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Dugoročno planiranje makedonskog sistema snabdevanja električnom energijom

Long Term Planning of Macedonian Electricity Supply System

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Rezime **-** U radu su prezentovani alternative za razvoj makedonskog elektroenergetskog sistema u delu snabdevanja električnom energijom. Softverski program MESSAGE se koristi za modeliranje sistema, za razvoj scenarija, za analizu troškovno optimalnih energetskih puteva i za određivanje optimalne kombinacije tehnologija za proizvodnju električne energije. Proračuni za period 2020-2050 se vrši u intervalu od 5 godina. Razvijena su dva scenarija:

- Scenario 1 – BAU (*business as usual* - bez primene mera) scenario, gde preovladava trenutna energetska struktura, sa trendovima poput trenutnog razvoja. Potrebe za električnom energijom zadovoljavaju termoelektrane na ugalj, termoelektrane na gas, hidroelektrane i elektrane na obnovljive izvore energije.
- Scenario 2 - Green scenario, gde su gasne termoelektrane i nuklearne elektrane sa malim modularnim reaktorima tehnologije za bazno opterećenje, a predviđena je intenzivna izgradnja proizvodnih kapaciteta koji koriste obnovljivi izvori energije.

Daljom analizom se dobijaju mogućnosti fleksibilnosti u izgradnji novih objekata u okviru perioda, ekonomski pokazatelji i odgovarajući uticaj na životnu sredinu. Da bi se napravila ekonomska analiza za određenu tehnologiju, kalkulacije se prave za parametre koji su standardni za projekte, kao što su: neto sadašnja vrednost, odnos koristi i troškova, period otplate i interna stopa povratka projekta. Analiziran je uticaj na životnu sredinu preko aspekta emisije CO_2.

Ključne reči - dugoročno planiranje, ekonomski pokazatelji, uticaj na životnu sredinu, alatka MESSAGE, optimalna kombinacija tehnologija

Abstract **-** In the paper alternatives for expansion of the Macedonian electricity supply system are presented. MESSAGE tool is used for modelling the system, for developing the scenarios, to analyse cost optimal energy pathways and to determine the optimal electricity generation technology mix. The calculations for the period 2020-2050 are made in a 5-year interval. Two scenarios are developed:

- Scenario 1 – BAU (Business as Usual) scenario, where the current energy structure prevailed, with trends like the current development. The electricity demand is satisfied by coal-fired thermal power plants, gas-fired thermal power plants, hydro power plants and renewable power plants.
- Scenario 2 - Green scenario, where gas-fired thermal power plants and nuclear power representative with small modular reactors are base load technologies, and also intensive construction of production capacities on renewable energy sources is forced.

By making further analysis, the possibility of flexibility in the construction of new facilities within the interval, economic indicators, and appropriate impact on the environment are obtained. In order to make an economic analysis for a particular technology, calculations are made for parameters that are standard for projects, such as: net present value, benefit - cost ratio, payback period and internal rate of return. The environmental impact is analysed of aspect of CO_2 emissions.

Index Terms - Long term planning, Economic indicators, Environment impact, MESSAGE tool, Optimal technology mix

I INTRODUCTION

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts) is an optimization model used for medium to long-term energy system planning. The tool combines technologies and fuels to construct so-called "energy chains", making it possible to map energy flows from supply (resource extraction) to demand (energy services). The model can help in the design of long-term strategies by analysing cost optimal energy mixes, investment needs and other costs for new infrastructure, energy supply security, energy resource utilization, rate of introduction of new technologies, environmental constraints [1].

In [2], the authors used MESSAGE tool to evaluate the competitiveness of nuclear power plants considering different expansion scenarios for the Brazilian electric system. A research carried by [3] present the possibility and evaluate implications of deploying nuclear power plant in the Nigeria energy mix using MESSAGE for informed electrical energy demand forecast, design energy security pathway in most efficient, cost effective and environment friendly approach.

In this paper, alternatives for expansion of the Macedonian electricity supply system are presented. MESSAGE tool is used to provide the optimal electricity generation technology mix sufficiently enough to feed the country electricity demand.

Two scenarios for the Macedonian electricity supply system for the period 2020 (base year) - 2050 are analysed:

- Scenario 1 – BAU (Business as Usual) scenario, where the current energy structure prevailed, with trends like the current development. The electricity demand is satisfied by coal-fired thermal power plants, gas-fired thermal power plants, hydro power plants and renewable power plants.
- Scenario 2 - Green scenario, where gas-fired thermal power plants and nuclear power representative with small modular reactors (SMR) are base load technologies, and also intensive construction of production capacities on renewable energy sources is forced.

The hydro electricity production candidates are the same for both scenarios, and the additional electricity needs are covered with import.

The authors investigated these two scenarios in their previous work [4]. Energy mix in activity (yearly generated electricity) and activity in representative day for each scenario are presented in the paper. By making further analysis, the economic indicators and appropriate impact on the environment of aspect of CO_2 emissions are going to be presented in this paper.

II MESSAGE MODEL STRUCTURE AND INPUT DATA

In this paper, the MESSAGE tool is used to provide proficient optimized energy scenario that guarantee diverse energy resource option, energy security and efficient delivery system with optimal energy resource mix. The input data for the analysis in the MESSAGE tool were taken from [5-10].

The following general data, data for load region and electricity demand were used:

- Planning period: 2020 (base year) to 2050 in 5 years' time interval
- Discount rate: 8%
- Electricity demand: 7000 GWh/799 MWyr in first year, 2,5% annual growth rate
- Seasons: 4 seasons, each with 1 day representative

The representative day for each season is divided in 3 parts, modelling with 3 intervals inside 0,6/0,2/0,2 which is equivalent of 14,4 hours / 4,8 hours / 4,8 hours for base load/peak load/night load.

Some of the inputs for the scenarios are:

- Imported electricity: 45.7 \$/MWh with growth rate of 3% per year, with capacity of 340 MW for Scenario1 and 200 MW for Scenario 2;
- Coal import and Coal Extraction: 29.9 \$/MWh;
- Oil import: 43.95 \$/MWh, which is near 500 Euro/ton oil;
- Gas import: 35.05 \$/MWh, which is near 250 Euro/1000 Nm^3.

Fig. 1 presents the chain structure for the energy supply system modelled in MESSAGE, where all options as fuel types and technologies are modelled. Available capacities (in MW) for the planning period 2020-2050, for the both scenarios are given in Fig. 2 and Fig.3. According to the input data entered in the MESSAGE tool, the results of both scenarios are obtained. Installed capacity (in MW) for each scenario is given in Fig.4 and Fig.5.

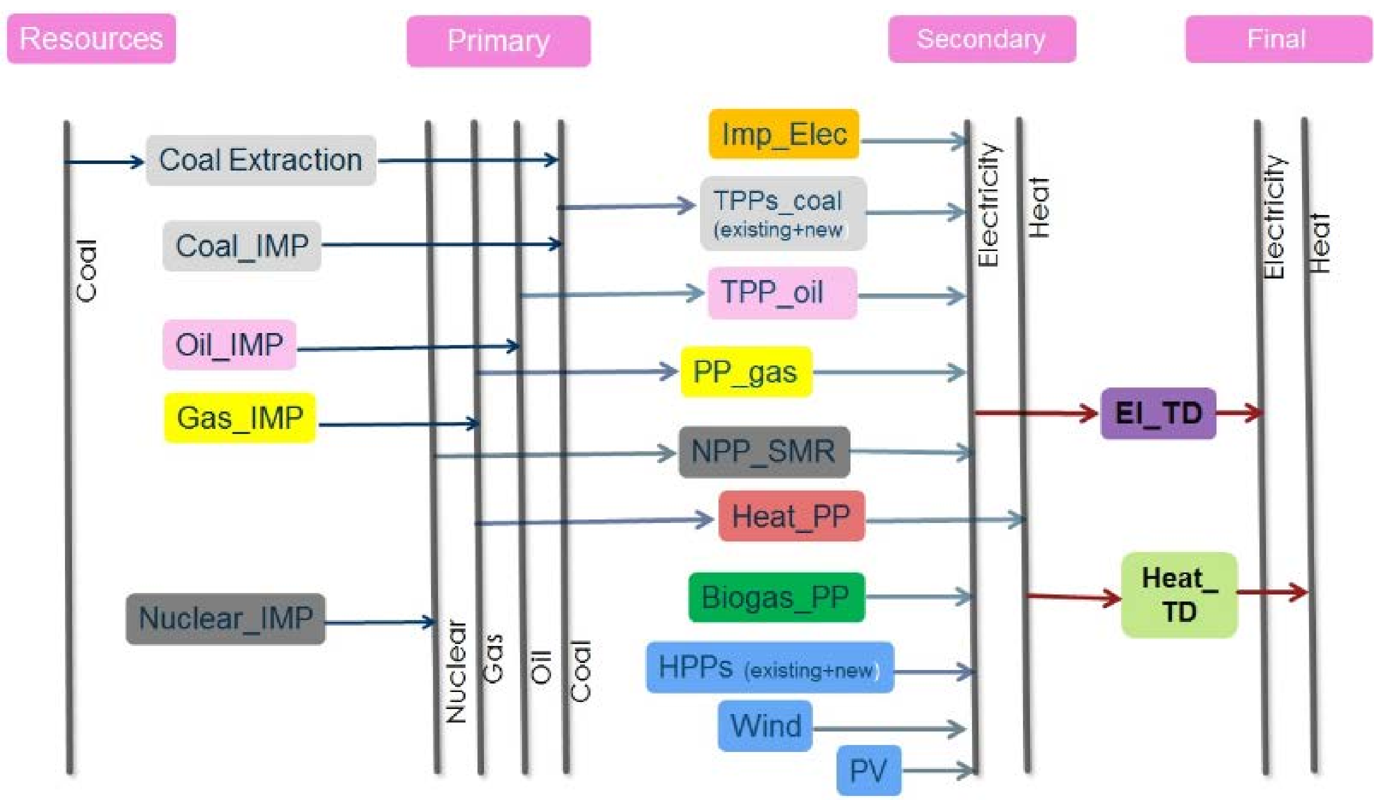

Figure 1. Design of chain structure for energy supply system

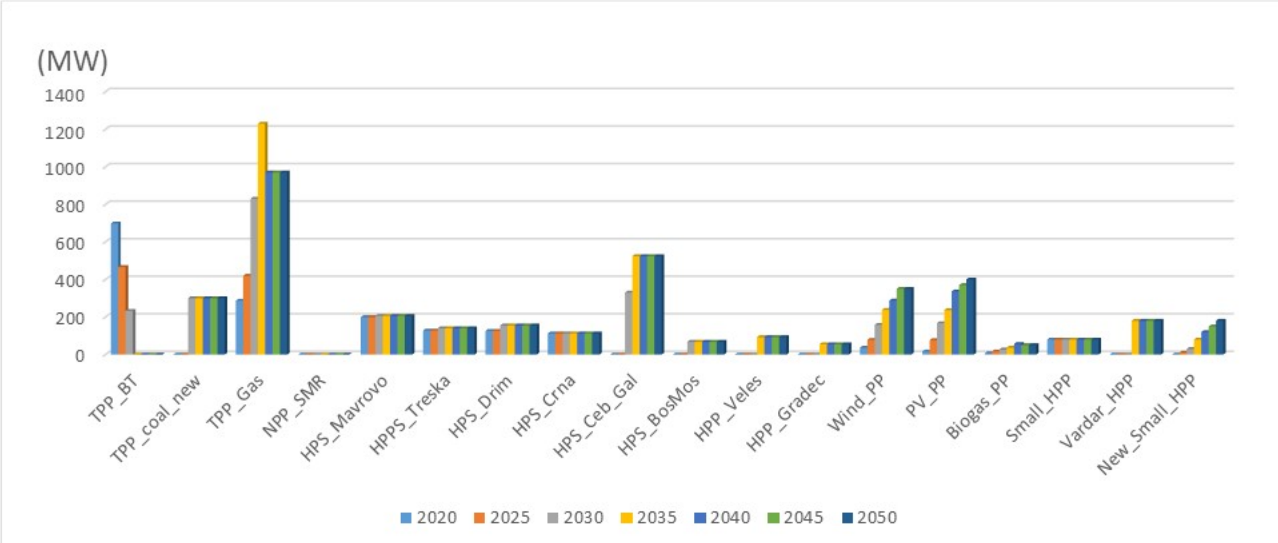

Figure 2. Available capacities (in MW) for the planning period 2020-2050, for Scenario 1 - BAU

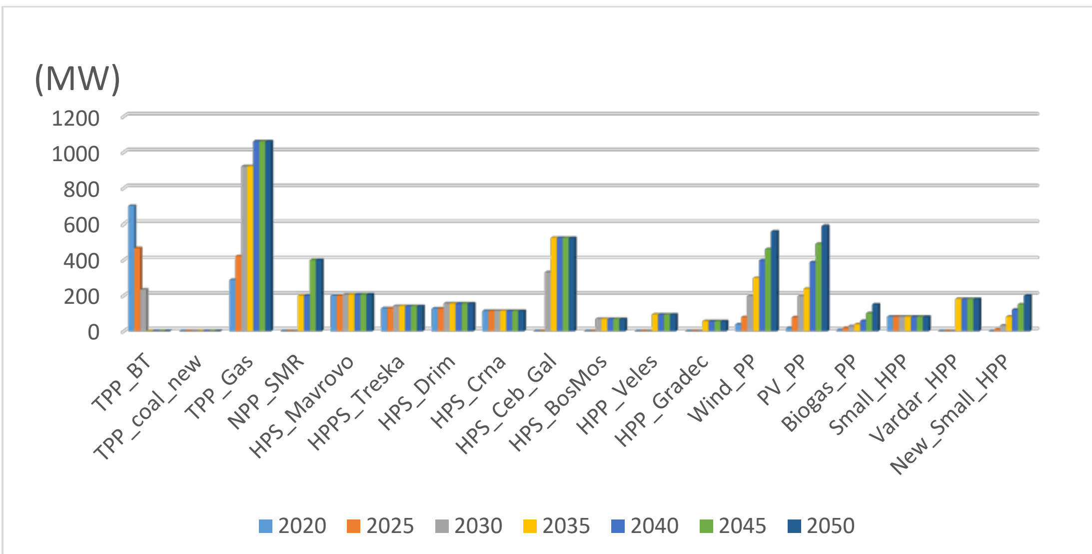

Figure 3. Available capacities (in MW) for the planning period 2020-2050, for Scenario 2 – Green

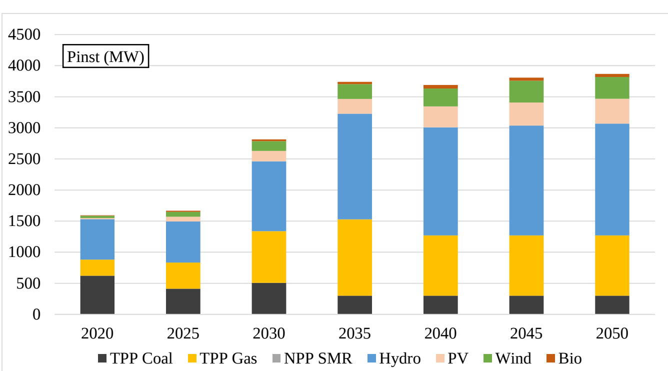

Figure 4. Installed capacities (in MW) for Scenario 1 - BAU

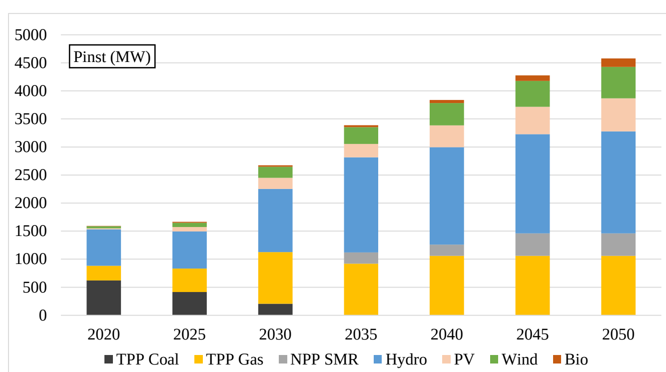

Figure 5. Installed capacities (in MW) for Scenario 2 - Green

III Environmental impact from CO_2 emission

Carbon emission, or CO_2 emission mainly depend on activity of thermal power plants on fossil fuels (coal and gas). According the results from each scenario, chemical content of fossil fuel and technology, the CO_2 emission per generated secondary energy is approximately:

- 1 kg CO_2/kWh generated electricity from coal-fired TPP with 35% efficiency
- 0,35 kg CO_2/kWh generated electricity for gas-fired TPP with 60% efficiency
- 0,27 kg CO_2/kWh generated electricity for gas-fired Heat PP with 80% efficiency

The activity of secondary production and generated energy for each scenario is given in the Table 1. The heat production is the same for each scenario.

According the activity and the CO_2 emission per generated secondary energy, the total CO_2 emission for each scenario are presented in the Fig.6 and Fig. 7.

Table 1. Generated electricity and heat for each scenario

	Electricity (GWh)				Heat (GWh)
	BAU		GREEN		
	Coal	Gas	Coal	Gas	
2020	1934	1367	3161	1367	681
2025	1589	2488	2540	2488	790
2030	0	4134	0	5216	916
2035	0	4144	0	3694	1062
2040	0	5285	0	5216	1231
2045	104	5948	0	6500	1427
2050	1840	5948	0	6500	1654

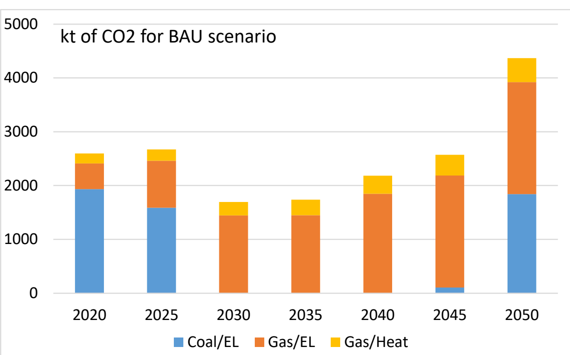

Figure 6. Yearly total emission (in kt of CO_2) per fuel for BAU scenario

The emission in GREEN scenario is the greatest in the first decade due to larger electricity production from coal. The reason is because the import electricity in this scenario is reduced to 200 MW comparing with 340 MW in BAU scenario.

The last decade the emission from GREEN is smallest because there is no coal and SMR nuclear option replace the greater part of base load needs.

The large emission of CO_2 in 2050 for BAU is due to new TPP on coal in 2050.

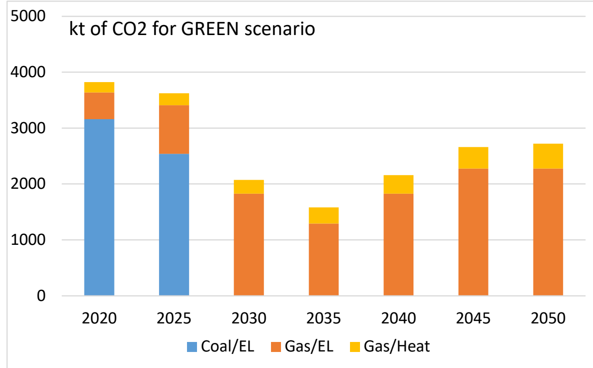

Figure 7. Yearly total emission (in kt of CO_2) per fuel for Green scenario

IV Economic Analysis for Generated Energy of the Different Technologies

In order to obtain an economic analysis for a particular technology, calculations have been made for parameters that are standard for projects and investments, such as:

- net present value (NPV);
- benefit - cost ratio (BCR);
- payback period (PBP);
- internal rate of return (IRR).

According the input data for all technologies in supply system, the economic analysis is done for having the value of produced energy as an output from certain technology in the operating period. The value of produced energy is getting in order to have reasonable PBP and to have some minimum NPV at the end of operation period.

The rate parameters for all technologies are given in Table 2.

Table 2. Rate parameters for all technologies

Loan rate (%)	4
Inflation rate (%)	2
Discount rate (%)	6

Loan rate is only for the loan taken for investment for the period of repayment. Inflation rate is for all costs and benefits during the operation period. Discount rate is for cash analyses to be levelled all costs and benefits to the first year of project consideration.

Economic analyses of gas-fired thermal power plant

Input data for this technology are given in Table 3a and Table 3b. The capacity factor is CF=0.80.

Annual annuity is 26.71 M€. The discounted cash flow for gas-fired thermal power plant is presented in Fig. 8.

The production price of electricity is 80 €/MWh in the first year operation and inflation rate of 2 %. This value is driven mainly because fuel costs and carbon tax.

PBP is 22 years, NPV is 67 M€, BCR is 1,033 and IRR is 9%.

Table 3a. Input data for gas-fired thermal power plant

Costs (€/MWh)		Benefit (€/MWh)		Pinst=200 MWe	Inv=600 €/kW
Fuel	35	Electricity	80	Pth=100 MWt	Inv=200 €/kW
O&M	15	Heat	50	Wel=1400 GWh	Tot_Inv=140 M€
Eco (Carbon)	20	Eco	0	Wheat=300 GWh	

Table 3b. Input data for gas-fired thermal power plant

Total Loan (M€)	140
Year of repayment (Years)	6
Construction period (Years)	3
Period of operation (Years)	40

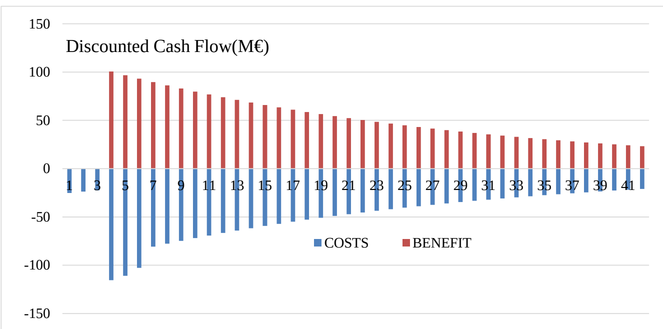

Figure 8. Discounted cash flow for gas-fired thermal power plant

Economic analyses of SMR - nuclear technology

Input data for this technology are given in Table 4a and Table 4b. The capacity factor is CF=0.91.

Table 4a. Input data for SMR- nuclear technology

Costs (€/MWh)		Benefit (€/MWh)		Pinst=200 MWe	Inv=5300 €/kW
Fuel	8	Electricity	60	Pth=100 MWt	Inv=500 €/kW
O&M	15	Heat	40	Wel=1600 GWh	Tot_Inv=1120 M€
Eco (Carbon)	8	Eco	10	Wheat=300 GWh	

Table 4b. Input data for SMR-nuclear technology

Total Loan (M€)	1120
Year of repayment (Years)	10
Construction period (Years)	5
Period of operation (Years)	60

Annual annuity is 138.9 M€. The discounted cash flow for SMR-nuclear technology is presented in Fig. 9.

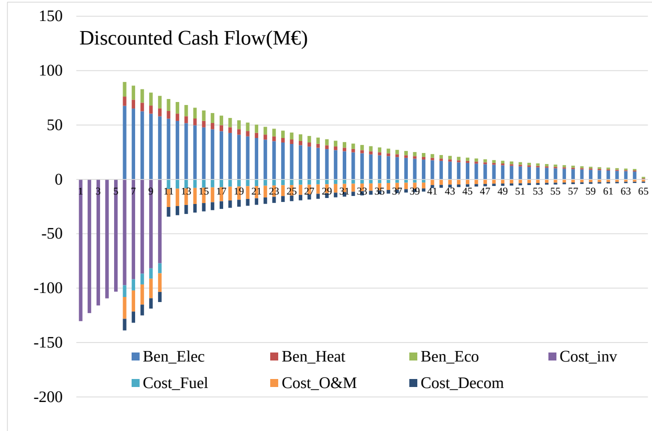

Figure 9. Discounted cash flow for SMR-nuclear technology

The production price of electricity is 60 €/MWh in a first year operation and inflation rate of 2 %. The price for heating is 40 €/MWh. This value is driven mainly because investment and ECO cost is because decommissioning.

PBP is 45 years, NPV is 129 M€, BCR is 1.064 and IRR is 6.6%.

Small IRR is because of long period of operation and relatively low price of electricity and heat generated energy.

Economic analyses of PV technology

Input data for this technology are given in Table 5a and Table 5b. The capacity factor is CF=0.16.

Table 5a. Input data for PV technology

Costs (€/MWh)		Benefit (€/MWh)		Pinst=100 MWe	Inv=700 €/kW
Fuel	0	Electricity	60	Pth=0 MWt	Inv=0 €/kW
O&M	15	Heat	0	Wel=140 GWh	Tot_Inv=70 M€
Eco (Carbon)	2	Eco	5	Wheat=0 GWh	

Table 5b. Input data for PV technology

Total Loan (M€)	70
Year of repayment (Years)	5
Construction period (Years)	2
Period of operation (Years)	30

Annual annuity is 15.72 M€. The discounted cash flow for PV technology is presented in Fig. 10.

The production price of electricity is 60 €/MWh in a first year operation and inflation rate of 2 %. This value is driven mainly because investment. ECO cost is because recycle of materials.

PBP is 17 years, NPV is 32 M€, BCR is 1.319 and IRR is 10%.

This technology is not any beneficial by the Government with feed in tariff, because the total quota of photovoltaic power plants who can use feed in tariff is fulfilled. But this technology has relatively small investment for private concessioners and is commercially available.

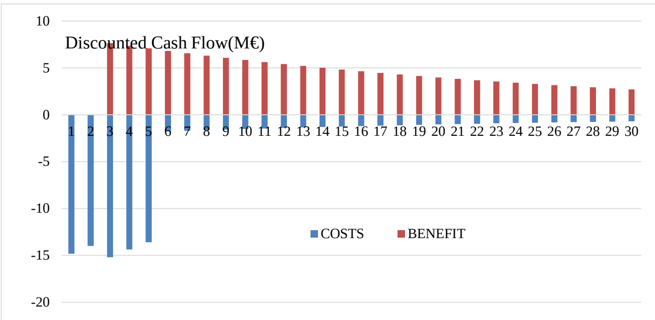

Figure 10. Discounted cash flow for PV technology

Economic analyses of wind power technology

Input data for this technology are given in Table 6a and Table 6b. The capacity factor is CF=0.28.

Table 6a. Input data for wind power technology

Costs (€/MWh)		Benefit (€/MWh)		Pinst=100 MWe	Inv=1500 €/kW
Fuel	0	Electricity	60	Pth=0 MWt	Inv=0 €/kW
O&M	15	Heat	0	Wel=250 GWh	Tot_Inv=150 M€
Eco (Carbon)	2	Eco	5	Wheat=0 GWh	

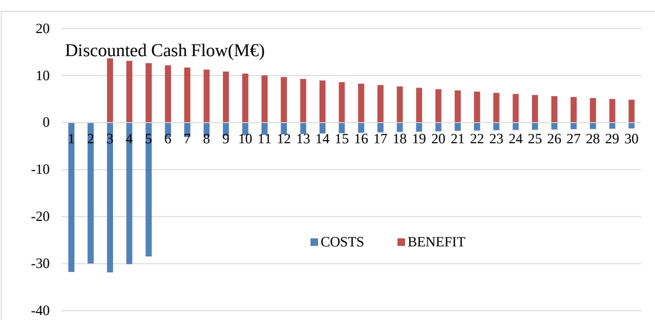

Figure 11. Discounted cash flow for wind power technology

Annual annuity is 33.69 M€. The discounted cash flow for wind power technology is presented in Fig. 11.

Table 6b. Input data for wind power technology

Total Loan (M€)	150
Year of repayment (Years)	5
Construction period (Years)	2
Period of operation (Years)	30

The production price of electricity is 60 €/MWh in a first year operation and inflation rate of 2 %. This value is driven mainly because investment. ECO cost is because recycle of materials.

PBP is 22 years, NPV is 34 M€, BCR is 1.167 and IRR is 8.2%.

This technology is still beneficial by the Government with feed in tariff of 89 €/MWh, and it is still acceptable investment for private concessioners.

Economic analyses of biogas power technology

Input data for this technology are given in Table 7a and Table 7b. The capacity factor is CF=0.8.

Table 7a. Input data for biogas power technology

Costs (€/MWh)		Benefit (€/MWh)		Pinst=10 MWe	Inv=3500 €/kW
Fuel	50	Electricity	120	Pth=5 MWt	Inv=200 €/kW
O&M	30	Heat	50	Wel=70 GWh	Tot_Inv=36 M€
Eco (Carbon)	0	Eco	10	Wheat=20 GWh	

Table 7b. Input data for biogas power technology

Total Loan (M€)	36
Year of repayment (Years)	5
Construction period (Years)	2
Period of operation (Years)	30

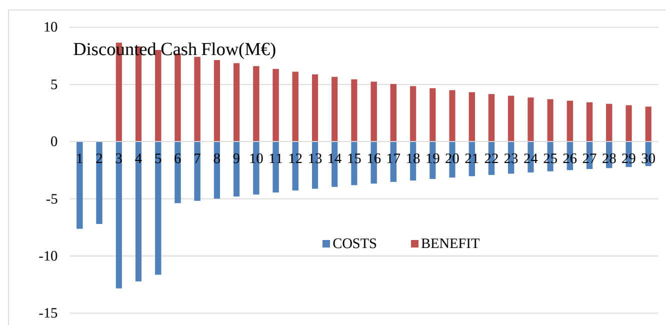

Figure 12. Discounted cash flow for biogas power technology

Annual annuity is 8.09 M€. The discounted cash flow for biogas power technology is presented in Fig.12.

The production price of electricity is 120 €/MWh and 50 €/MWh for heat output with additional is 10 €/MWh as an ECO beneficial.

PBP is 19 years, NPV is 11 M€, BCR is 1.08 and IRR is 9%.

This technology is still beneficial by the Government with feed in tariff of 140 €/MWh for electricity only, and it is still acceptable investment for private concessioners.

Economic analyses of hydro power technology

For this purpose, HPP Veles as hydro power representative is considered for calculation. Input data for this technology are given in Table 8a and Table 8b. The capacity factor is CF=0.38.

Table 8a. Input data for hydro power technology

Costs (€/MWh)		Benefit (€/MWh)		Pinst=93 MWe	Inv=1800 €/kW
Fuel	0	Electricity	50	Pth=0 MWt	Inv=0 €/kW
O&M	20	Heat	0	Wel=310 GWh	Tot_Inv=167.4 M€
Eco (Carbon)	0	Eco	10	Wheat=0 GWh	

Table 8b. Input data for hydro power technology

Total Loan (M€)	167.4
Year of repayment (Years)	10
Construction period (Years)	6
Period of operation (Years)	50

Annual annuity is 20.64 M€. The discounted cash flow for hydro power technology is presented in Fig. 13.

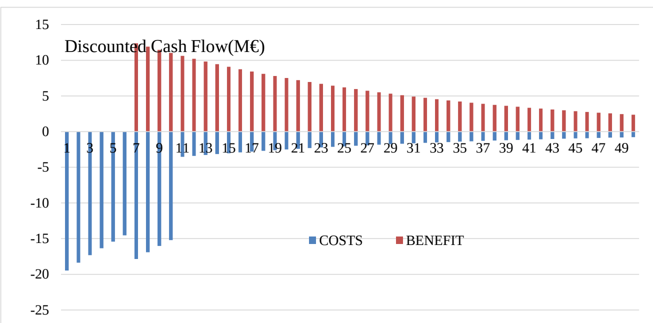

Figure 13. Discounted cash flow for hydro power technology (HPP Veles)

The production price of electricity is 50 €/MWh in a first year of operation with additional 10 €/MWh as an environmental acceptable technology. This value is driven mainly because investment.

PBP is 37 years, NPV is 26 M€, BCR is 1.09 and IRR is 7%.

This technology is representative for hydro power technologies. The price for generated electricity is very dependent on hydrology variation during the year.

All these technologies for energy production give different price of energy output depend on many parameters, or price of energy is a function of investment, operating life, costs, capacity factor, etc. The calculations are made of standard input technical and economic parameters. Some parameters and factors can be taken additional as, balancing costs, auxiliary services as benefit, frequency regulation, reserve capacity, energy storage capacity, etc.

V Conclusion

Based on the research in this paper, for development of the Macedonian electricity supply system, certain conclusions can be made.

Reducing carbon emissions from the energy sector

In order to achieve the goal set in the national energy policies, it is necessary to find a way to reduce emissions from existing coal-fired TPPs. On the one hand, the ageing of the equipment, and on the other hand the reduction of the quantities of domestic coal from the existing mines are additional reasons for their reduced production and searching for a way to replace them.

One option in the BAU scenario is to build new modern block(s) with imported coal, where all desulphurization and deNOx technologies would be implemented, but carbon dioxide emissions would be further penalized and included as an additional cost in production. This price is 30 €/tCO_2 with a tendency for further growth, which will certainly additionally burden the production price over 30 €/MWh, i.e. emission of 1.0 tCO_2/MWh.

Another option is to replace the existing base coal technologies with new modern gas technologies, i.e. construction of combine cycle gas turbines (CCGT) with an efficiency of about 60%. In case some of them in urban areas to be used as cogeneration plants (CHP) for electricity and heat production, they would significantly increase the efficiency up to 80% with significantly reduced carbon emissions of 0.27 tCO_2/MWh. Such an option is presented in the second GREEN scenario.

Construction of infrastructure for natural gas supply

To ensure a safe amount of natural gas, it is necessary to build additional supply gas pipe lines taking into account the international gas corridors. With the operability of the two supply lines (the existing one from Bulgaria and the new one from Greece) about 2 bcm per year are provided, which is enough for the quantities projected in both scenarios of this paper. For the coal option, additional cost would be the transport of large quantities for which the railway infrastructure should be strengthened.

Intensive construction of RES technologies

With intensive construction of RES technologies, mostly photovoltaic systems, wind farms, small HPPs, as well as biogas power plants, the energy production infrastructure can be further improved. These option especially intensively is in the second GREEN scenario. This option is also in line with the national energy strategy. According the dynamics of construction of RES technologies, it is necessary to pay special attention to the rest of the production system of conventional technologies of thermal power plants, and especially of hydro power plants. This is important in terms of reliable and secure operation and functionality of the power system. It is necessary to provide sufficiently flexible capacities of hydro units, reversible hydro power plants or gas-fired power plants that would respond to the dynamic and unpredictable behaviour of RES in the energy system.

The challenge for new technologies from the nuclear option

The nuclear option through the construction of SMRs and/or sharing the large units is represented in the second GREEN scenario. From a technical point of view, small modular reactors are the most suitable for small power grids, but for countries with no experience in nuclear technology it is a great challenge. This means providing human resource and establishing infrastructure of necessary national institutions such as nuclear regulatory bodies. Therefore, this option is taken as a technology that is realistically possible after 2030. At the same time, the vendors are expected to improve and make this technology commercially available.

LITERATURA/REFERENCES

[1] International Atomic Energy Agency. MESSAGE-Model for Energy Supply Strategy Alternatives and their General Environmental Impact, User Manual, 2007.

[2] Neiva, B.C., Aronne I.D. MESSAGE as a Tool for the Evaluation of the Competitiveness of the Thermonuclear Generation in Brazil, in Proc. *International Nuclear Atlantic Conference, INAC 2007*, Rio de Janeiro, Brazil, 30 September-5 October 2007. https://inis.iaea.org/search/searchsinglerecord.aspx?recordsFor=SingleRecord&RN=39093832

[3] Abdullahi K., Myung-Sub R. Long term energy plan for Nigeria using MESSAGE code for energy optimization, International Journal of Engineering Research & Technology, Vol. 5, No. 11, pp. 210-2013, 2016. http://dx.doi.org/10.17577/IJERTV5IS110160

[4] Nikolova-Poceva S., Chaushevski A. Long Term Electricity Supply System Planning Including Nuclear Power Option, BgNS TRANSACTIONS, Vol. 25, No. 1, pp. 64-70, 2021. https://repository.ukim.mk/bitstream/20.500.12188/21558/1/12_S.%20Nikolova-Poceva%2c%20A.%20Chaushevski.pdf [pristupljeno 05.03.2022]

[5] Ministry of economy. National Energy and Climate Plan of the Republic of North Macedonia, 2020, Third Draft Version.

[6] MANU. Strategy for Energy Development of the Republic of North Macedonia up to 2040, 2019. https://economy.gov.mk/Upload/Documents/Energy%20Development%20Strategy_FINAL%20DRAFT%20-%20For%20public%20consultations_ENG_29.10.2019(3).pdf

[7] MANU. Revised issue of the Strategy for Energy Development of the Republic of North Macedonia up to 2040, 2020.

[8] Annual Reports from Energy and Water Services Regulatory Commission of the Republic of North Macedonia. 2021. https://www.erc.org.mk/odluki/2022.06.02_RKE%20GI%202021-FINAL-ENG.pdf

[9] Annual Reports and Data from AD MEPSO.

[10] Annual Reports and Data from AD ESM.

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