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Long Term Electricity Supply System Planning Including Nuclear Power Option

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Abstract. This paper presents alternatives for expansion of the Macedonian electricity supply system. MESSAGE tool is used for modeling the analyzed system, for developing the scenarios, to analyze cost optimal energy pathways and to determine the optimal electricity generation technology mix. The time horizon for the case study is from 2020 (base year) to 2050. Two scenarios are developed and analyzed. Nuclear energy resource and small modular reactors are considered as an option in the second – green scenario.

Keywords: long term planning, electricity supply system, MESSAGE tool, optimal technology mix.

1 Introduction

Energy planning and related activities require a large amount of data from relevant sources, institutions, analysis of documentation, as well as contact with a number of institutions concerned in the energy sector. There is no doubt that climate change presents a serious challenge to economic development in the country. Decision makers at all levels of government and in the private sector, need information about the economic impacts of climate and the costs and benefits of adapting to it. Careful planning and strategic investments will be required to adapt to the changes and mitigate their impact while pursuing a longterm sustainable growth and development path.

The long term economic impact of all this is that the power that is currently produced (or planned) from thermal power plants on fossil fuels have to be replaced, usually with generating capacities on resources that are more capital costly with operating basis other than conventional technologies. An approximation of damages that can be calculated is the cost of the additional capacity needed to replace the existing conventional generating units that can't be delivered to meet the loads.

Environmental impacts of different energy resources and technologies can be one factor for planning the future energy sector for new production capacities. The goal in keeping the environment clean is zero emission or to implement the new technologies for reducing the gas emissions into the atmosphere, and/or to pay emission penalties.

The economics of any large energy project depend on national or even local conditions, including the capital costs, labour and materials, the regulatory environment, and the availability and costs of alternative generating technologies. Also, deeper understanding of the risks involved in project finance and risks evolution over time is important for both practitioners and policymakers. In particular, further research in this area might help in the implementation of risk sensitive capital requirements providing market participants with the incentives for a prudent and, at the same time, efficient allocation of resources across asset classes. This is particularly relevant, given the predominant role of internationally active banks in project finance and the fundamental contribution of project finance to economic growth, especially in emerging economies.

It is important to have analysis of the current situation in energy sector (supply and demand side) taking into account the existing and possible candidates of power production capacities according the previous studies and documentation. In this process it is necessary to have the National priority and criteria's for future energy system: available domestic fossil resources, natural meteorological and climate conditions for the renewable energy sources, reduction of GHG emissions, environmental protection, social and economic condition, final energy price and levelized cost of energy (LCOE) from new capacities, available human resources, security supply system for sustainable development etc.

In [1], 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 [2] 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.

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 design long-

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term strategies by analyzing 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 [3].

In this paper, long term planning for expansion of the Macedonian electricity supply system is carried out. Two scenarios for the Macedonian electricity supply system for the period 2020–2050 are analyzed. MESSAGE tool is used to provide the optimal electricity generation technology mix sufficiently enough to feed the country electricity demand.

2 Development Scenarios for the Electricity Supply System until 2050

2.1 Methodology for developing electricity supply system scenarios

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. To obtain the input data that are need to be entered in the MESSAGE tool some of the references that was used are [4–9] listed in the reference list.

At first it is need to define the electricity supply system through energy resources and technologies (existing and new capacities planned to be build) that are realistic in the period under consideration 2020–2050. Technologies are defined by their inputs and outputs (activity variables) and by their power output (capacity variables). They are represented by a set of techno-economic data as: plant factor, plant life, investment costs, fixed and variable operations and maintenance (O&M) costs, energy conversion efficiencies, historical capacities, emission factors, availability of the technology, the operation of the storage hydro power plants and renewable fuel power plants during the seasons of the year. The model takes into account the year of installation of the power plants and the retirement at the end of their useful life. For the new available technologies in the period until 2050, the necessary resources that are considered are: natural gas, the possibilities for using renewable energy sources (RES) and nuclear energy source as an option is also considered. Also, the input data are entered for load region and load duration curve, limits and bounds on technologies and constraints.

By using the MESSAGE tool, the calculations for the period 2020–2050 are made in a 5-year interval. Two scenarios are developed:

- **BAU scenario** (Business as Usual), where the current energy structure prevailed, with trends like the current development without a nuclear option. The electricity demand is satisfied by coal-fired thermal power plants, gas thermal power plants, hydro power plants and renewable fuel power plants.
- **Scenario 2** (Green scenario), where gas thermal power plants and nuclear power representative with small modular reactors (SMR) are base load technologies, intensive construction with RES is forced and possibility for greater construction or involved nuclear power.

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

By making further analysis the data on the annual operation of the electricity supply system within a 5-year interval, and the possibility of flexibility in the construction of new facilities within the interval, are obtained. In the end, based on the analysis, recommendations and directions for system development were made with appropriate conclusions.

2.2 MESSAGE model structure and basic input data

The following general data, data for load region and electricity demand are entered in the tool:

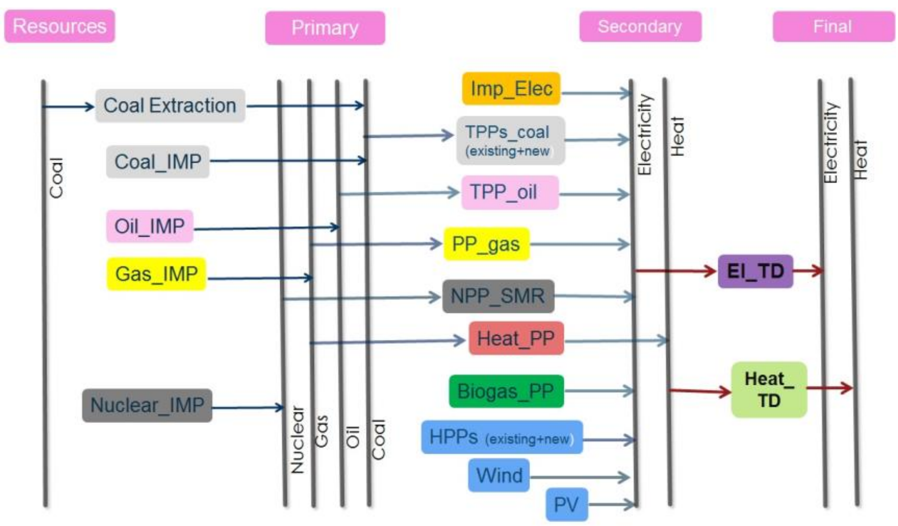


Figure 1. Design of chain structure for energy supply system.

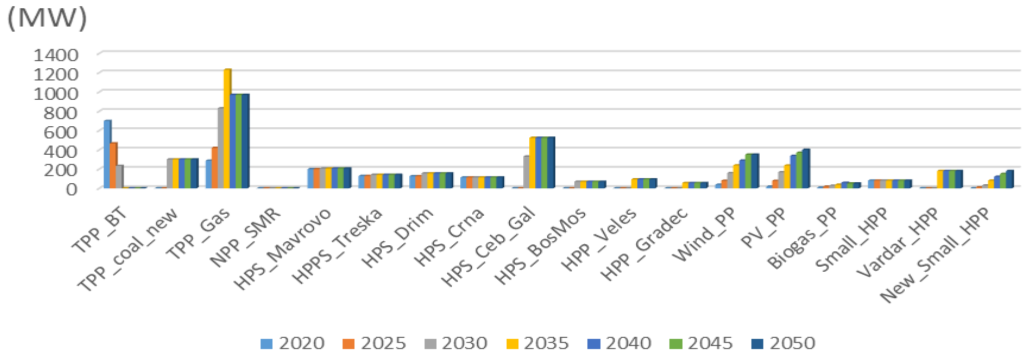


Figure 2. Available capacities (in MW) for the planning period 2020-2050, for Scenario 1.

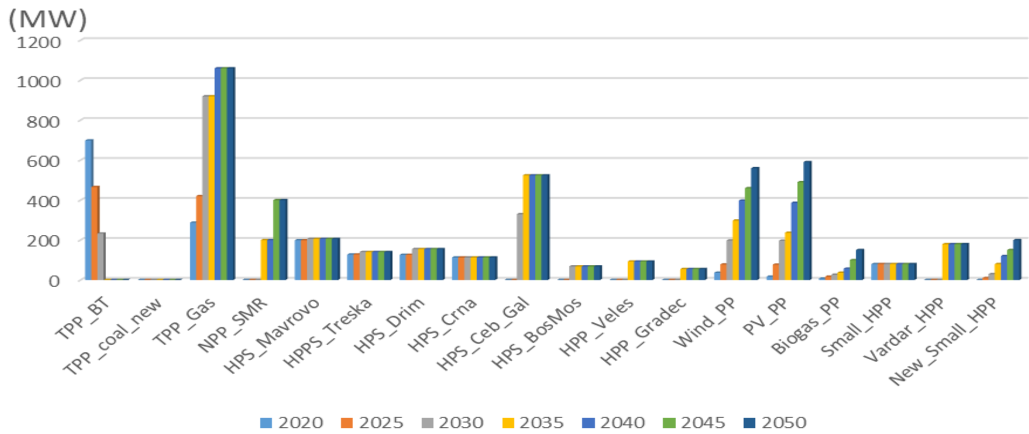


Figure 3. Available capacities (in MW) for the planning period 2020-2050, for Scenario 2.

Planning period:	2020 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 14.4hours/4.8hours/4.8hours for base load/peak load/night load. The time horizon for the case study is from 2020 (base year) to 2050. Figure 1 presents the chain structure for the energy supply system modeled in MESSAGE, where all options as fuel types and technologies are modeled. In this paper only electricity supply system is presented, while the results for the heat supply system will not be presented.

2.3 Scenarios for long term electricity supply system development

The scenarios under investigation for future electricity supply system development strategy are:

Scenario 1 – BAU Scenario;

Scenario 2 – Green Scenario.

Available capacities (in MW) for the planning period 2020–2050, for the both scenarios are given in Figure 2 and Figure 3.

Some of the inputs for the scenarios are:

- Imported electricity 400 $/kWyr with growth rate of 3% per year, with capacity of 340 MW for Scenario 1 and 200 MW for Scenario 2;
- Coal import and Coal Extraction: 262 $/kWyr;
- Oil import: 385 $/kWyr, which is near 500 Euro/ton oil;
- Gas import: 307 $/kWyr, which is near 250 Euro/1000 Nm^3.

3 Results and Discussion

According to the input data entered in the MESSAGE tool, the results of both scenarios with appropriate comments and discussion are presented in this part of the paper. Installed capacity (in MW) for each scenario is given in Figure 4 and Figure 5.

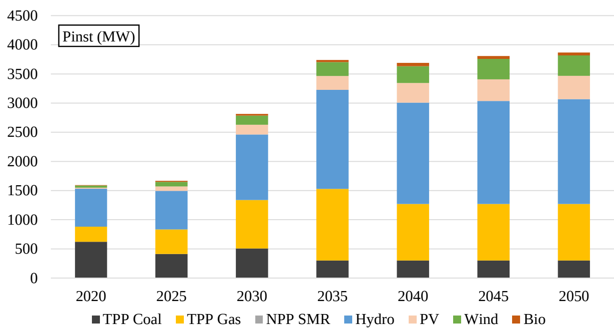


Figure 4. Installed capacities (in MW) for Scenario 1.

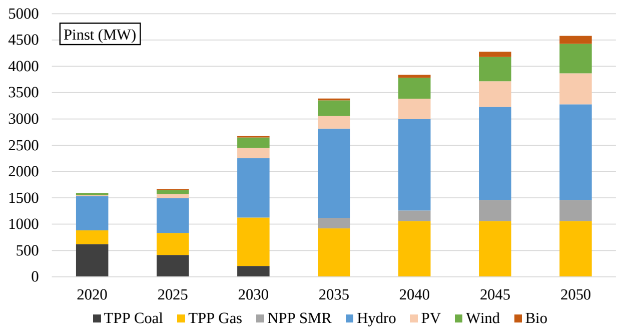
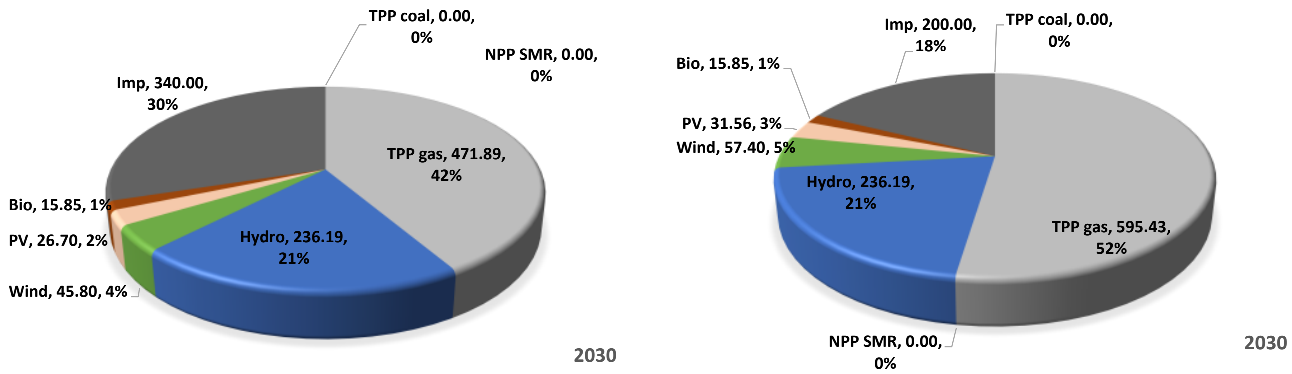


Figure 5. Installed capacities (in MW) for Scenario 2.

3.1 Yearly activity in generated electricity for each scenario

Also, yearly generated electricity for each scenario is obtained. In the starting year 2020 the generated electricity from the analyzed production capacities is near the same for both scenarios. Only the differences is between the generated electricity from the existing TPP Bitola and imported electricity, which are compensated depend on available electricity import. The activity of other technologies are same.

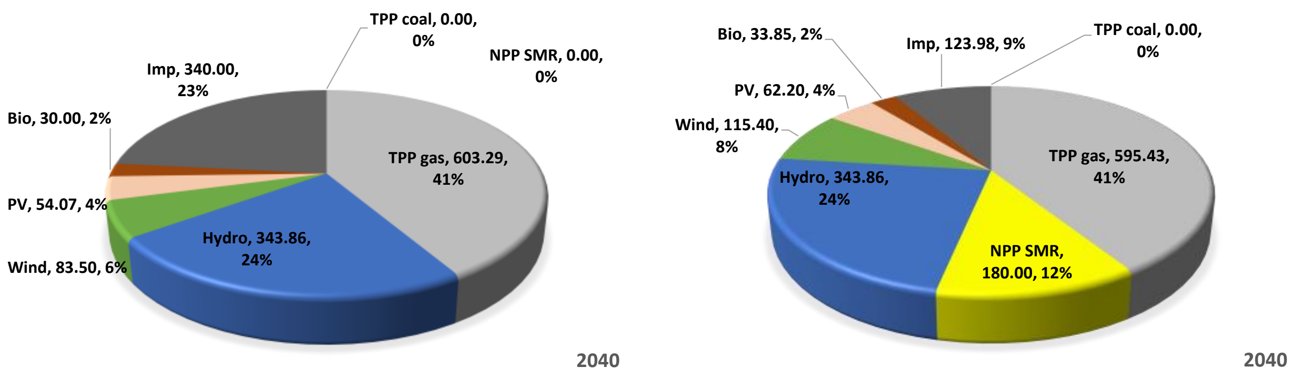
The differences between scenarios can be noticed in activity after 2030. Therefore, in the next Figures 6–8 are comparing the energy mix in activity (generated electricity in MWyr and in percentage) for both scenarios for the year 2030, 2040 and 2050.



BAU Scenario

Green Scenario

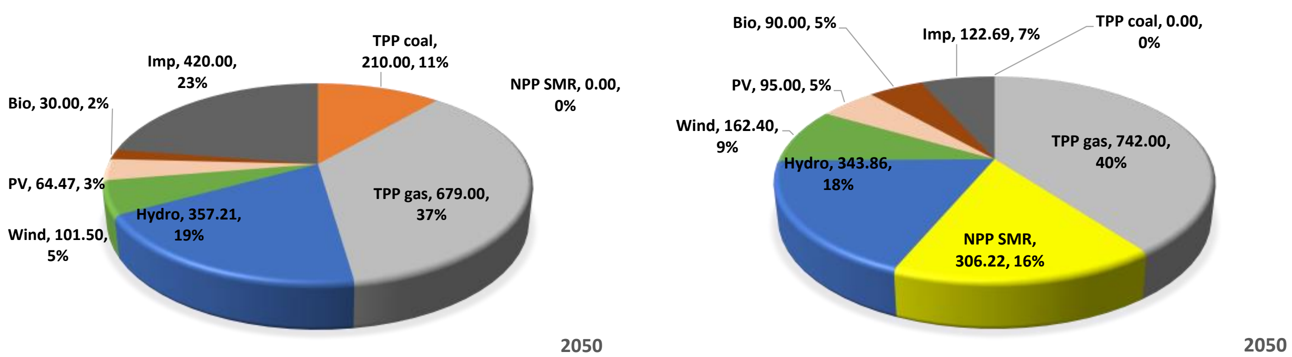
Figure 6. Energy mix in activity (generated electricity in MWyr and in percentage) for 2030.



BAU Scenario

Green Scenario

Figure 7. Energy mix in activity (generated electricity in MWyr and in percentage) for 2040.



BAU Scenario

Green Scenario

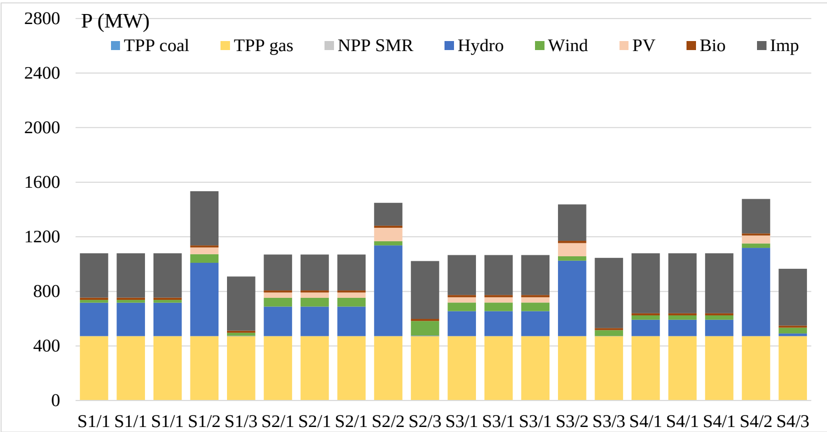
Figure 8. Energy mix in activity (generated electricity in MWyr and in percentage) for 2050.

In the BAU Scenario imported electricity have significant part in activity for covering the electricity demand. The Green scenario has increased part of nuclear power after 2040, which replace large portion of imported electricity comparing with the Scenario 1. Also the contribution of RES (PV, wind power plants, biogas power plants and small hydro power plants) is larger than the Scenario 1.

3.2 Activity in representative day for each scenario

Taking into account the load duration curve, the representative day demand and the yearly activity of the electricity supply system, we can obtain the structure of the covered demand inside of the representative day for each season in each scenario. Covering the electricity demand for representative days for the years 2030, 2040 and 2050 for BAU scenario are presented in the following Figures (9–11), placed in the table.

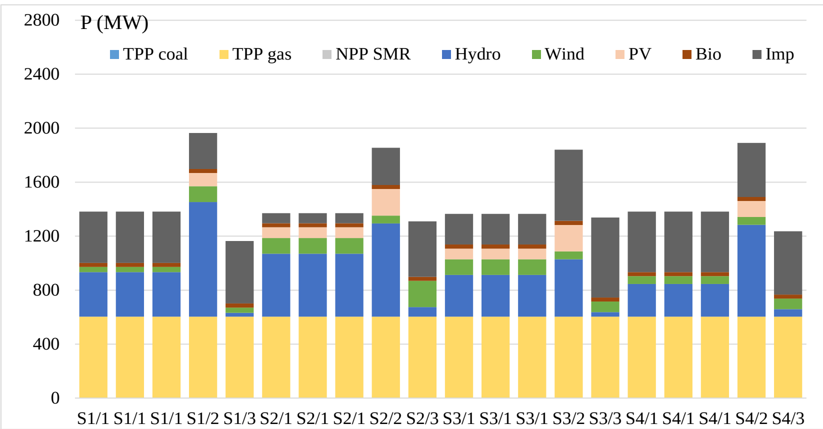
Covering the electricity demand for representative days for the years 2030, 2040 and 2050 for GREEN scenario are presented in the following Figures (12–14), placed in the table.



BAU 2030

- Base load mainly covered from the gas TPPs,
- Storage hydropower plants covered variable part of the electricity demand,
- Significant electricity import

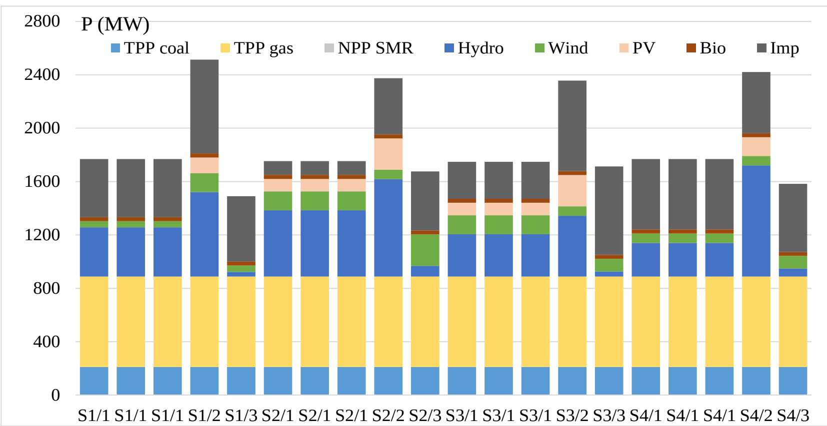
Figure 9. Daily supplying of the electricity demand for representative days for BAU scenario for 2030.



BAU 2040

- More gas is spent for covering base load because of the increased needs mainly from gas TPPs,
- Storage hydropower plants covered variable part of the electricity demand and slowly coming RES technologies,
- Still significant electricity import

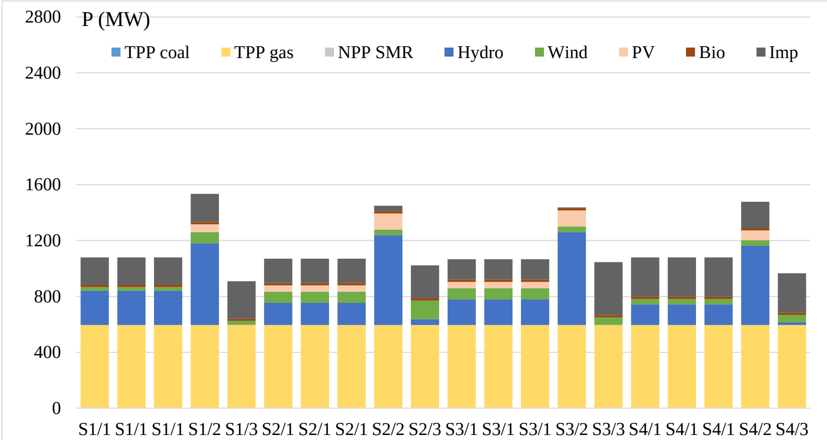
Figure 10. Daily supplying of the electricity demand for representative days for BAU scenario for 2040.



BAU 2050

- Base load is mainly covered from the new coal-fired TPP and gas TPPs,
- Storage hydropower plants covered variable part of the electricity demand,
- More electricity production from the RES technologies,
- Still significant electricity import

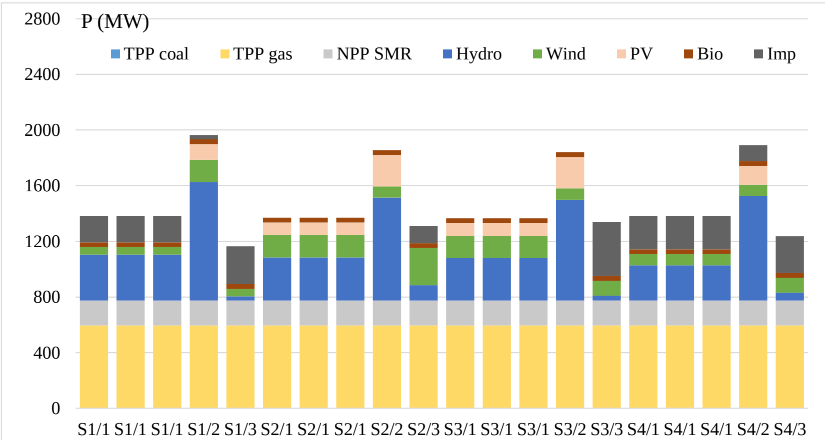
Figure 11. Daily supplying of the electricity demand for representative days for BAU scenario for 2050.



GREEN 2030

- Base load is covered only from gas TPPs,
- Storage hydropower plants covered variable part of the electricity demand,
- Electricity production from the RES technologies,
- Small portion of electricity import

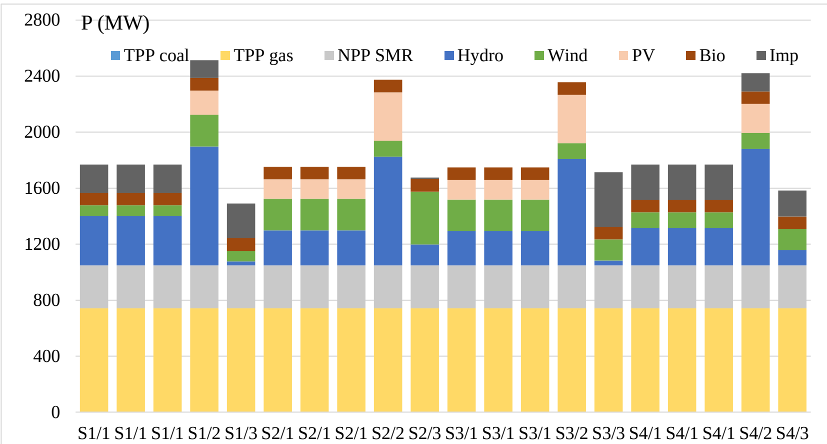
Figure 12. Daily supplying of the electricity demand for representative days for GREEN scenario for 2030.



GREEN 2040

- Base load is covered from gas TPPs and from nuclear production capacity (1 unit of 200 MW),
- Storage hydropower plants covered variable part of the electricity demand,
- Electricity production from the RES technologies,
- Small portion of electricity import

Figure 13. Daily supplying of the electricity demand for representative days for GREEN scenario for 2040.



GREEN 2050

- Base load is covered from gas TPPs and from nuclear production capacity (2 units with total 400 MW),
- Storage hydropower plants covered variable part of the electricity demand,
- Significant more electricity production from the RES technologies,
- Reducing electricity import

Figure 14. Daily supplying of the electricity demand for representative days for GREEN scenario for 2050.

On the first column of the tables are presented graphs of daily supplying of the electricity demand for all representative days, in all 4 seasons in 2030, 2040 and 2050 for the both scenarios. The first base period in a day is three times longer (0,6), than the other two parts (peak and night part) of a day (0.2), so the representative of the first part of a day is presented with 3 bars. While, the second column of the tables give short description of the main characteristic of the certain graph.

4 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 deNO$_x$ technologies would be implemented, but carbon dioxide emissions would be further penalized and included as an additional cost in production. 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. 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 power plants that would respond to the dynamic and unpredictable behavior 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.

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