model assumptions – we implicitly assume an autonomous demand adjustment due to electricity price increase given by elasticity of demand with respect to GDP as econometrically estimated in (de Bruyn et al., 2011) at +0.12.[2]

Electricity generation

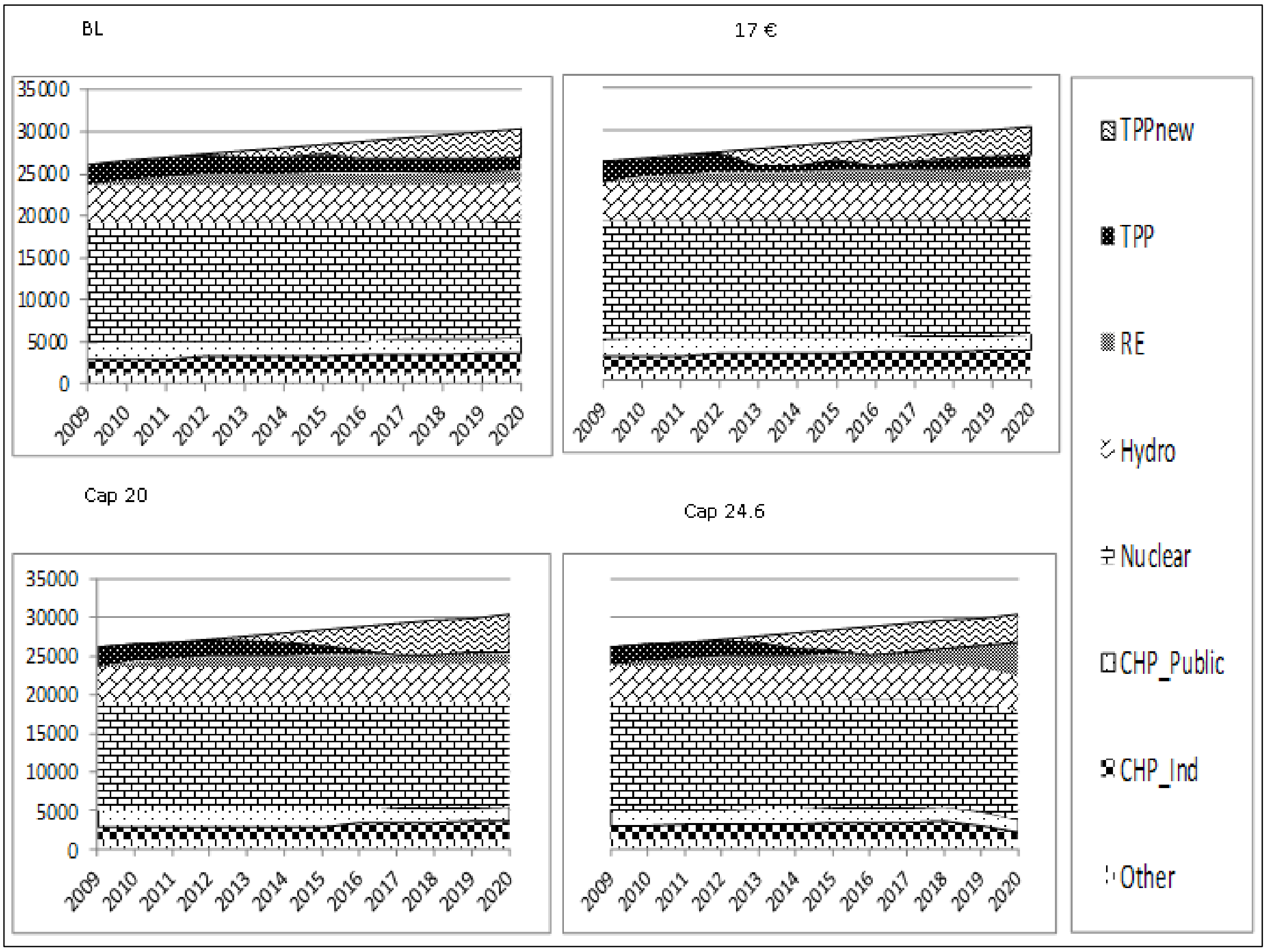
According to our assumptions, the electricity generation in the Slovak Republic will remain dominated by nuclear energy. Its 54% share in 2009 will go down slightly at about 46% in the year 2020 in all scenarios.[3] In all scenarios, 70 MW of biomass technology producing electricity are installed in 2014, because this source is already prepared to construction. The installation of wind power plants has the same pattern in all scenarios – there are installed 296 MW in total till 2020. The Figure 1 shows the structure of electricity generation in all four scenarios. In the **Baseline scenario**, the increasing electricity demand together with the

[2] The elasticity of demand can be directly included only in CGE models or in partial equilibrium models.

[3] Underneath lays the assumption that the new nuclear blocks in PP Mochovce will replace the old blocks that are going to phase out in PP Jaslovské Bohunice so that the total 2009 level of 14 TWh produced nuclear energy remains constant over the period.

planned shutdown of part of currently operated thermal power plants (TPP) is covered by installation of new natural gas combined cycle technology (525 MW in 2020), installation of wind power plants and slightly higher generation in industrial CHPs. In the ***17€* scenario**, the electricity generation structure is very similar as in *BL*, in 2020 it is just the same. The only difference is that the new natural gas sources are installed earlier and replace the TPP more quickly.

Figure 1 Structure of electricity generation (GWh)



Note: TPPnew – newly installed thermal PPs; TPP – thermal PPs recently operated; RE – renewable energy sources; Hydro – hydro PPs; Nuclear PPs, CHP_Public – public combined generation cycles; CHP_Ind – industrial combined generation cycles; Other – other PPs

There is a significant change in the ***CAP20* scenario**, all TPP are shutdown in 2017 and replaced mainly by new natural gas sources (563 MW already in 2017 and 723 MW in total in 2020). There is also a slight shift from public to industrial CHPs. The wind installations are same as in previous scenarios. In the ***CAP24.6***, the reduction of electricity generation in the TPP is even faster than in *CAP20*. But in contrary to the *CAP20,* the installation of new nature gas sources is slightly lower than in scenarios *BL* and *17€*. There is significantly higher installation of RES, namely of biomass and biogas technologies. Furthermore, 626 MW of photovoltaic panel are newly installed in 2019. Because the electricity generation in industrial CHPs is determined mainly by the industrial heat demand, there is a shift in electricity generation from industrial CHPs to public electricity generation at the end of the period.

Fuel consumption and costs

Data in the base year 2009 describe real Slovak energy market and economy in that year and therefore are common for all scenarios. In 2009, the total fuel consumption in all stationary sources are 91,129 TJ of hard coal (HC), 37,355 TJ of brown coal (BC), 60,374 TJ of nature gas (NG), 16,525 TJ of oil, 24,474 TJ of biomass (BM) and 552 TJ of biogas (BG). The fuel use in public electricity sector of HC, BC, NG, oil and BM amount to 8,743, 24,316, 133, 229 and 586 TJ, respectively. Fuel use of all stationary sources and other detailed results for all scenarios in year 2020 are described in Table 4 in the Annex.

In the ***BL*** **scenario**, the total fuel consumption in public electricity sector is higher 4% in 2020 than in 2009. The HC and BC consumptions in public power plants decrease approximately by a half in 2020 compared to 2009, also use of heating oil is reduces by a third. On the other hand, consumption of NG is boosted on 1556 times higher level (20,780 TJ) than in 2009. The biomass use is more than tripled and solid fuels are almost doubled (from 312 to 596 TJ). In all stationary sources, only BC consumption decreases by 25%, all other fuel uses increase (see Table 4 in Annex for detail). The total fuel consumption in all stationary sources is 9% higher in 2020 than in 2009. The total fuel costs in 2020 are 42.7% higher than in 2009 (€1679 million instead of €2396 million). During the whole study period, there are invested €1082 million into new energy sources in the *BL* scenario, of which €834 million in the public electricity sector.

In the ***17€*** **scenario**, the fuel use in all stationary sources is very similar with the in *BL* scenario. However, we can observe a moderate trend to decrease consumption of BC, NG and HC and to increase the BM combustion compared to the *BL* scenario. In the public electricity sector, we can see slightly higher BM consumption during the study period due to the EU ETS trading, but in 2020 the fuel use is just the same as in *BL*. The total investments into new technologies are in sum over the study period €40 million higher than in *BL*.

In the ***Cap20*** **scenario**, the fuel consumption in public electricity sector decreases by 4.2% compared to the 17€ scenario in 2020. Over the period, total fuel use in public electricity sector also decreases 4% in this scenario. Consumption of HC, BC, NG decreases by 16.7%, 43.2% and 8.1% compared to the 17€ scenario in 2020, respectively. On the other hand, BM consumption is more than doubled. Including electricity generation in combined generation cycles in public and industrial CHP plants, the share of electricity from renewable energy will rise from 18.4% in 2009 to 20.1% in 2020. The share of renewable electricity is however slightly lower than in the 17€ scenario (20.2 %). To achieve this fuel consumption reduction in public power plants, a total investment of €951 million is needed until the year 2020, what is €117 million more than in the BL. The additional investments are spent purely on new natural gas power plants. These investment costs can be partly regained by saving on fuel inputs in the power sector in comparison to the BL scenario, which was estimated to be €28 million but there is an increase in fuel costs of €10 million compared to the 17€ scenario between 2009-2020.

In the ***Cap24.6*** **scenario,** there is an electricity generation shift from industry CHPs towards public electricity sector since 2019. Therefore the comparison of fuel consumption, fuel mix and cost in the public electricity sector with other scenarios is not consistent due to higher electricity generation by almost 1.7 TWh between 2019 and 2020. For this reason we don't focus on these variables in public electricity sector. Although higher electricity generation, investments into conventional sources in the CAP24.*6* scenario are lower than in the CAP20 and in the 17€ scenarios because of huge development of RES. Total investments in the *CAP24.6* scenario are much higher (by €2,687and 3,811 million, respectively) than in the two previous scenarios, but they are spent mainly on renewable sources, e.g. the main part (€1,846 million) goes on photovoltaic power plants. There are installed 626 MW of photovoltaic power plants in 2019. The CAP24.6 scenario is the only one scenario, where photovoltaic and biogas power plants are installed. We stress again that the increase of investment costs in the CAP24.6 scenario is partly caused by higher electricity generation in public electricity sector.

Total fuel consumption in the CAP24.6 scenario in 2020 is by 5 % higher than in the 17€ scenario. This is caused by two factors: first, substitution of NG by BM with lower efficiency and second, movement of part of electricity generation from industry CHPs towards public electricity sector, where the benefits from combined generation of heat and electricity are not utilized. Consumptions of BC, NG and solid fuels decrease by 43.5%, 24.4% and 2.3% compared to the 17€ scenario in 2020, respectively. On the other hand, consumptions of HC, BM and BG rise by 30.5%, 168% and 1744% (from 713 TJ on 13,145 TJ) compared to the 17€ scenario in 2020, respectively. Including electricity generation in combined generation cycles in public and industrial CHP plants, the share of electricity from renewable energy rises from 18.4% in 2009 to 29.8% in 2020.

Impacts on air quality

CO_2 abatement measures will induce an effect also on other air pollutants such as SO_2, NO_x, CO, and particulate matter, which we compute for all stationary sources for each scenario in our model.

Reduction of classical air pollutants has two economic effects. First, the reduction in emission leads to a reduction in damage, which we quantify using so called ExternE method (see for instance Preiss et al., 2008 or Weinzettel et al., 2012). Specifically, we compute avoided external costs due to emission reductions related to impact on human health, crops, building materials and biodiversity that are associated with climate change. Table below shows detailed results regarding the external costs reported in millions Euro per each pollutant and per each impact category.

Table 2 Damage costs and loss of public revenue from emission charges

	2009	**2020**			
		BL	17€	CAP20	CAP24.6
NOX	142	162	160	149	136
PPMco	2	2	2	2	2
PPM25	38	41	40	38	34
SO2	317	198	193	154	141
CO2	666	714	703	631	595
Total of externalities, € mil.	**1165**	**1117**	**1099**	**973**	**909**
Human Health	438	351	344	298	273
Loss of Biodiversity	12	12	12	11	10
Crops	9	11	11	10	9
Materials	18	13	12	10	9
North Hemispheric modelling	22	16	16	13	12
Climate Change	666	714	703	631	595
Total of externalities, € mil.	**1165**	**1117**	**1099**	**973**	**909**
Percentage change					
- wrt BL2020			-1.6%	-12.8%	-18.6%
- wrt 2009		-4.1%	-5.7%	-16.4%	-22.0%
Absolute change, € mil.					
- wrt BL2020			-18.1	-143.3	-208.1
- wrt 2009		-48.0	-66.1	-191.4	-256.1
Emission charges, € mil.	10.1	9.5	9.5	8.8	8.4
- wrt BL2020			-0.10	-0.73	-1.13
- wrt 2009		-0.53	-0.62	-1.26	-1.66

Table 2 reports also the second category of economic impact – loss of public (governmental) revenues. Air pollution released by stationary sources is charged in Slovakia with a rate of €64 per tonne of SO_2, €48 per tonne of NO_x, €32 of tonne of CO and €160 of tonne of particulate matters. Reduction in these emissions results in losses in public revenue raised from these emission charges. Using these charge rates, we find that this loss is quite small compared to the avoided damage. Moreover, the losses on the side of the public sector in fact mean cost reductions on the business side, yielding zero net social cost.

5. Conclusions

As mentioned above, our optimization is performed only for electricity generation delivered to grid, industrial heat demand, and district heat demand and energy consumption of the rest of the economy are projected according to our assumptions. The *17€* scenario fits the reality at most and is very similar as the *BL* scenario. Aware of the fact, that the Slovak public electricity sector reaches lower CO_2 emission intensity than the EC benchmark already in 2009 (0.465 t CO_2 per MWh), we have constructed two scenarios with more strict restriction on CO_2 emission than in *17€* scenario. Under our assumptions, the maximal feasible CO_2 emission reduction in the Slovak Republic is 24.6 percents compared to the year 2005. The average carbon intensity of public electricity generation will drop to 0.057 tCO_2 per MWh in *Cap24.6* scenario in 2020. The *Cap24.6* scenario leads to 15.4% reduction of CO_2 in 2020 compared to the *17€* scenario. At the same time, the total production costs in all stationary sources are higher by €481 million (18.6%) in *Cap24.6* scenario than in *17€* scenario in 2020. On the other hand, due to the emission reduction, the externality costs are €190 million lower in *CAP24.6* scenario than in *17€* scenario in 2020.

The results indicate that the Slovak Republic is able to reduce the emissions more than it is required by the EU wide 20% reduction target. But these conclusions should be carefully interpreted since it is very difficult to determine the exact implication of possible intervention on the energy sector and the economy as a whole. Since the elasticity of demand is considered only implicitly, the energy demand reaches the same level in all analysed scenarios. If the elasticity of demand was included directly in the model, it would be reasonable to assume that the energy demand in CAP24.6 scenario would be lower than in the remaining scenarios. The demand reaction on higher production cost of electricity would depend also on that through which channel the higher production costs would be passed on to customers. For example if part of the higher production cost was cover from governmental budget through general taxation, the impact on electricity demand would be lower than if the whole increase in production cost was passed to customers.

Annex

Table 3 New renewable energy technologies included in MESSAGE model

Sector	Energy Source	Plant size MW	Plant factor	Operation time (h/a)	Plant life (yr)	Investment costs (€/kWe)	FOM (€/kWe.r)	Efficiency	Output limit (MWh)
Electricity	Biomass_El_a	25	90%	7534	30	2225	84	26%	2657
	Biomass_El_b	25	90%	7534	30	2610	115	28%	
	Biomass_El_c	25	90%	7534	30	2995	146	30%	
	Biogass_agr_Ela	0.5	87%	7534	25	2550	115	28%	1182
	Biogass_agr_Elb	0.5	87%	7534	25	4290	140	34%	
	Wind1	2	90%	4030	25	1125	35		1125
	Wind2	2	90%	4030	25	1325	40		
	Wind3	2	90%	4030	25	1525	45		
	Photovoltaic1	0.05	90%	1051	25	2950	30		217
	Photovoltaic2	0.05	90%	1051	25	3850	36		
	Photovoltaic3	0.05	90%	1051	25	4750	42		
Industrial district heat	Biomass_50	50	80%	4030	30	360	14.4	75%	
	Biomass_a	10	80%	4030	30	350	17	89%	
	Biomass_b	10	80%	4030	30	380	16	89%	
	Biomass_lc	5	80%	4030	30	390	17	87%	

Table 4 Scenarios results

		BL		17€		CAP20			CAP24.6		
		2009	2020	2020	Δ% wrt BL2020	2020	Δ% wrt BL 2020	Δ% wrt 17€ 2020	2020	Δ% wrt BL 2020	Δ% wrt 17€ 2020
Emissions											
CO_2	[kt]	35 030	37 587	37 024	-1%	33 202	-11.7%	-10.3%	31 313	-16.7%	-15.4%
SO_2	[t]	61 451	38 259	37 390	-2%	29 750	-22.2%	-20.4%	27 297	-28.7%	-27.0%
NOx	[t]	34 463	39 379	38 868	-1%	36 117	-8.3%	-7.1%	33 123	-15.9%	-14.8%
PM	[t]	6 086	6 972	6 901	-1%	6 455	-7.4%	-6.5%	6 073	-12.9%	-12.0%
PM2.5	[t]	2 422	2 586	2 537	-2%	2 423	-6.3%	-4.5%	2 182	-15.6%	-14.0%
PM10	[t]	4 894	5 561	5 502	-1%	5 355	-3.7%	-2.7%	5 045	-9.3%	-8.3%
CO	[t]	109 828	127 892	127 754	0%	129 673	1.4%	1.5%	128 418	0.4%	0.5%
Additional economic costs											
AIC	[mil.EUR]	15	96	100	4%	200	107.7%	99.5%	438	356.1%	338.2%
O&M	[mil.EUR]	n.a.	37	33	-11%	82	119.7%	147.6%	143	281.2%	329.6%
Fuel Cost	[mil.EUR]	1 683	2 402	2 400	0%	2 359	-1.8%	-1.7%	2 486	3.5%	3.6%
$CO_{2\ Allowances\ Costs}$	[mil.EUR]	-	-	53	n.a.	-	n.a.	n.a.	-	n.a.	n.a.
Total Cost	**[mil.EUR]**	**1 698**	**2 535**	**2 586**	**0**	**2 640**	**4.1%**	**2.1%**	**3 067**	**20.9%**	**18.6%**
Fuel in all stationary sources											
hard coal	[TJ]	91 129	95 330	95 110	0%	79 184	-16.9%	-16.7%	124 162	30.2%	30.5%
brown coal	[TJ]	37 355	27 882	26 093	-6%	14 812	-46.9%	-43.2%	14 755	-47.1%	-43.5%
gasses	[TJ]	214 763	240 119	238 748	-1%	219 320	-8.7%	-8.1%	180 559	-24.8%	-24.4%
heating oils and wastes	[TJ]	16 525	18 032	18 013	0%	17 907	-0.7%	-0.6%	17 896	-0.8%	-0.7%
solid fuels	[TJ]	34 390	53 603	53 584	0%	53 293	-0.6%	-0.5%	52 363	-2.3%	-2.3%
biomass	[TJ]	24 474	32 841	36 228	10%	77 532	136.1%	114.0%	96 989	195.3%	167.7%
biogas	[TJ]	552	715	713	0%	711	-0.6%	-0.3%	13 145	1737.9%	1743.6%
nuclear	[TJ]	155 366	155 366	155 366	0%	155 366	0.0%	0.0%	155 366	0.0%	0.0%
Total fuels	**[TJ]**	**574 553**	**623 886**	**623 855**	**0%**	**618 125**	**-0.9%**	**-0.9%**	**655 235**	**5.0%**	**5.0%**

Table 5 Fuel prices in the MESSAGE model (selected years)

€2007/GJ	Gas	Hard coal	Brown coal	Biomass	Light oil	Heavy oil
2010	5.7	2.65	3.8	4.8	9	6.4
2015	6.8	2.8	4.1	4.9	11.1	7.9
2020	8.2	3	4.3	5.2	13.6	9.7
2025	8.3	3	4.2	5.7	14.5	10.3
2030	8.4	2.9	4.1	5.8	15.4	11

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