A REALISTIC EU VISION OF A LIGNITE-BASED ENERGY SYSTEM IN TRANSITION: CASE STUDY OF SERBIA

by

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Several contracting parties to the treaty establishing the Energy Community of the South East Europe, currently in energy transition, have electricity production dominantly based on lignite which contrasts their new reality. Planning approach to designing a new feasible energy policy is presented in this paper. This novel approach in using EnergyPLAN tool stems from analysis of market operation of lignite thermal power plants on hourly basis, and quantification of the feasibility of the energy policy and its alignment with EU vision, and is presented in few scenarios. It was found out that the Serbian energy system is highly sensitive to the electricity market and CO_2 tax increase, because the marginal costs for lignite generation will increase to more than 50 €/MWh. Shifting in the merit order will be observed even at lower CO_2 tax levels, because of the intensity of the emission of the electricity sector (calculated to be higher than 700 gCO_2/kWh_e, according to current energy policy). Based on the increased use of renewable energy sources and more efficient energy conversion technologies, socio-economic and energy policy feasibility would be increased, while long-term marginal costs would be improved by 2 €/MWh and emission intensity by 258 gCO_2/kWh_e, compared to the current energy policy. These contributions, shown in the Serbian case, are of general importance for other lignite dominated contracting parties to Treaty establishing the Energy Community.

Key words: *lignite, national energy system, energy transition, Europe 202020 goals, simulation model, CO_2 tax*

Introduction

This research was performed to assist the lignite-based contracting parties (CP) to the treaty establishing the Energy Community (ECT) from the South East Europe (Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Montenegro and Kosovo[**]) among other CP (Albania, Croatia, Moldavia, and Ukraine) to enhance the feasibility of their current energy policies and to align them with the European Union policies (EU vision). The energy development of Serbia [1] and other CP to the ECT, which are undergoing energy transition, will probably continue to use of lignite for the next few decades, since they do not have another source and this source could be highly competitive in the electricity market conditions [1] with

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tax subsidies [2] and without external costs consideration. Under the ECT [3], CP have been constrained to implement the core parts of the EU acquis communautaire and to adopt development plans with a view to bringing their energy systems in line with generally applicable standards of the EU. Therefore, for these CP, the EU 202020 energy vision, creates a new reality constrained with: sustainability, competitiveness, and security of supply [4]. Furthermore, three key goals, namely, the increased share of renewable energy sources (RES) in gross final energy consumption (GFEC), CO_2 emissions reduction and reductions in total primary energy supply (TPES), as statistical indicators, are provided by the European Commission (EC) and allow the quantification of the performance of the CP during their EU accession process. For the mentioned CP special focus should be given to the CO_2 goal and to the electricity sector because of its higher CO_2 intensity and year round operation.

The methodology for planning energy transition in those CP should be focused on efficiency of the large lignite combustion plants and on limitations of its operation through, *e. g.*, emission limitation directives. A study [5], based on the cost benefit analysis of the investment costs (640-704 M€) and operation and maintenance costs (67-69 M€/year) for the implementation of Large Combustion Plant Directive (LCPD) and the Industrial Emissions Directive (IED) in Serbia show very high benefit to cost ratio (27-29), in particular for the society as a whole, including local external costs [6], without the global externalities. As an alternative to upgrading thermal power plants (TPP) to meet emission limit values of the LCPD/IED, so called *opted-out* has been preferred option in the case of ageing TPP [7], among other alternatives such as refurbishment *e. g.* boiler replacement [8], conversion and reuse of the site [9]. According to this option, a retirement plan has been mentioned in [10], but national emission reduction plan still need to be developed by the operator until 31. 12. 2015. and approved [11]. The future market reality of the CP will be establishing a mechanism for operation of network energy markets and the creation of a single energy market of the Energy Community coupled with EU markets [12]. The financial reality for the CP include CO_2 emission taxes and the lack of investments. Contrary to most EU member states, CP depend on foreign factors for realising capital-intensive projects [13]. The regulation of new investments do not recommend the building and financing of new lignite TPP with specific emission levels higher than 500 gCO_2/kWh [14, 15], except in the case of *no feasible alternatives* [16] which is still higher than average EU27 of 400 gCO_2/kWh_e, [17].

The purpose of this research is to develop a planning methodology for a feasible energy policy in the lignite based CP to the ECT. To be feasible, this energy policy should be realistic and in line with the EU vision, it should meet all the new policies and market and financing constraints.

Lignite has been viewed as being critical to the security of supply [10, 18], however lignite combustion is highly CO_2 emission intensive and it accounts for most of direct CO_2 emissions inventory of the CP (so called life cycle emissions are not evaluated within this article). The damage attributable to climate change caused by greenhouse gases emissions represents an external cost associated with energy generating technologies, should be included in the total socio-economic cost of energy planning model [19]. By imposing the price on such emissions, an incentive is created to switch to technologies with lower emissions [20] resulting in shifting of the base load units to the margin [21], with less operating hours. A study [20] indicated that coal is competitive with a CO_2 tax of less than 30 $/$tCO_2$, but in the case of the mentioned CP (lignite and low efficient technologies) this competitiveness point can occur at the lower CO_2 tax. Increasing the CO_2 tax to 30 €/tCO_2 causes marginal electricity generation costs increased to 70 €/MWh, in German case [22], and to 62.19 and 71.38 €/MWh in the case of new build plants in Bosnia and Herzegovina and Croatia, respectively [23]. In order to become realistic, the energy system of each of the CP should be planned and operated based on different planning methodology preferably based on open source tools [24]. Using the EnergyPLAN tool, a study [19] demonstrated that implementation of a policy on renewable energy and more efficient energy conversion technologies can have positive socio-economic effects under the market conditions, as in the case of Denmark, especially if the external costs are included. Under market conditions, in the absence of CO_2 tax, the lignite TPP operation hours would likely increase. The high share of lignite consumption and its significant impact on CO_2 emission enables the planning methodology based on the limitation of the operation of the TPP using EnergyPLAN tool to be highly accurate and applicable in the CP to the ECT, even for a lower, CO_2 tax.

In this paper three scenarios are created and analysed: the base scenario for year 2009, the scenario in accordance with the current Serbian energy policy documents and one more feasible future scenario with a realistic EU 202020 vision. In this scenario, the faster implementation of renewable energy and efficient energy conversion technologies will be employed. The feasibility of energy policy in Serbia will be quantified based on EU 202020 goals and total annual socio-economic costs for three scenarios. Afterwards, the EU vision alignment will be quantified through sustainability, competitiveness and security of supply indicators for these scenarios.

Methodology

The EnergyPLAN simulation tool was chosen for the national energy system modelling because it is a user friendly, free, bottom-up model, with an hourly time-step [25] and the ability to accept input data (fig. 1). The EnergyPLAN tool may be used to assist the planning of the national energy systems by simulations of the electricity, heat and transport sectors with sce-

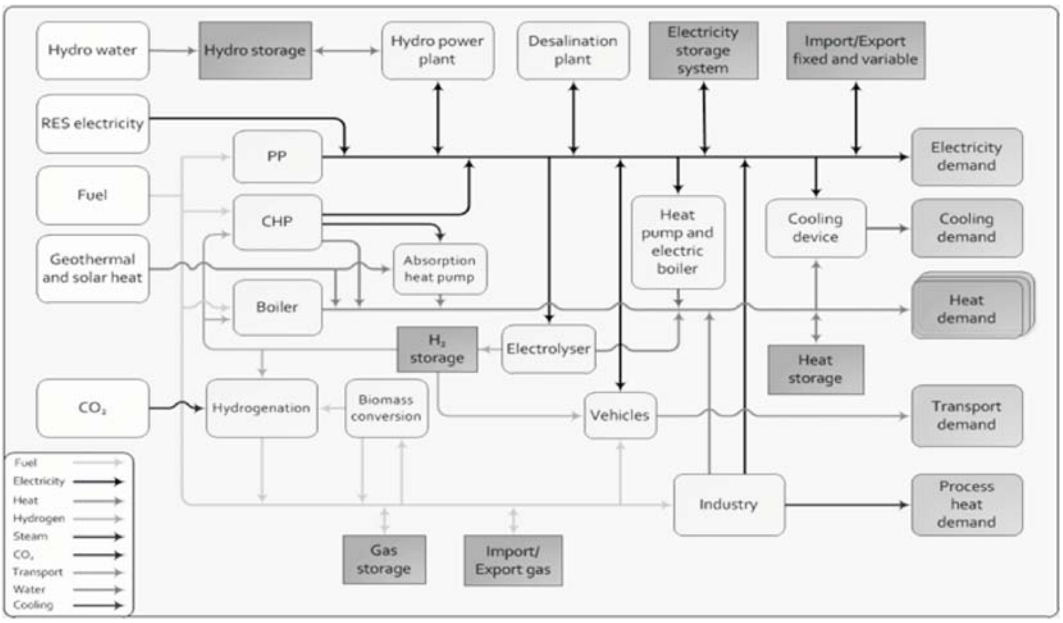

Figure 1. EnergyPLAN System Diagram – Version 11.2 - November 6, 2013

narios for renewable energy penetrations in EU members [26-29], and CP [30-33] and its socio-economic costs [34]. In this paper, the national system was described by energy demands, generation capacities and efficiencies, types of energy sources, annual energy balances, fuel consumptions, costs, and CO_2 emissions. As a result from the EnergyPLAN tool, three indicators were used to quantify a national energy system:

(1) The annual generation costs required to supply the required energy demand, including socio-economic consequences of the generation: presented directly, consisted of: total fuel costs, marginal operation costs, annual investment costs, fixed operational costs, electricity exchange costs and benefits, total natural gas exchange costs and CO_2 tax payments.
(2) Amount of CO_2 emissions resulting from energy consumption and generation: presented directly.
(3) Total primary energy supply (TPES) by fuel type: presented directly.

The share of renewable energy sources and the energy savings are calculated outside of EnergyPLAN because the EnergyPLAN tool calculates the RES share in TPES instead of GFEC, which is used as the EU 202020 goals.

In the analysis, both EnergyPLAN operation optimisation strategies of technical (seeking to meet the national demand) and market (plant operators seek to optimise their profits at electricity market) were performed, and each were used in both modes of island and connected [34]. For the market conditions, electricity costs were obtained from the European Energy Exchange historic curve for the German-Austrian border [35].

Case study: Serbian energy transition

Serbia is an energy transition country, *i. e.*, a CP to the ECT, with around 2/3 of the electricity production coming from lignite and the rest from hydro (with biomass for heating 21.2% of RES in GFEC). Specific target of 27% has been set for its RES goal. The other two goals of CO_2 reductions and reductions in TPES, specific targets were not declared, and therefore they will be assumed to be 20%, as the Serbian energy policy will be aligned to the EU energy policy after 2020. The emissions reduction was focused on the electric utility sector, controlled by the CO_2 tax. Taking into account that emission allowances currently at 6.17 €/tCO_2 [35], assumption is 10 €/tCO_2 until 2020.

The energy strategy of the Republic of Serbia (Strategy) [10], with an aim to be in line with goals of the energy strategy of the CP to the ECT [36] and to comply with the EU acquis communautaire, has been drafted. The Strategy covers the topics and accounts for the contents of the following documents:

– Draft National Renewable Energy Action Plan (NREAP), [37],
– National Energy Efficiency Action Plan (NEEAP), [38], and
– Summarised list of projects, [39].

This Strategy continues the policy of least-cost end-user energy prices for electricity and heat without taking into account the total socio-economic costs of energy production (external costs of carbon dioxide and import/export payments are not covered).

The energy strategy of the CP to the ECT [36] was criticised in [40], especially for the huge fossil fuel investments, which could move the region further from reaching the EU 20:20:20 goals and increase socio-economic cost. In accordance with the LCPD [41], Serbia is planning to close some (874 MW) of existing lignite-, gas- and oil-fired plants [36]. The emissions intensity from the electricity sector in Serbia is approximately 850 gCO_2/kWh$_e$ [42], with a goal to be at 600 gCO_2/kWh$_e$ in 2020 [10]. In the Serbian case, this biomass is limited to 10%:90% of the energy composition between biomass and lignite. Among other policies *e. g.*

[30], the increase of variable renewable energy production with flexibility options on the demand side (smart grid, storage applications, *etc.*), a feasible policy for CO_2 reduction could be the *build big-close small* approach and co-generation [43], along with further shifting to natural gas also bearing in mind its socio-economic costs, especially local externalities, since they are huge barrier for economic growth in Serbia [44]. A feasible future scenario should be based on the following assumptions:

– a part of the TPP is closed, while another part is upgraded according to LCPD,
– proposed new lignite TPP are not commissioned, according to the new investment policy of the European Investment Bank, World Bank and similar EU, U. S. based investment institutions, and
– a regional energy market is functional, according to the Energy Law [45], the emissions trading scheme or equivalent CO_2 tax mechanism used to include all socio-economic costs exists.

Scenario development

The EnergyPLAN tool was utilised to assess three different scenarios of the Serbian energy policy, that were chosen among many other scenarios, as being the most representative:

(1) Base scenario (BS), for the year 2009, in island mode technical operation optimisation along with an average market price of 40 €/MWh and no emissions-associated payments.
(2) Strategy energy efficiency scenario (SEES), based on the Strategy [10], NEEAP [38] and NREAP [37] for the year 2020. The connected mode market operation optimisation was used with an average of 50 €/MWh and a tax of 10 €/tCO_2.
(3) Future scenario (FS), based on the assumptions for the year 2020. The connected mode market operation optimisation was used, with an average of 50 €/MWh and a tax of 10 €/tCO_2.

External electricity market response to import/export has been modelled for the basic price of 50 €/MWh and price elasticity of 0.1 €/MWh.

Base scenario

The BS scenario is modeled from the bottom using island mode system in the EnergyPLAN tool as in [30] with detailed scenario assumptions related to TPP shown in tab. 1.

Table 1. Scenario assumptions relating to TPP and CHP plant size and average efficiency [46]

	TPP max [MW]	TPP min [MW]	TPP max with CHP [MW]	TPP efficiency η [%]
BS	3,936	2,786	4,289	0.317515
SEES	4,011	2,260	4,401	0.328826
FS	2,920	1,380	4,170	0.326338

Strategy – energy efficiency scenario

The SEES scenario has been created based on Strategy [10], renewable energy policy from NREAP [37] and on energy efficiency measures proposed in NEEAP for the year 2020 [38]. Currently 22.8 TWh have been already utilised (from large hydro and from biomass for heating). Based on the tertiary reserve study, the integration of only 1.2 TWh with power limited to 500 MW of wind. The photovoltaic (PV) production technical potential was constrained based on the half-half placement of PV and solar water heating systems on the available rooftops to 450 MW or 540 GWh. A gross final energy consumption of 113 TWh in 2020 was projected. The projected CO_2 emissions are 48.08 Mt CO_2. According to LCPD, some TPP will be upgraded with investment costs (498 M€) and yearly operational costs (53 M€), some opted-out. Based on retirement plan, TPP Kolubara will be shut down before 2020 (2017-2019), while others operated under *opt-out* until 2024: Morava (2020), TENT A1-2 (2020-2022), and Kostolac A (2020-2024).

The SEES assumptions were created for the year 2020, in which, according to the Strategy [10]:
- existing TPP have been upgraded according to LCPD, and operated under retirement plan, new Kostolac B3 has been built, details given in tab. 1,
- instead of the existing, the new combined heat and power (CHP) plant in Novi Sad of 340 MW_e, with combined electric efficiency (gas and steam) of 40%, and with total fuel utilization of 85%, has been built [47],
- Bistrica pumped storage hydro power plant has been built (680 MW, 60 GWh),
- consumption of lignite for district heating has been increased to 3.59 TWh/a, oil to 2.5 TWh/a, natural gas to 6.75 TWh/a and biomass to 1.63 TWh/a,

according to renewable energy policy and electricity demand from NREAP [37]:
- demand for electricity has been increased to 41.1 TWh/a of which 1.8 TWh/a for cooling, and 2.9 TWh/a for heating,
- wind capacity has been increased to 500 MW and PV capacity has been increased to 10 MW,
- solar thermal generation for individual household has been increased to 1.95 TWh/a, according to the procedure in [48], resulting in 0.64 TWh/a of utilized heat demand,
- demand in transport sector has been increased to 28.56 TWh/a equally among available fuels,
- waste to energy incineration plant of 3 MW has been modeled with 8,000 hours of work adding 0.024 TWh/a (0.015 TWh/a heat and 0.009 TWh/a electricity) to the group III district heating,
- biodiesel plants production will be increased to 2.9 TWh/a to substitute diesel in transport sector,
- biomass supply in district heating has been increased to 1.279 TWh/a and fixed for a group III CHP plant,
- biogas plant yearly output has been increased to 0.8 TWh/a of biogas,
- 0.8 TWh/a of biomass has been used to produce 0.29 TWh/a of bio petrol,
- small run-of hydro plants capacity has been increased to 471 MW producing additional 1.262 TWh/a, and
- landfill gas has been used as CHP plant fuel in district heating group III to replace 0.08 TWh/a of natural gas,

and according to energy efficiency measures proposed in NEEAP [38].

Future scenario (FS)

The FS scenario was created based on the energy demand from the SEES scenario, but with different investment assumptions:
- instead of Bistrica, 600 MW of run-of-hydro power plants, according to [39], have been built,
- 700 MW of wind, 200 MW of PV plants and 200 MW of geothermal power plants have been built,
- co-firing of biomass with lignite has been fully increased in the existing TPP,

- 0.5 TWh/a of electric heating has been replaced with heat pumps with same heat demand [49],
- lignite and fuel oil consumption in large CHP plants connected to district heating (group III) has been replaced with natural gas and biomass,
- the CHP plant from district heating group III size has been increased for 860 MWel [39], with efficiencies assumed as in SEES scenario,
- solar thermal yearly production has been doubled in comparison to the SEES, and
- new TPP units are not being built along with further closure of existing ones below 300 MW, Kostolac A1 and TENT A3-4 opted-out and with other units upgraded (see tab. 1) with investment (326 M€) and operation cost of 39 M€ [5].

For the assumed scenarios, simulations using the EnergyPLAN tool, policy and socio-economic feasibility, followed with a policy alignment with the EU vision, according to chosen indicators, were quantified.

Quantification of the Serbian energy policy feasibility

Table 2 presents the calculations quantifying the feasibility of reaching of the EU 202020 goals and their specific targets followed with socio-economic feasibility for Serbia.

Table 2. Feasibility of the Serbian energy policy in reaching EU 202020 goals

EU 202020 Goals		BS	SEES	FS	EU 202020 targets
RES in GFEC	%	21.6	31	42.7	27
CO_2 reduction	%	0.0	–0.6	23.1	20
TPES reduction	%	0.0	–7.6	2.2	20

In the SEES, the RES penetration is 31%, and in the FS the RES penetration is 42.7% (due to the increased RES in electricity and heat, co-firing in TPP and bio fuels usage). Therefore, the goal of 27% of RES in GFEC in 2020 was achieved.

The total CO_2 emission reductions compared to the BS are obtained as negative once for 0.6% in the SEES (tab. 3) because of the projected increase in demand for heating, cooling and the transportation sector, and, consequently, the higher fossil fuel generation. Reductions in emissions are achieved in the FS in the amount of 23.1%, according to the target level of 20%.

In tab. 2, the results indicate that in the SEES, the usage of primary energy is higher by 7.6% compared to the BS, and in the FS case, reductions of 2.2% in comparison to the BS are achieved. This increased usage of primary energy is the result of the increased generation of fossil fuel power plants in SEES scenario, reductions are result of different technology and fuel mix.

To discuss the socio-economic feasibility, the total annual costs for all three scenarios are shown in fig. 2. In comparison to the BS, the total system costs are shown in fig. 2 (the total height of the bars).

The total system costs are higher in both the SEES (8,412 M€) and FS (8,263 M€) in comparison to the BS (6,869 M€). These higher costs are the consequence of higher investment and emission costs but also of the projected increased consumption. The total socio-economic costs in the FS are lower than in the SEES, due to lower investment, fixed and marginal operation, fuel and emission costs.

Serbia-EU vision alignment according to the indicators

For the quantification of the alignment of the Serbian plans with the EU energy policy vision, three indicators were used: sustainability, competitiveness, and security of supply. In the BS, the operation of generators was technically optimised during simulation in the EnergyPLAN tool to meet the national demand with no additional operations for export. New market conditions in 2020, according to the SEES, are positive for the operation of TPP (with no or low CO_2 taxes) and, therefore, from the results of the simulation, an increase in the total energy generation can be observed in comparison to the BS in fig. 2.

The TPP yearly average energy generation of 3,156 MW in the BS (27.7 TWh/a) is increased to 3,240 MW in the SEES without a CO_2 tax ("SEES no tax"). Due to favourable market conditions for export production of TPP was increased to 28.5 TWh/a. In the SEES scenario, the average operation in TPP was limited to 3,167 MW (27.8 TWh/a), where their market competitiveness and operation were decreased due to the 10 €/tCO_2 tax. Further limitations in the average operation in TPP to 2,162 MW (19 TWh/a) is achieved in the FS. With an increased CO_2 tax to 30 €/tCO_2 in the FS ("FS HIGH tax"), the average operation of TPP is even further decreased to 2,026 MW (17.8 TWh/a). This further decrease indicates the high sensitivity of lignite based energy systems to the market conditions in the presence of CO_2 tax.

The emission intensity of the Serbian electricity system in different scenarios compared with the average EU emission intensity and the national emission intensity reduction

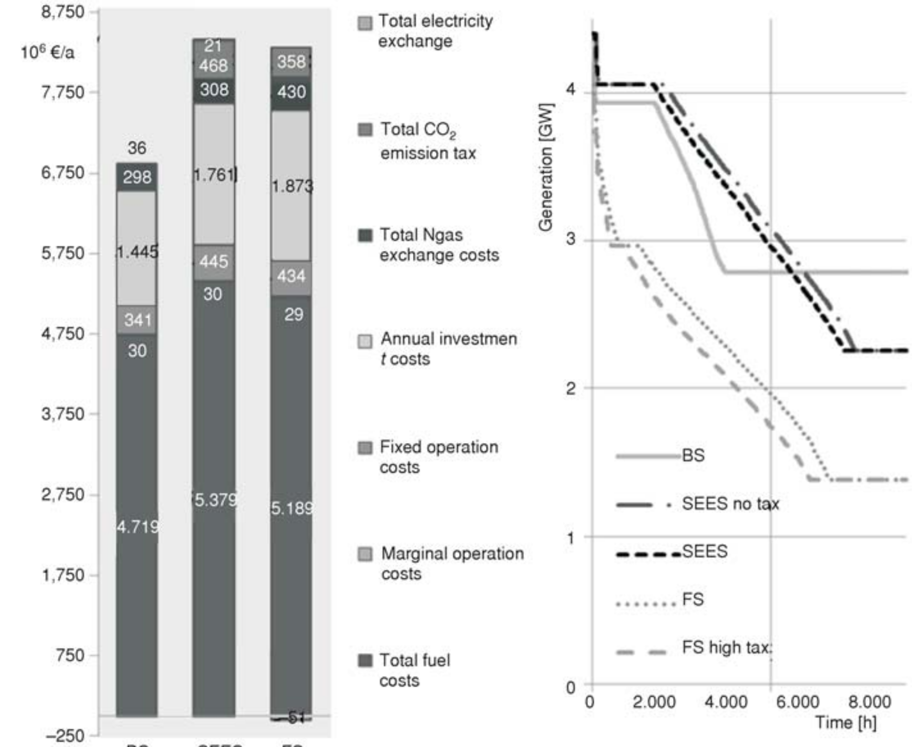

Figure 2. Socio-economic feasibility of energy system (left), load duration hours of TPP caused by CO_2 tax, market price and increased RES penetration (right)

goal for 2020 is shown in fig. 3. In the SEES, the emission intensity is decreased to 785 gCO_2/kWh_e, but it remains higher than the national emission intensity reduction goal for 2020 (600 gCO_2/kWh_e). The further emission intensity reduction to 526 gCO_2/kWh_e was achieved in the FS, reaching the national intensity reduction goal for 2020, but is still significantly higher than the EU average (400 gCO_2/kWh_e). The emissions intensity could be used as a competitiveness indicator, which shows how difficult it will be for the lignite based transition countries to compete in market conditions with emissions trading and a higher CO_2 tax.

The decrease in competitiveness of the Serbian electricity sector due to increased marginal generation costs in TPP because of higher CO_2 tax are shown in fig. 3.

The relative competitiveness increase in the SEES in comparison to the BS was achieved based on the efficiency increase of the average TPP. The further competitiveness increase in the FS is achieved through further average efficiency increases of the TPP and from the use of biomass used for co-firing with lignite. One should bear in mind that these costs should be increased for the average externalities from the dust, NO_x, and SO_2 calculated to be 13.5 €/MWh [5] for Serbia.

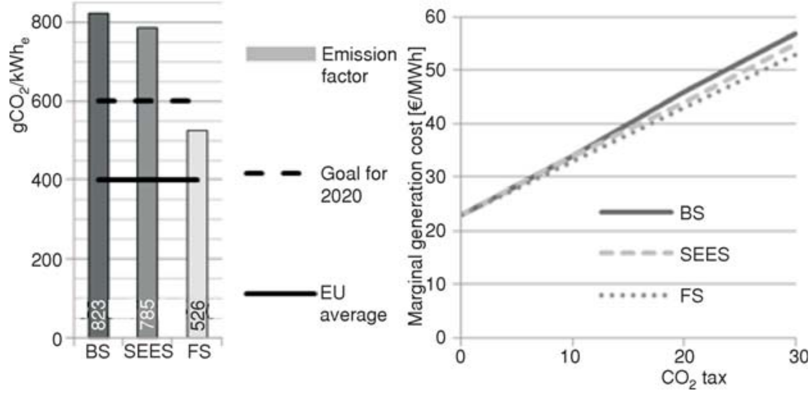

Figure 3. Emission intensity of Serbian electricity sector in comparison to EU (left); sensitivity analysis of TPP marginal generation costs under CO_2 prices change (right)

The long term security of supply, measured as the imported energy share in TPES during one year, has decreased from 48.8%, in the BS, to 46.8% in the SEES because TPES increased and the usage of locally available lignite increased. In the FS, the security of supply decreased because the imported energy share increased to 51.5%, mainly as a result of the increased natural gas imports.

Conclusion and policy implications

In this paper, it has been shown that the tailoring of a realistic energy policy in the market condition to align with the EU vision is not an easy task for the lignite based CP to the ECT. Reaching all of the three key statistical Europe 20:20:20 goals simultaneously (tab. 2) is a challenge in their specific conditions. Lignite based energy systems are highly sensitive to the market conditions and CO_2 tax. Thus, it is not socio-economically feasible to produce electricity for export in the case with the external costs included in the CO_2 tax. Therefore, it is recommended that a more sustainable policy be tailored that aligns with the EU energy policy vision and will not create socio-economic drawbacks for the CP to the ECT. This situation was illustrated for the Serbian case in the future scenario, where the total socio-economic costs are reduced in comparison to the SEES (fig. 2). The TPPs operation decrease can be observed only with the implementation of CO_2 taxes. TPES and CO_2 reductions plans should be modified to enable the further decrease in the socio-economic costs of the energy policy in the new EU reality.

A novel approach for the tailoring of energy policy for lignite based energy transition countries towards Europe 2020 energy vision (sustainability, competitiveness and security of supply) was proposed, based on several results in this paper, and particularly on the load duration curves of TPP (fig. 2). From these results, a more sustainable energy system could be proposed, based on the limitations and control of the operation hours of their TPP with an imposed CO_2 tax and with the further closure. Realistic CO_2 taxes in lignite based energy transition countries reduce the competitiveness of high emission technologies in the electricity market. An emissions intensity that is higher than the EU average, (fig. 3, left), together with an increased marginal generation cost with a CO_2 tax (fig. 3, right) and with a high share of fuel costs in total socio-economic costs, leads to the reduced long term market competitiveness. The decrease in the emissions intensity can be achieved by the increased RES generation and the efficient conversion technologies that compete with the generation from TPP and decrease the number of their operation hours. The vision of sustainability and minimal socio-economic costs decreases the security of supply in the CP by increasing the import of natural gas. Reconciliation of the visions of sustainability and of security of supply is possible through the implementation of renewable energy.

Based on this approach, using EnergyPLAN, a more feasible energy policy and national emission reduction plan could be proposed for Serbia (or lignite based CP to the ECT).

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