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ASSESMENT OF THE MACEDONIAN POWER SYSTEM POTENTIAL TOWARD GREEN ENERGY TRANSITION

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Abstract: This paper presents original analysis of Macedonian energy sector. The options for installing RES capacities are investigated by using the EnergyPLAN software. Analysis was conducted for base scenario and two renewable scenarios designed for achieving a sustainable future with lower CO_2 emissions, higher level of RES share, import independence and lower LCOE prices. The results have shown that achieving these goals is possible in the two renewable scenarios. The electricity production from RES is increased from 22.2% in Scenario 1 to 86% in Scenario 2 and 110% in Scenario 3. The annual CO_2 emissions will decrease from 3.04Mt/annual in Scenario 1 to 0.67Mt/annual and 0.41Mt/annual in the second and third scenarios, respectively. This paper also analyzes how the change of CO_2 prices can affect the LCOE. The LCOE increases by 103.8% in Scenario 1 when CO_2 price increases from 20 to 100eur/t while in the third scenario increases by only 8.16% because of the low CO_2 emissions. This shows how the renewable scenarios can be almost independent and predictable in terms of CO_2 emissions and costs.
Keywords: Energy sector; Electricity production; EnergyPLAN; LCOE; Renewable energy

1. INTRODUCTION

According to the latest edition of the IEA's Electricity Market Report from July 2022, global demand growth for electricity is slowing significantly in 2022. After global electricity demand grew by a strong 6% in 2021, it is expected growth to slow to 2.4% in 2022.[1] In the IEA's Electricity Market Report from 2021 it was stated that global demand for electricity fell by about 1% in 2020 due to the impacts of the Covid-19 pandemic, and is set to grow by almost to 5% in 2021 and 4% in 2022 – as economies recover, boosted by stimulus spending.[2][3] However, because of the Covid-19 crisis and Russia's invasion of Ukraine the situation is worse than what was expected back in 2021 and the war in Ukraine aggravated the economic outlook for 2022 and 2023. Industry consumes more than 40% of final electricity demand and 20% is consumed by commercial and services.[1] Energy consumption is rising in residential and commercial buildings, and this increased demand for electricity and heat leads to a high emission of greenhouse gases (GHG).

For this purpose, most of the European and non-European countries have already begun to recheck their climate and energy policies. Improvement in sustainable energy supply is crucial in order to provide reliable and clean energy sources and provide a quality life on this planet [4]. Parallel with growth of global demand for affordable and reliable energy, energy trends emphasize more ambitious transition towards low-carbon economy, with renewable energy sources (RES), energy efficiency (EE) and GHG emissions as the most important enablers of transition. The EU tends to be climate-neutral by 2050 – to become an economy with net-zero GHG.[5] The path to a climate-neutral society is an urgent challenge and an opportunity to build a sustainable future at the same time. Aiming to achieve these goals, all parts of society and economic sectors should play a role: power sector, industry, mobility, buildings, agriculture, and forestry.

While IEA's January 2022 forecast indicated that global electricity sector emissions would remain flat in 2022 and 2023, they now expect a decline of around half a percent in 2022 and one percent in 2023. For 2022 it is expected renewables to reclaim the title of fastest-growing source of electricity supply, after having held it from 2018 to 2020 already but losing to coal in 2021. Boosted by record new capacity installations in 2021 and another expected record in 2022, and after being hampered by unfavourable weather in 2021, output could grow by over 10% in 2022. Exceeding demand growth and slowing down global fossil fuel use by 1%, low-carbon generation grows in total by 7%, as nuclear generation is down 3% (induced by lower capacity availability and retirements in Europe). [1]

Regarding the Macedonian energy sector, current electricity consumption relies on about 30% import, and the rest is supplied by domestic generation capacities, mainly lignite fired thermal power plants TPP Bitola and TPP Oslomej, and several large hydro power plants (HPP).[6] The mentioned thermal power plants are relatively old and face challenges of future coal supply. In accordance with the latest Strategy for Energy Development the total installed capacity for electricity production is 2.06GW, of which 48% are thermal power plants and 34% small and large hydro power plants, 15% natural gas fired CHP plants and only 3%

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

other renewable sources (PV plants, wind power plants, biogas fired power plants, etc.).[6] The biggest organization in North Macedonia for electricity production is Elektrani na Severna Makedonija/ Power Plants of North Macedonia (ESM), a company owned by the state, with approximately 70% of the total installed capacity in the country. ESM is the owner of the two, previously mentioned; coal fired TPPs, TPP Bitola and TPP Oslomej, and the large HPPs, as well. Similar to other European countries, the energy sector has the greatest impact on GHG emissions, making this sector the main target for reducing CO_2 emissions. North Macedonia has lower GHG emissions per capita by approximately 30% compared to EU, but the GHG emissions per GDP are five times higher than EU in 2014. One Macedonian citizen emits on average 5.9 tonnes CO_2-eq, which is 2.8 tonnes lower CO_2-eq compared to the level of EU citizens in 2014.[6] Regarding the average electricity prices, they are lower than the average prices in the Balkan and EU countries, according to the Energy and Water Services Regulatory Commission of the Republic of North Macedonia (ERC). The second half of 2021 was marked by significant disturbances in the functioning of the electricity market due to the high price increase. This affected the operation of the power system from the point of view of continuous engagement of the system reserves, that is, the appearance of a significant imbalance of the entire power system, which led to the emptying of the water in the reservoirs. Parallel to this situation, the electricity production of the largest electricity producer AD ESM also decreased. The lack of electricity was provided by imports and by putting into operation the oil fired TPP Negotino. A crisis situation in the electricity supply continues in 2022 as well.

An unfavorable energy mix with a predominant role of the lignite fuelled TPPs, a high reliance on energy import, poor condition of the energy system and inefficiency in energy production and use are the biggest problems that the Macedonian energy sector faces. For this purpose, the country is willing to follow the good practice of EU actions into the energy field, such as climate and energy policies. The Strategy for Energy Development of the Republic of North Macedonia until 2040 relies on EU energy union five dimension framework: secure, efficient, environmentally friendly and competitive energy system that is capable to support the sustainable economic growth of the country. This strategy defines three different scenarios – Reference, Moderate transition and Green, and evaluates the results of strategic goals by six indicators for each strategic goal. [6] Due to the increased supply capacities, in all the three scenarios net import decreases. The price of CO_2 is what makes the trade-off between building own capacities or importing. The import is highest in the period of 2025-2030 in the Moderate scenario, since TPP Bitola will be decommissioned. Furthermore, TPP Oslomej is decommissioned in all three scenarios, so a solar power plant could be the transformation solution (80 – 120 MW) with the same infrastructure (site and transmission network) and employees. The same approach could be applied for TPP Bitola. With regards to security of supply, due to higher RES generation the situation in this period is better in Green scenario. Since TPP Bitola is revitalized in 2025 the Reference scenario exhibits least import dependency. [6]

The global energy situation, the unstable and unpredictable energy prices, the high levels of GHG emissions caused by the energy sector and the low percentage of RES in the Macedonian energy system were the main reasons for this paper to be written. The purpose of this paper is not to provide the basis for predicting the future energy system, but to form a basis for an informed, transparent and conscious deliberation of potential development pathways for the energy system in The Republic of North Macedonia. This is based on both technical and economic simulation strategies. Combining conventional and RES technologies, three scenarios for the expansion of the Macedonian power system were created and analyzed.

2. METHODS

Three most common methodological approaches to energy system modeling are optimization, simulation and equilibrium tools or models, is said in a paper written by Martins et al. [7]. In this paper, for the energy system analysis EnergyPLAN simulation tool was used which is created for the study and research in the design of future sustainable energy solution with a focus on Macedonian energy system with high shares of RES. The main purpose of the EnergyPLAN model is to analyze the energy, environmental, and economic impact of various energy strategies. This software has the ability to support designs of national energy planning strategies with technical and economic analyses of the consequences of different scenarios and investments. [8][9][10]

Although the main motive for the development of EnergyPLAN was the national-scale energy systems, this tool is also frequently used for many other geographical scales mostly because it has the ability to accept input data, is free and with an hourly time-step (Figure 1). Besides from the conventional and widely used energy technologies, EnergyPLAN contains a big range of new technologies which are innovative, such as

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wave power, district heating and cooling, tidal power, concentrated solar power, thermal storage, biogas production, biomass gasification, and various other technologies.

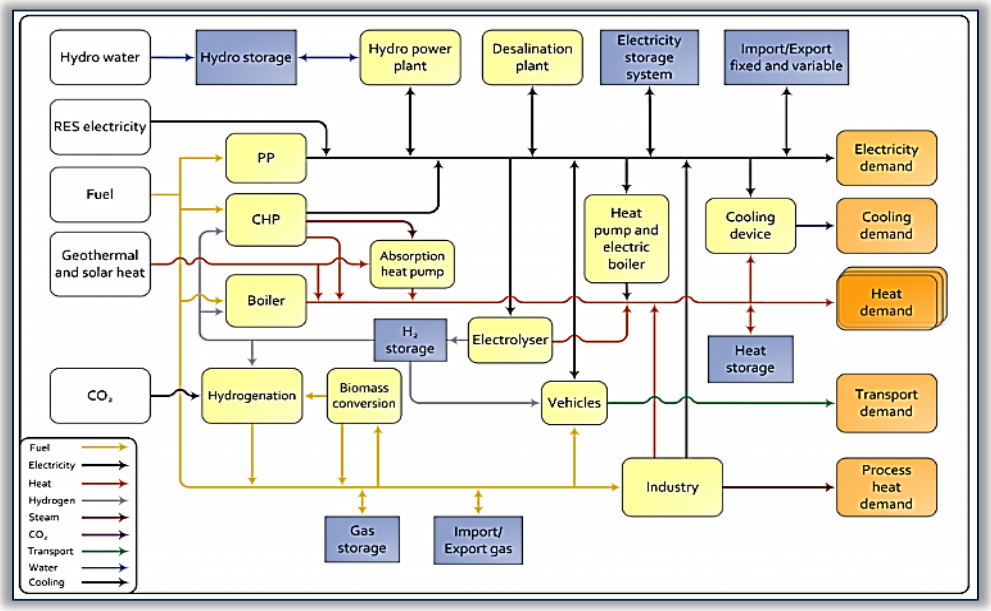

Figure 1. Flow diagram of the EnergyPlan model

Within the one-year period, EnergyPLAN simulates the energy system on an hourly resolution level, therefore, for longer-spanning analyses, several simulations should be run.[11]

The EnergyPLAN model requires two of the following technical parameters:
- The total annual production and/or demand (i.e. TWh/year).
- The capacity of the unit installed (i.e. MW).
- The hourly distribution of the total annual production and/or demand (total 8784 hours).

In this paper, the Macedonian system was described by electricity demands, capacities and efficiencies of the plants to generate electricity, types of energy sources, annual energy balances, fuel consumptions by the power plants, fixed and variable costs, investments, CO_2 emissions, etc. As a result from the EnergyPLAN tool, for the three analyzed scenarios, seven indicators were used to quantify Macedonian energy system:
- Electricity Production by type of technology;
- Fossil Fuel supply by fuel type;
- Electricity produced by RES, share and quantity;
- Amount of CO_2 emissions resulting from energy consumption and generation;
- The annual generation costs required to supply the required energy demand, including socio-economic consequences of the generation, consisted of: total fuel costs, annual investment costs, fixed and variable operational costs, CO_2 costs;
- LCOE by type of power plant;
- LCOE as a function of CO_2 price.

3. SCENARIOS

As part of this paper, three scenarios were created. The first scenario is modeled in accordance with the current situation in the country, while the other two scenarios are greener scenarios, with high renewable generation capacity, and revitalization and/or replacement of huge part of the existing generation capacities in order to enable higher energy transformation efficiency and to achieve green energy transition.

The production capacities of the installed power plants were acquired from ESM's annual reports [12], annual reports given by Energy and Water Services Regulatory Commission of the Republic of North Macedonia (ERC) [13] and Daily information reports by Electricity Transmission System Operator of North Macedonia (MEPSO) [14]. All demands and productions are exogenously defined using hourly time series, and for that purpose hourly load data of Macedonian electricity power system has been obtained from MESPO's [14] electronic database. In all three scenarios electricity and district heating demands are the same, 7.483TWh/year and 0.55TWh/year, respectively.

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In Table 1 are presented the costs which were putted in using data obtained from The Strategy for Energy Development of the Republic of North Macedonia until 2040 [6]. The fuel prices were actual prices on the market when the scenarios were created: coal price is 3.7eur/GJ, oil price is 10eur/GJ and 25eur/GJ is the price of natural gas.

Table 1. Investment and O&M costs

	Large Power Plants	Wind	Photo Voltaic	Hydro Power	Hydro Pump	River Hydro
Specific Investment [eur/kW]	1090	1500	800	1500	1200	2000
Period [years]	30	20	40	50	50	50
Fixed O&M [% of Inv.]	0.74	1.7	3.925	0.2	0.25	0.15
Variable O&M [eur/MWh-e]	3.7			2.1	2.1	

Scenario 1

The first scenario presents the actual situation in the country; therefore, the energy system of Macedonia has been reconstructed in the model. As shown in Table 2, the total installed capacity is 1,350 MW, of which 591 MW is the installed power in the coal fired TPP (Bitola 1, Bitola 2 and Oslomej, while Bitola 3 and TPP Negotino were not considered in this sceanrio), 698MW present the power of HPPs, 36.8MW wind power plant Bogdanci, and 24MW is the total installed power of the PV plants. The calculations are based on 5,000 working hours per year of the TPP Bitola1 and Bitola2 and 3,000 working hours of the TPP Oslomej. The efficiency of the TPPs is 31.1% and it was calculated in accordance with the latest information regarding the Macedonian TPPs parameters (produced electricity, fuel consumption, heat values), whilst the efficiency of the dammed HPPs was inputted as 90%.

Table 2. Scenario 1: Electric capacities of Power plants

TPP	HPP	Wind	PV
TPP Bitola 1= 233MW	Dammed hydro= 557.4MW	36.8MW	24MW
TPP Bitola 2= 233MW	River hydro= 140.6MW		
TPP Oslomej= 125MW			

Scenario 2 – High RES share

The key generation capacity in Scenario 2 consists of 3,752.8MW, presented in Table 3. It was considered North Macedonia to phase-out TPP Bitola 2, TPP Bitola 3 and TPP Oslomej of the existing conventional capacity, while to add ~ 2.5GW of RES and gas fired CHPs. The installed capacity of combined heat and power plants (CHPPs) is 487.4MW (287.4MW existing plant TE-TO and 200MW new gas CHPPs) with efficiency up to 50%. The capacity of dammed HPP will go up to 1332.4MW with efficiency of 0.9MW, and 458MW of this capacity is a reversible HPP called Cebren. The installed capacity of wind power plants is 300MW and 1000MW of PV Plants.

Table 3. Scenario 2: Electric capacities of Power plants

CHP	TPP	HPP	Wind	PV
Gas CHP TE-TO= 287.4MW	TPP Bitola 1=233MW	Dammed hydro= 1,332.4MW (of which pump back = 458MW)	300MW	1,000MW
Gas CHP= 200MW		River hydro= 400MW		

Scenario 3 – High RES share

The crucial goal of the third scenario is to considerably increase the installed capacities of RES. With the country's portfolio based almost completely on RES, total installed power is 4,419.8MW. This is the highest installed capacity compared with the other two scenarios. The installed power is 1,732.4MW HPP (dammed and river hydro); 800MW wind power plants; 1,400MW PV plants, 287.4MW existing gas CHP TE-TO and 200MW new gas fired CHP, as shown in Table 4. It was considered TPPs in Bitola and Oslomej to be phased-out of the existing conventional capacity; and most important is that coal-fired and oil-fired power plant were not analyzed in this scenario. Meanwhile, ~ 3.4 GW of RES and gas power plants will be adjoined.

Table 4. Scenario 3: Electric capacities of Power plants

Gas CHP	HPP	Wind	PV
Gas CHP TE-TO= 287.4MW	Dammed hydro= 1,332.4MW (of which pumped back = 458MW)	800MW	1,400MW
Gas CHP= 200MW	River hydro= 400MW		

All the data was entered in EnergyPlan tool, and simulation for each scenario was performed. The following outputs were obtained by the EnergyPlan software:

- Electricity produced by the PPs;
- Imported/ exported quantity of electricity;
- CO_2 emissions;
- RES share;

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- Fuel consumptions;
- Investment, variable, fixed, fuel, CO_2 and other costs;

LCOE was separately calculated, outside of EnergyPLAN, because LCOE calculations are not within its range. LCOE was calculated for each PP and also for the whole system. With the intention of illustrating the effect of CO_2 price, LCOE was calculated for five values of CO_2 price. The following equation was used for calculating LCOE for the whole energy system:

$$\text{LCOE} = \frac{\text{Total annual costs} - \text{Exchange costs}}{\text{Total annual output}} \ [\text{eur/MWh}] \quad (1)$$

LCOE for each PP was calculated using the following equation:

$$\text{LCOE}\left[\frac{\text{eur}}{\text{MWh}}\right] = \frac{\text{Investment [eur/a]}}{\text{Output [MWh/a]}} + \frac{\text{Fixed O\&Mcosts [eur/a]}}{\text{Output [MWh/a]}} + \text{Var. O\&Mcosts}\left[\frac{\text{eur}}{\text{MWh}}\right] + \frac{\text{Fuel price}\left[\frac{\text{eur}}{\text{MWh}}\right]}{\text{PP efficiency}} + \frac{CO_2\text{price}\left[\frac{\text{eur}}{\text{t}}\right] \times CO_2\text{content}\left[\frac{\text{t}}{\text{MWh}}\right]}{\text{PP efficiency}} \quad (2)$$

4. RESULTS AND DISCUSSION

For each scenario, the aim is to assess the impact on energy, environment and economy. To do so, for each scenario, the electricity production is measured by power plant type and the fossil fuel supply is measured by fuel type to analyze the impact on energy, the RES share and RES electricity production are presented and the total annual carbon dioxide emissions are measured to assess the impact on environment and, last but not least, the LCOE by type of technology, LCOE as a function of CO_2 price and annual costs by type, for each scenario are presented to analyze the impact on the economy.

Impact on Energy

Scenario 2 and Scenario 3 will have a steep growth of electricity generated from RES. However, hydro energy will be the largest share in electricity generation, as shown in Figure 2. It is noticeably that right now, in Scenario 1, the Macedonian energy sector mostly relies on coal production capacities. Furthermore, this figure outlines how the role of RES power increases in the two proposed scenarios. Compared with Scenario 1, the increase in the electricity production will be around 81.8% in the second and 106.8% in the third scenario, because of the large increase in the installed electricity capacities. In those scenarios PV and wind will be the fastest growing technology. The amount of electricity production by the installed PV plants will be increased by 3,575% and 5,050% in the second and third scenario, respectively. The electricity generated by wind energy will increase by 650% in Scenario 2 and 1,890% in the third scenario, compared with Scenario 1.

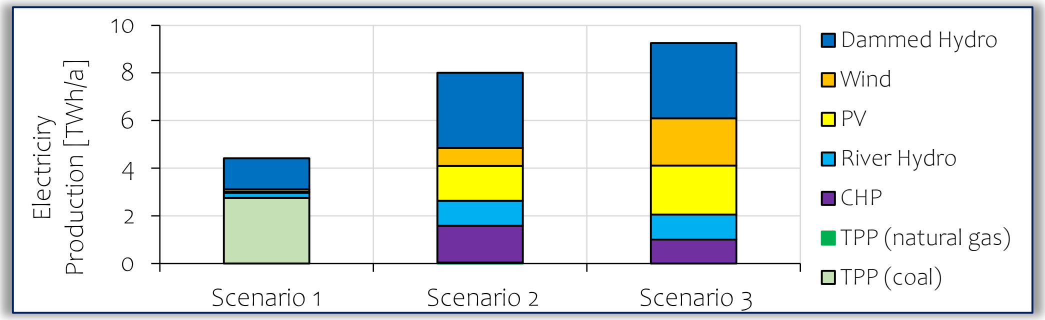

Figure 2. Electricity Production for each scenario by type of technology

Figure 3 displays the annual fossil fuel consumption for all three scenarios. Actually, the presented fuels from the analyzed scenarios: coal and natural gas, are the only energy sources that are not renewable. As one can see, Scenario 1 is based on the burning of coal, with annual consumption of almost 9TWh, whilst the other two scenarios are using natural gas in the installed CHPs and TPPs, and only a small amount of coal is used as fuel in Scenario 2.

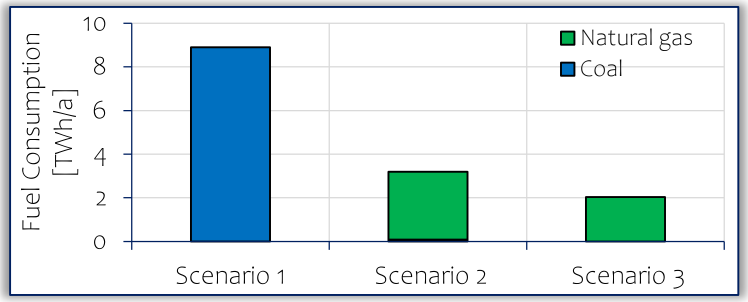

Figure 3. Fossil Fuel consumption for each scenario

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Impact on Environment

Due to the dominant use of coal in the country for electricity production, there is significant potential for GHG emissions reductions, which can be best achieved with adding RES. Figure 4 shows the RES share in all three scenarios. The second and third scenarios will have a sustained growth in electricity generation from RES. Renewable energy production will increase from 22.2% in Scenario 1 to 86% in Scenario 2 and 110% in Scenario 3. Hence, the RES share of electricity production is 286% higher in Scenario 2 than in Scenario 1, and 396% higher in Scenario 3 than in Scenario 1.

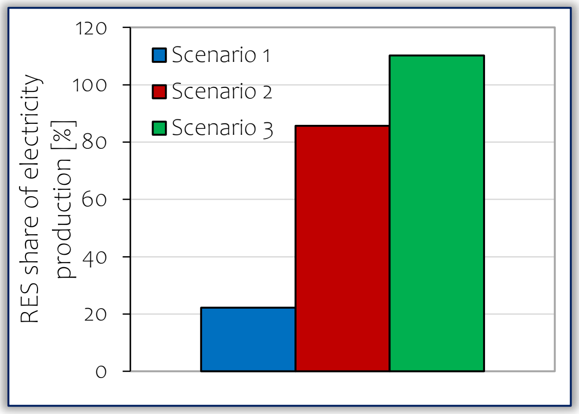

Figure 4. RES share of electricity production

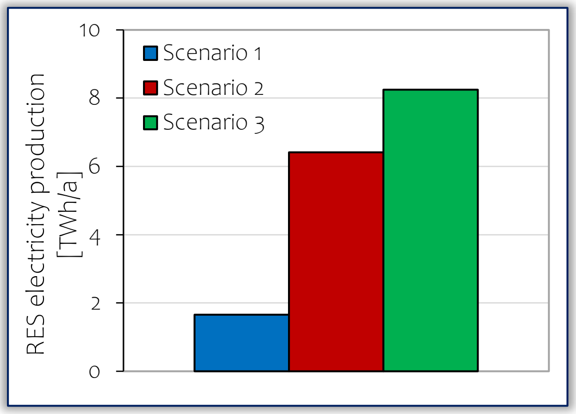

Figure 5. RES electricity production

As shown in Figure 5, from 1.66TWh produced in Scenario 1, the electricity produced by RES will increase up to 6.41TWh and 8.25TWh in Scenario 2 and Scenario 3, respectively.

It is expected zero carbon fuels to have a much more higher role in the future primary energy consumption, with RES winning growth race (Figure 4 and Figure 5). Driven by the decline in the coal utilization, CO_2 emissions will be higly reduced, as shown in Figure 6. CO_2 represents the majority of GHG emissions in all three scenarios. In the second scenario CO_2 emissions decrease for nearly 78% compared with Scenario 1 and similar in the third scenario, for nearly 86% compared with Scenario 1.

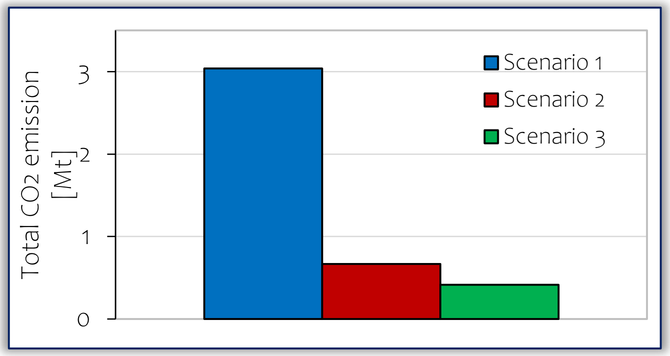

Figure 6. CO_2 emissions for each scenario

Impact on Economy

Figure 7 presents the annual costs for the analyzed scenarios. The annual costs in Scenario 1 are quite higher than in the other two scenarios, mostly because of the costs for electricity exchange. In contrast to the exchange costs in Scenario 1, in the second and in the third scenario the electricity exchange costs are negative. Actually, in these two scenarios the excess electricity is exported. The CO_2 costs are highest in Scenario 1 because of the coal fired TPPs, while in the other two scenarios natural gas is used in the TPPs and CHPs, and that results with conspicuously higher fuel costs. The main driver for significantly higher O&M and investment costs in the proposed scenarios is mostly because of the higher installed power capacities, as presented in the chapter 3. As shown, Scenario 3 is most cost-effective scenario.

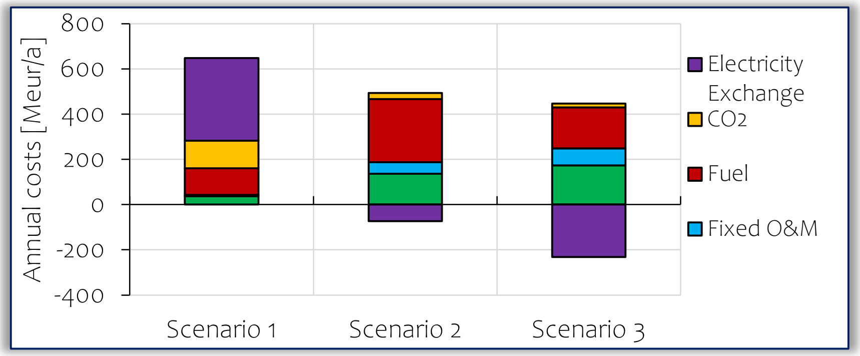

Figure 7. Annual costs for each scenario

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

In the last few years, LCOE produced by RES has fallen a lot; therefore, renewable technology for electricity production is becoming competitive to widely used traditional energy sources. According to Figure 8, the highest cost for electricity production appears in the second scenario for electricity generated in natural gas fired TPPs and CHPPs, and this is as a result of the high price of natural gas and also, because of the low quantities of electricity produced in those power plants as shown in Figure 2. As stated by the presented results, electricity generated by gas TPPs and CHPPs won't be competitive in the second and third scenarios. However, the total LCOE is lower in the second and third scenarios; because those scenarios are mostly based on RES. It can be seen that the two proposed scenarios will remain cost effective, even if the LCOE of natural gas fired plants is high. This directly shows how CO_2 price results on the economy. According to these results, it is obvious that the biggest disadvantage with the coal fired PPs are the CO_2 and environment-unfriendly particles emissions, while the high price of the natural gas and high LCOE are the biggest disadvantages of the natural gas fired PPs.

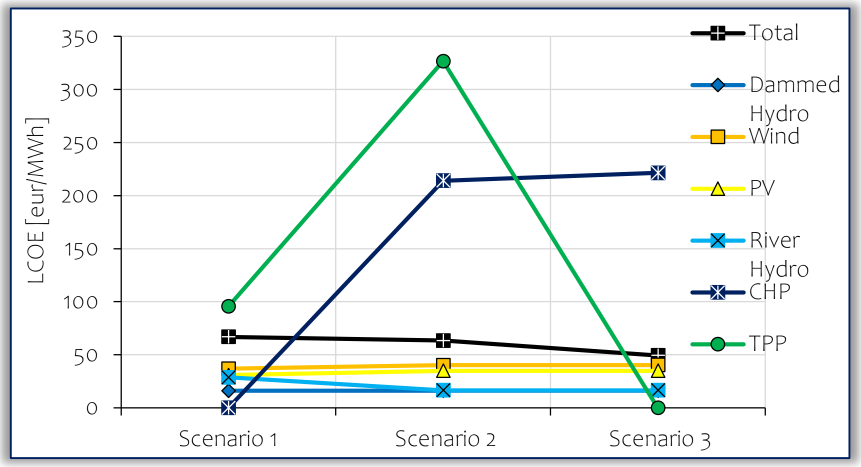

Figure 8. LCOE by type of power plant, for each scenario

In this paper is analyzed how the change of the CO_2 price will affect the LCOE. The results obtained in the analysis are presented in Figure 9. The change of the CO_2 price mostly affects Scenario 1; because coal fired PPs are the main electricity production plants. The LCOE increases from 53 up to 108eur/MWh in Scenario 1, from 63 to 69eur/MWh in Scenario 2 and from 49 to 53eur/MWh in Scenario 3, when the CO_2 price is increased from 20 to 100eur/t, respectively.

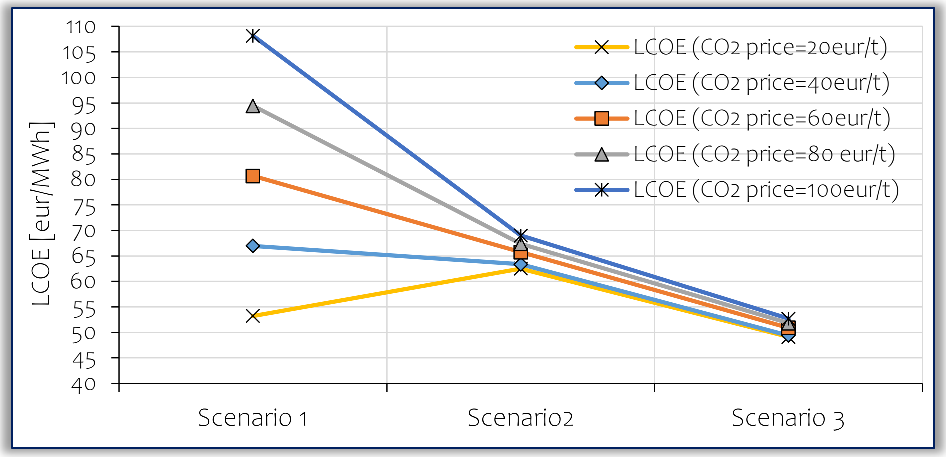

Figure 9. LCOE for each scenario as a function of CO_2 price

5. CONCLUSIONS

In this paper Macedonian energy system has been analyzed in order to analyze the possibilities for the expansion and improvement of Macedonian power system, reduction of GHG emissions and increasing RES capacities. Combining different technologies, mostly renewable ones, three scenarios have been created using the EnergyPLAN software. The created scenarios: Scenario 1, Scenario 2 and Scenario 3 were comparatively evaluated using seven indicators. The scenarios enabled to assess the impact of the installed power plants on energy, environment and economy. This topic was chosen due to the high values of GHG emissions from the current power plants that are part of the Macedonian energy system.

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Currently, according to Scenario 1, the Macedonian energy sector is mostly based on the capacities for electricity production from coal TPPs. Furthermore, the values of installed RES capacities increase in the two proposed scenarios. The increase in electricity production will be around 81% in the second scenario and 107% in the third scenario, due to the large increase in installed capacity for electricity generation.

There is a significant potential for reducing GHG emissions, which is achieved in Scenario 2 and Scenario 3 by installing new RES capacities. In terms of emissions, the two proposed scenarios will show substantial drops in the CO_2.

The annual costs in Scenario 1 are much higher than the other two scenarios, mostly because of the costs for importing electricity. CO_2 costs are highest in Scenario 1 due to the existing coal fired TPPs, while in the other two scenarios natural gas is used in TPPs and CHPs, resulting in significantly higher fuel costs. This paper analyzes how the change of CO_2 prices will affect the LCOE. The change in the price of CO_2 mostly affects Scenario 1 because coal fired TPPs are the main electricity production capacities. While in Scenario 1 the LCOE is increased by 103.8% when the price of CO_2 increases, in Scenario 2 and Scenario 3 LCOE is increased only by 9.5% and 8.16%, respectively. This shows how CO_2 price may affect LCOE in the future and how the proposed and analyzed scenarios can be almost independent and predictable in terms of emissions and costs caused by CO_2 emissions.

From the achieved results it can be concluded that the third scenario is the optimal scenario in terms of energy needs, it is economically viable and has the most approving impact on the environment. Therefore, in the coming years the Government ought to encourage investment in the RES sector, so as to boost usage of RES which would allow sustainable development of the energy sector in the country.

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ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN–L 1584 – 2665