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## Environmental and economic aspects of higher RES penetration into Macedonian power system

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### ABSTRACT

The energy sector in Macedonia is the main emitter of greenhouse gases (GHG) with share of about 70% in the total annual emissions. Furthermore, within the energy sector, 70–75% of emissions are associated with the electricity generation due to the predominant role of the lignite fuelled power plants. This makes the electricity sector the most significant key source and, at the same time, the main target for CO<sub>2</sub> emissions reduction. Recently, the government has adopted a strategy for the use of RES which identifies a target of 21% of final energy consumption from RES by 2020. The main goal of this paper is to investigate environmental and economic aspects of higher penetration of renewables into energy system of Macedonia. For this purpose a reference energy scenario for the power system expansion is developed by making use of EnergyPLAN model. The reference energy system was developed for the year 2020, and then used in the scenario analyses. The analyses of four 'RES' scenarios reveal that renewables can reduce CO<sub>2</sub> emissions between 0.84% and 9.54% compared to reference scenario. Increase of CO<sub>2</sub> price for double, compared to today's price, will lead to increase of annual operating costs over 26% in all the scenarios considered. In the case of doubling the lignite price, annual operating costs in scenarios will be increased between 6.5% and 7.6%.

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### 1. Introduction

At the moment the most critical issues in European energy sector are security of supply and greenhouse gas emissions. These emissions are closely related to energy generation and exploitation and because of this they're becoming one of the major technological and socio-political challenges in the world [1]. One of the most promising solutions for alleviation of energy import and diversification of the energy resources, which at the same time reduce the GHG emissions, are renewable energy sources. Besides that, the utilisation of RES provides for additional environmental benefits (mitigating local pollution), create employment and leads to potential development of rural economies. Unfortunately, the intermittent nature of renewable energy sources (RES), except biomass, leads to substantial RES penetration limits, especially during the period of low electricity consumption such as the night time [2] and [3]. To solve such a problem, effective tools are needed

to provide insights into the problem and to provide possible solutions [4].

In order to increase penetration limits of intermittent or variable RES and use them effectively it is necessary to increase flexibility of the power system. Flexibility can be increased by use of more dispatchable plants, by better interconnection with other power systems, by demand side measures and by energy storage [5]. This energy storage is used in order to transfer energy surplus from the period of excess electricity production to other more appropriate periods [6] and [7]. However, due to high investment cost in the storage systems the usage of RES is becoming even more expensive [8] and [9].

Many authors have evaluated and analyzed the benefits of integration RES and energy storage in terms of reduction CO<sub>2</sub> emissions and energy import dependency. The use of RES-pumped hydro storage systems is proposed in [10], RES-hydrogen systems in [11] and use of RES-heat pumps and thermal storage systems in [12].

In the case of Macedonia, electricity production is based mainly on the low-quality domestic lignite and hydro. Macedonia's electricity consumption is characterised by excessive demand peaks in winter, which are largely due to the use of electricity heating to supplement fuelwood heating in the residential sector during very cold periods [13]. To some years ago, due to stagnation in the

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industry, particularly in heavy, energy-intensive industry, the country was able to generate all the electricity to be self sufficient but, in recent years, the increasing electricity demand has been covered by import, and during the last few years the import of electricity has grown rapidly [14] and [15]. Having this in mind, it is necessary to reduce the energy import dependency and GHG emissions by improving the energy efficiency and increasing the energy production from RES [16] and [17].

The main goal of this paper is to investigate environmental and economic aspects of higher penetration of RES into power system of Macedonia. As a first step, a reference model of the power system for the year 2020 has been developed by expansion of the reference model for the year 2008, generated in our previous study [18]. Then, comparative analyses are conducted for high penetration of RES in four 'RES' scenarios defined in line with the Macedonian strategy for RES [19]. The environmental aspects are considered through the potential of 'RES' scenarios for reduction of CO<sub>2</sub> emissions, while the economy aspects are addressed analysing the sensitivity of 'RES' scenarios to the future lignite price and CO<sub>2</sub> price.

## 2. Methodology

To create a model of the Macedonian energy system and to conduct environmental and economic analysis for higher RES penetration into power system of Macedonia, EnergyPLAN model [20] has been used. The main purpose of the model is to assist the design of national energy planning strategies on the basis of technical and economic analyses of the consequences of different national energy systems and investments [21]. The EnergyPLAN is an input/output model which incorporates heat and electricity supplies as well as the transport, individual and industrial sectors [22]. The input of the energy system consists of the following:

- Energy demands
- Energy production units and resources
- Regulation
- Costs

General inputs for these four groups are electricity and heat demand, energy station capacities, fuel consumption in energy stations, capacity of renewables stations, fuel consumption in individual buildings, industry and transport, fuel and CO<sub>2</sub> costs, operation and investment cost of energy station capacities and different regulation strategies. Outputs are fuel consumption, import/export of electricity, CO<sub>2</sub> emissions and the total cost of the energy system [22].

The EnergyPLAN model has already been used for the scenario analysis of energy systems with a high share of the intermittent sources as well as for the socio-economic feasibility studies. Hence, it has been applied to analyse energy systems with a high percentage of combined heat and power (CHP) and wind power [23], large scale integration of fluctuating renewable energy sources into the electricity system [24], socio-economic feasibility studies for 100% renewable energy systems [25], as well as in the analysis of 100% renewable energy systems of Croatia [9], Denmark [26] and Ireland [27].

Furthermore, the model can be used for technical analysis, market exchange analysis and feasibility studies. Technical analysis is used for large and complex energy systems at the national, local or regional level where different technical regulation strategies can be applied. In the case of the market exchange analysis each plant optimises according to businesses-economic profits, including any taxes and CO<sub>2</sub> emissions costs [21]. For these analyses technical regulation and market-economic regulation can be used. The

technical regulation minimise the import/export of electricity and seeks to identify the least fuel-consuming solution [21]. In this paper, balancing both heat and electricity demands, has been used as a technical regulation strategy. In this strategy, electricity production from the CHP units follows the production of heat. Basically, the decrease in heat production from CHP leads to decrease in electricity production from CHP. Hence, the CHP plants during the winter follow heat production while, during the summer period, when the heat demand is very low, CHP plants are working as a condensing plant. Furthermore, in the analyses of the Macedonian energy sector in [18], EnergyPLAN model and technical regulation strategy has been used.

## 3. Planning of the Macedonian energy system

### 3.1. Reference energy system

Energy system of Macedonia for 2020 has been reconstructed in EnergyPLAN model (2020 reference scenario) expanding the 2008 reference scenario from [18]. Reference scenarios 2008 and 2020 were constructed according to the scenario with energy efficiency measures from the Macedonian Strategy for Energy Development, which takes into account the already implemented measures for energy efficiency, the obligation to raise the electricity price to the market price until 2015, as well as realisation of the measures stipulated in the National Energy Efficiency Action Plan for energy savings in the amount of 33% of the target for 2020 [16]. According to that scenario, the total electricity consumption in the 2006–2020 period will increase by 41%, while in the industry by 58.7% and by 27% in the residential sector. Furthermore, the results obtained in [18], show that EnergyPLAN model gives a high level of accuracy and that reference system could be used in the future analyses of the Macedonian power sector.

Table 1 provides the basic parameters of the lignite and hydro power plants in Macedonia. The total installed capacity of thermal power plants fuelled by lignite is 800 MW while the installed capacity of hydro power plants is 580 MW, with a maximal annual production of around 7900 GWh [14]. Data for hourly production of wind farms was calculated by making use of hourly wind speed provided by METEONORM program [28]. Hourly production data for hydro power plants have been obtained from [29] for year 2009 while hourly load data for Macedonian power system have been provided by [30]. Load curve for hourly district heating demand has been calculated by using degree-day and temperature obtained from METEONORM program [28].

**Table 1**  
Basic parameters of power plants in Macedonia [16].

Name of power plant	Number of aggregates	Installed power [MW]	Commissioning in system [year]	Type of power plant
Bitola	3	675	1982/1984/1988	Thermal PP
Oslomej	1	125	1979	Thermal PP
Vrutok	4	172	1957/1973	Hydro PP
Tikvesh	4	116	1966/1981	Hydro PP
Globochica	2	42	1965	Hydro PP
Shpilje	3	84	1969	Hydro PP
Kozjak	2	80	2004	Hydro PP
Raven	3	21.6	1959/1973	Hydro PP
Vrben	2	12.8	1959	Hydro PP
MAK ROT Program	–	37	–	Hydro PP
Other EVN	–	8	–	Hydro PP
Other companies	–	4.6	–	Hydro PP
Total	–	1380	–	–

**Table 2**  
Fuel prices and CO<sub>2</sub> content in the fuels used in the calculation [16] and [32].

	Crude oil	Fuel oil	Diesel	Petrol	Coal (lignite)	N gas	LPG	Biomass
Fuel prices [€/GJ]	17.97	12.93	17.78	19.50	1.76	10.18	11.27	3.26
CO <sub>2</sub> content in fuel [kg/GJ]	–	74	74	74	101.2	56.7	66.7	–

Macedonian electricity demand and fuel consumption used for reference energy system in 2020 was constituted by data obtained from [16]. Macedonian electricity demand is expected to rise from 8.64 TWh in 2008 to 10.05 TWh in 2020 equal to an annual rise of 2.5% [16]. Also, expected annual rise of energy demand in the industrial, residential, commercial and service, agriculture and forestry and transport sector, as determined in [16], have been included in the 2020 reference scenario.

Furthermore, investment costs for new energy units and price of fuel in the year 2020 have been obtained from [31] and from Strategic Energy Technology Information System (SETIS) web calculator [32]. In order to identify the price of fuel oil, diesel and petrol in the year 2020, assumption of the 150 \$/bbl (110 €/bbl) for the crude oil price was used [32]. The fuel price of fuel oil, diesel and petrol were calculated by using the price ratio between crude oil and these fuels as well as lower heating value of crude oil. The following ratios were used to calculate these prices [27]: ratio of crude oil to fuel oil was 0.71, crude oil to diesel was 1, and crude oil to petrol was 1.09. The fuel prices and CO<sub>2</sub> content in the fuels used in the calculation are presented in Table 2.

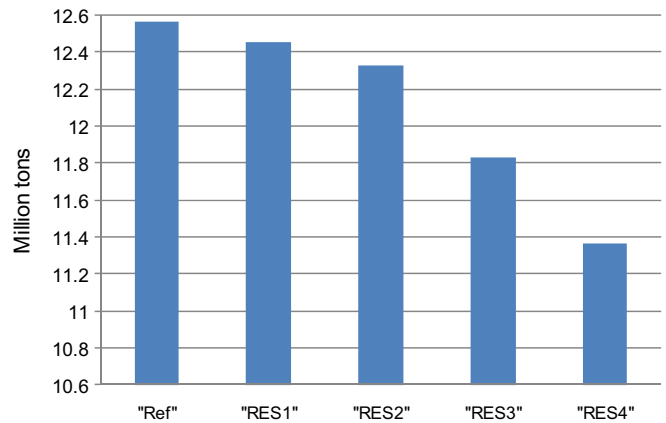
### 3.2. RES scenarios

Analyses of Macedonian energy system in 2020 were conducted for four different scenarios and closed energy system. Furthermore, it is assumed that at least 30% of the power at any hour must come from power units capable of supplying ancillary (central power plant, CHP and hydro power plant). Data for wind and PV electricity production in first two scenarios are obtained from [19]. The minimum capacity for the condensing power plant (PP) is set to 510 MW in all scenarios. The analyses of the hourly production of the condensing PP have shown that the minimum capacity is 510 MW, which is assumed in all 'RES' scenarios.

The first scenario, 'RES1', considers production of electricity from wind and PV systems in accordance with the lowest share of RES in the Strategy for utilisation of RES in Macedonia by 2020 [19]. Wind production of electricity is set to 180 GWh (1.79% of total electricity demand in 2020) while the PV production of electricity is set to 14 GWh (0.14% of total electricity demand in 2020). All other data were maintained as in reference energy system.

**Table 3**  
Installed components in the reference and the four 'RES' scenarios.

Scenarios	Installed components in the scenarios					
	Thermal power plant [MW]	Pump hydro storage [MW]	Wind production [% of total consumption]	PV production [% of total consumption]	Gas fired CHP [MW]	Power plant Minimum [MW]
'Ref'	800	–	–	–	227	510
'RES1'	800	–	1.79	0.14	227	510
'RES2'	800	–	3.58	0.41	227	510
'RES3'	800	332.8/347.3	10	0.5	227	510
'RES4'	800	332.8/347.3	15	1	227	510



**Fig. 1.** CO<sub>2</sub> emissions in the year 2020 for various scenarios.

The second scenario, 'RES2', considers production of electricity from wind and PV systems in accordance with the highest share of RES in the Strategy for utilisation of RES in Macedonia by 2020 [19]. Wind production of electricity is set to 360 GWh (3.58% of total electricity demand in 2020) while the PV production of electricity is set to 42 GWh (0.41% of total electricity demand in 2020). All other data were maintained as in reference energy system.

The third scenario, 'RES3', considers installations of all power plants from previous scenarios with the additional installation of one pump hydro storage (PHS) power plant. Assumptions for the 'RES3' scenario are:

- The electricity and heat demands are maintained at the same level as in the reference scenario.
- Production of electricity from PV is set to 0.5% of total electricity demand in 2020.
- Production of wind electricity is set to 10% of total electricity demand in 2020.
- New pumped hydro storage (PHS) power plant has been included. This PHS plant has a pump with capacity of 347.3 MW and a turbine with capacity of 332.8 MW.

The fourth scenario, 'RES4', is scenario with the highest share of electricity produced from RES. Assumptions for the 'RES4' scenario are:

- The electricity and heat demands are maintained at the same level as in the reference scenario.
- Production of electricity from PV is set at 1% of total electricity demand in 2020.
- Production of wind electricity is set at 15% of total electricity demand in 2020.

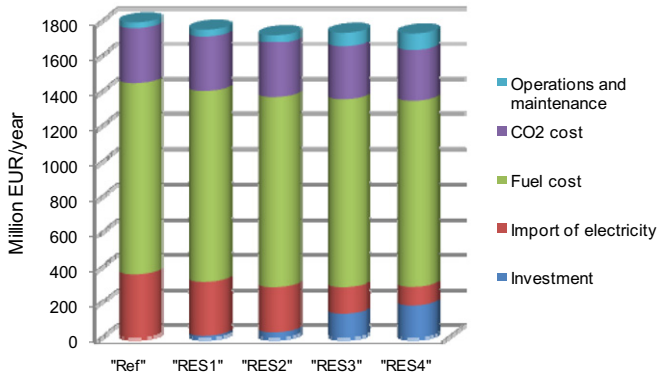


Fig. 2. Annual operating cost of the various scenarios.

Detailed description of installed components in four 'RES' scenarios as well as in reference scenario are given in Table 3.

#### 4. Results

##### 4.1. Environmental evaluation of 'RES' scenarios

The CO<sub>2</sub> content in the fuels from Table 1 have been used in order to calculate CO<sub>2</sub> emissions associated to each of the scenarios (Fig. 1.).

Results have shown that in the year 2020, decrease of CO<sub>2</sub> emissions in the 'RES1' scenario is 0.84% while in the 'RES4' scenario CO<sub>2</sub> emissions are lower for 9.54% compared to reference scenario.

##### 4.2. Economic evaluation of 'RES' scenarios

This section evaluates the impact of CO<sub>2</sub> price and lignite price on Macedonian energy system including sensitivity analyses to these parameters of the 'Ref' and the 'RES' scenarios. The first step is to calculate annual operating cost of 'RES' scenarios. For this calculation, fuel prices from Table 2 and CO<sub>2</sub> price of 25 €/t [33] have been used. Operating costs of the condensing lignite fired power plants in Macedonia were obtained from [16]. The total operating and maintaining (O&M) costs of lignite fired power plant in Macedonia are 7.7 €/MWh. The onshore wind and PV costs were obtained from a report completed by the Danish Energy Authority [31]: investment costs for onshore wind are 1.5 M€/MW and PV is 4 M€/MW. Fixed O&M costs for onshore wind are 12 €/MWh while the total O&M costs of PV are 20 €/MWh. Total annual operating cost of 'RES' scenarios are presented in Fig. 2 and Table 4.

Results presented in Fig. 2 have shown that the fuel price has the highest impact on economy. Also, CO<sub>2</sub> costs have a large share in total costs and these penalties are even higher than annual investment costs in RES technologies.

Table 4  
Annual operating costs in the reference and four RES scenarios.

Costs in million EUR	'Ref'	'RES1'	'RES2'	'RES3'	'RES4'
Investment	0	14	33	137	183
Import of electricity	364	308	259	155	111
Fuel cost	1086	1084	1080	1068	1057
CO <sub>2</sub> cost	314	311	308	296	284
Operations and maintenance	32	38	44	82	99
Total costs	1796	1755	1724	1738	1734

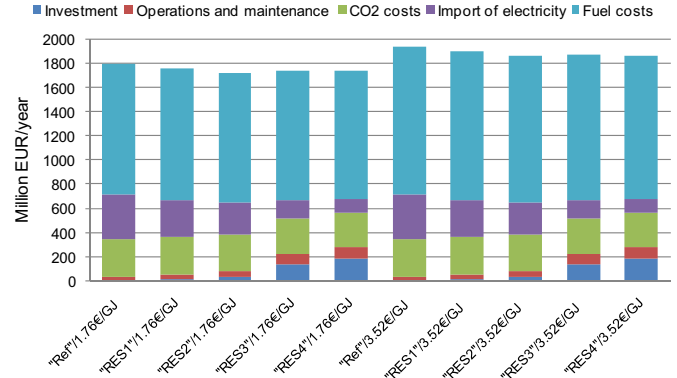


Fig. 3. Annual operating cost of 'RES' scenarios for lignite price of 31 €/t.

Furthermore, the annual operating costs were also calculated for higher coal and CO<sub>2</sub> prices as they are expected to be in the future. The case of doubling these prices is analyzed (coal price of 3.52 €/GJ, lignite price in Macedonian conditions 31 €/t; CO<sub>2</sub> price 50 €/t) and the results of this sensitivity analyses have been presented in Fig. 3 and Fig. 4.

Obviously (Fig. 3) the increase of lignite price will have a low impact on the total annual operating costs, but a very high impact on the operating costs of power plants fuelled by lignite. Doubled, the lignite price will lead to increase of total annual operation costs in 'RES4' scenario for 6.8% and for 7.5% in the reference scenario. Comparing the two 'Ref' scenarios, the fuel costs of lignite fired power plants are higher for 146 M€ in the doubled lignite price 'Ref' scenario. Furthermore, in doubled lignite price case, the annual operating costs of 'RES4' scenario are only 97 M€ higher than the ones of the 'Ref' scenario with current lignite price, and even lower for 49 M€ than the annual operating costs the 'Ref' scenario in doubled lignite price case.

Results of costs analysis, presented in Fig. 4, have indicated that increase of CO<sub>2</sub> price will have huge impact on the annual energy costs in Macedonia. The increase of CO<sub>2</sub> price from 25 €/t to future price of 50 €/t will lead to increase of annual operating costs over 26% in all the scenarios considered.

These results suggest that investments in regulation of the existing lignite fired power plants are needed in parallel with the measures for better utilisation of the less carbon intensive fuels. That will reduce the impact of the CO<sub>2</sub> price on the electricity price, as well as on the total operating costs of the power plants.

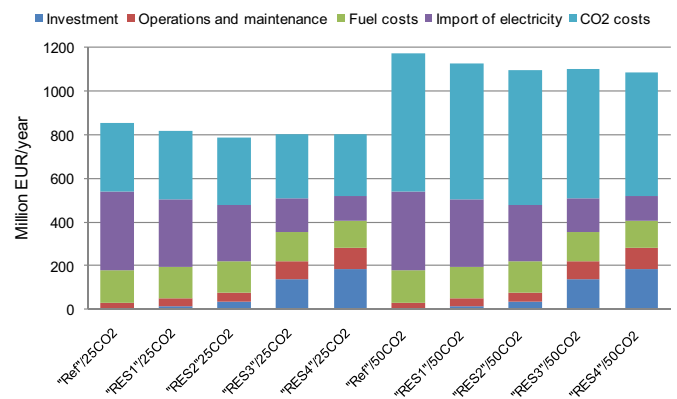


Fig. 4. Annual operating costs of 'RES' scenarios for CO<sub>2</sub> price of 50 €/t.

## 5. Conclusion

In this paper the energy system of Macedonia in the year 2020 is modelled and then used for scenario analyses of high penetration of renewables into existing energy system. The results of scenario analyses show that the CO<sub>2</sub> emissions from the energy sector can be reduced from 0.84% in the 'RES1' scenario to 9.54% in the 'RES4' scenario.

The results of sensitivity analyses show that coal price and CO<sub>2</sub> price have huge impacts on the economy of the energy system. In the case of increase of lignite price for double, annual operating costs in scenarios will be increased between 6.5% and 7.6%. Doubling the CO<sub>2</sub> price will lead to increase in the annual operating costs of over 26% in all scenarios. Furthermore, analyses show that the total electricity needs cannot be covered by own production and further investment in the generation capacities is indispensable. Also, the increased penetration of RES would require investments in the regulation system of the existing lignite fired power plants.

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