Journal of Electrical Engineering and Information Technologies, Vol. **7,** No. 1, pp. 13–21 (2022)
Article 192
Received: January 23, 2022
Accepted: February 20, 2022
In print: ISSN 2545–4250
On line: ISSN 2545–4269
UDC: 621.311.26
https://doi.org/10.51466/JEEIT2271187013n

Original scientific paper

ELECTRICITY GENERATION SYSTEM EXPANSION PLANNING INCLUDING ENERGY EFFICIENT TECHNOLOGIES

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A b s t r a c t: In the proposed paper scenarios for expansion of the Macedonian electricity generation system are investigated. In order to determine the optimal electricity generation technology mix sufficiently enough to feed the country electricity demand MESSAGE tool is used. The planning period for the case study is from 2020 (base year) to 2050. The environmental impact, for each scenario, is also analyzed of aspect of CO_2 emission.

Key words: electricity generation system; expansion planning; MESSAGE tool; optimal technology mix; environment impact

ПЛАНИРАЊЕ РАЗВОЈ НА СИСТЕМ ЗА ПРОИЗВОДСТВО НА ЕЛЕКТРИЧНА ЕНЕРГИЈА СО ВКЛУЧУВАЊЕ НА ЕНЕРГЕТСКИ ЕФИКАСНИ ТЕХНОЛОГИИ

А п с т р а к т: Во предложениот труд се истражувани сценарија за проширување на националниот систем за производство на електрична енергија. За да се одреди оптимален микс на технологии за производство на електрична енергија со цел да се задоволи побарувачката на електрична енергија, се користи алатката MESSAGE. Периодот на планирање за анализираните сценарија е од 2020 (базна година) до 2050 година. Исто така, за секое сценарио е анализирано влијанието врз животната средина од аспект на емисијата на CO_2.

Клучни зборови: систем за производство на електрична енергија; планирање на развој на системот; MESSAGE tool; оптимален микс на технологии; влијание врз животната средина

INTRODUCTION

The current situation of North Macedonia in the energy sector is strongly dependent on imports of oil derivatives, natural gas, and in the last decade strongly dependent on imports of electricity. About 30% of the electricity needs are supplied from the electricity market, which is certainly dependent on the movement of electricity prices. They have a strong dynamic nature in the last few years with range from 20 €/MWh to over 100 €/MWh. To provide a development strategy in the energy sector with reduced needs for imported energy, high investments are needed for the construction of new power generation capacities and the provision of funds for their ongoing maintenance.

In the paper, scenarios for expansion of the Macedonian electricity generation system are presented. In order to obtain the optimal technology mix for electricity generation sufficiently enough to feed the country electricity demand MESSAGE tool is used.

The following two scenarios for the planning period 2020 (base year) – 2050 are analyzed:

- **Baseline 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, hydropower plants and renewable power plants.
- **Moderate scenario**, where the existing coal-fired technologies are substitute with gas-fired

tech-nologies with CCGT (Combined Cycle Gas Turbines) and possibility for nuclear option via SMR (small modular reactors) is considered.

The electricity production by hydropower plants are the same for both scenarios. The additional electricity needs are covered with import.

MESSAGE tool is used for modelling the system, for developing the scenarios and to determine the optimal electricity generation technology mix.

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 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 [1].

RELATED WORK

In [2], the authors developed an energy model of the main national Chilean system and evaluated the effect of large injections of electrical energy on the structure of the matrix of electricity generation. Utilizing the planning tool MESSAGE, the following are studied: the impact of hydroelectricity generation in the south of the country, nuclear energy generation, and the effect of large blocks of energy that are dispersed and at times intermittent, as renewable energies are, in particular wind power. In [3], 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 [4] presents the possibility and evaluates 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 [5], the authors investigated two scenarios for expansion of the Macedonian electricity generation system:

Baseline scenario, where the current energy structure prevailed, with trends like the current development.

Green scenario, where gas-fired thermal power plants and nuclear power representative with SMR are base load technologies and also intensive construction with RES (renewable energy sources) is forced.

In this paper the second analyzed scenario (Moderate) is with steps to transform from Baseline to Green option (which is analyzed in [5]).

METHODOLOGY AND INPUT DATA

The diagram that depicts the methodology used in this research is presented in Figure 1.

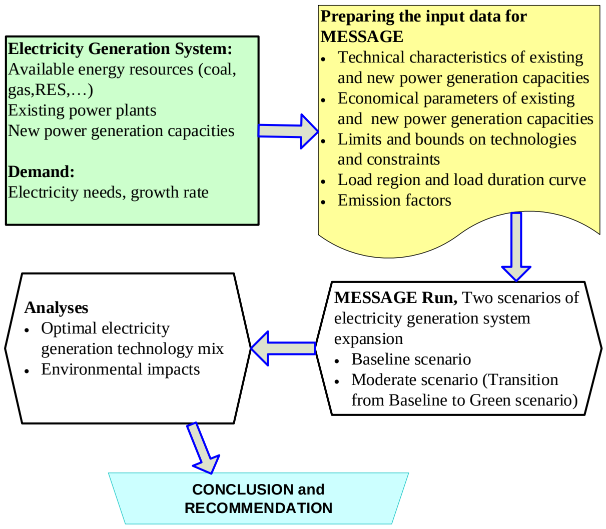


Fig. 1. Research methodology flowchart

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

- Time horizon: 2020 (base year) to 2050 in a 5-year interval;
- Discount rate: 8%;
- Electricity demand: 7000 GWh/799 MWyr in the 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. Figure 2 presents the chain structure for the energy supply system modelled in MESSAGE, where all options as fuel types and technologies are modelled. In this paper only electricity generation system is presented, while the results for the heat supply system will not be presented.

For the scenarios some of the inputs are:

- Imported electricity 400 \$/kWyr with growth rate of 3% per year, with capacity of 340 MW for Baseline scenario and 310 MW for Moderate scenario;
- Coal import and Coal Extraction: 262 \$/kWyr;
- Oil import: 385 \$/kWyr, which is near 500 €/ton oil;
- Gas import: 307 \$/kWyr, which is near 250 €/1000 Nm^3.

Available capacities for the planning period, for the Baseline and for the Moderate scenario, are given in Figures 3 and 4, respectively.

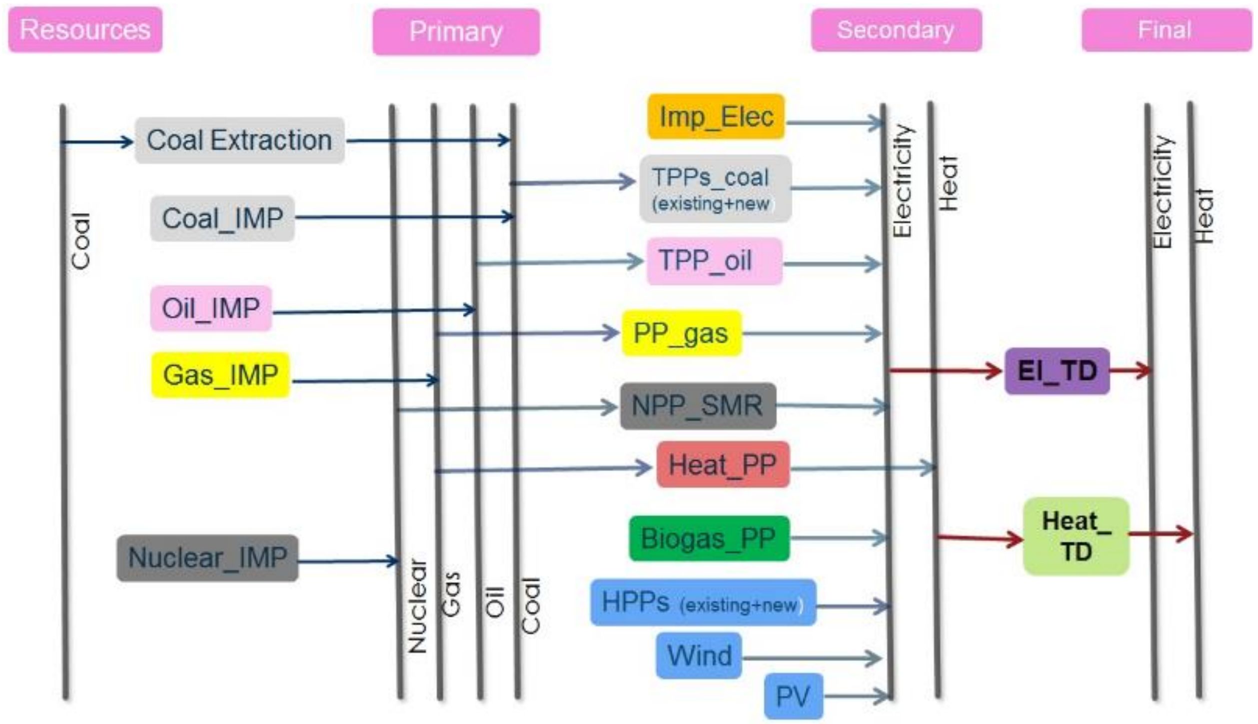


Fig. 2. Chain structure for energy supply system

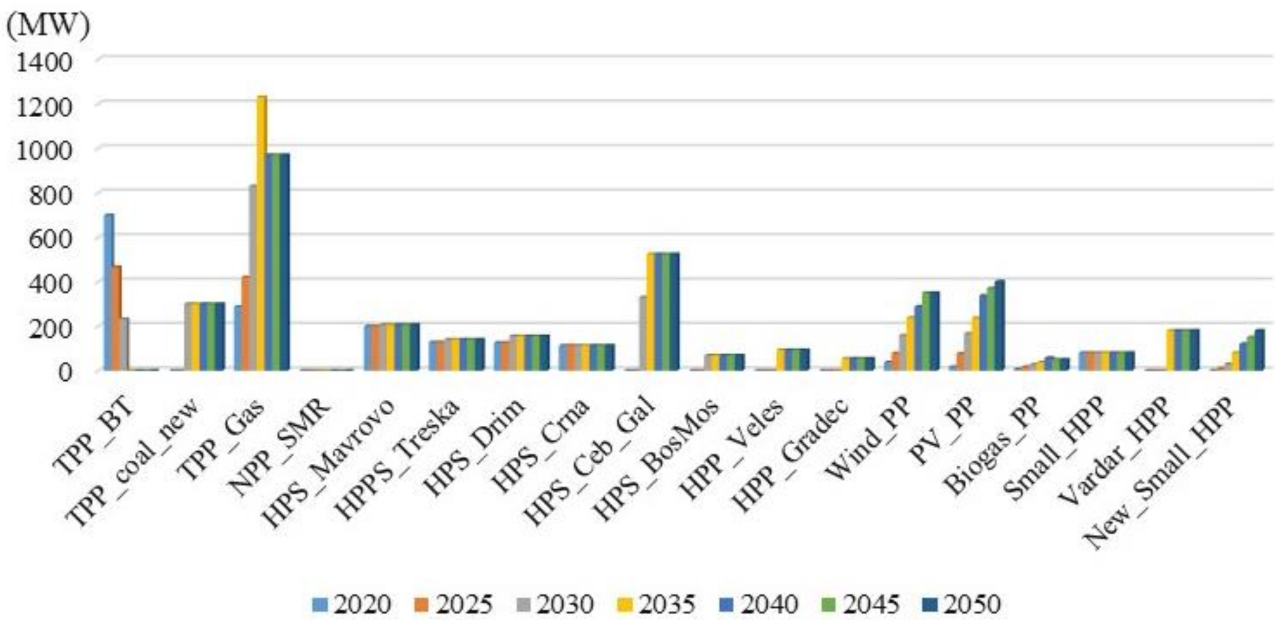


Fig. 3. Available capacities for the planning period for Baseline scenario

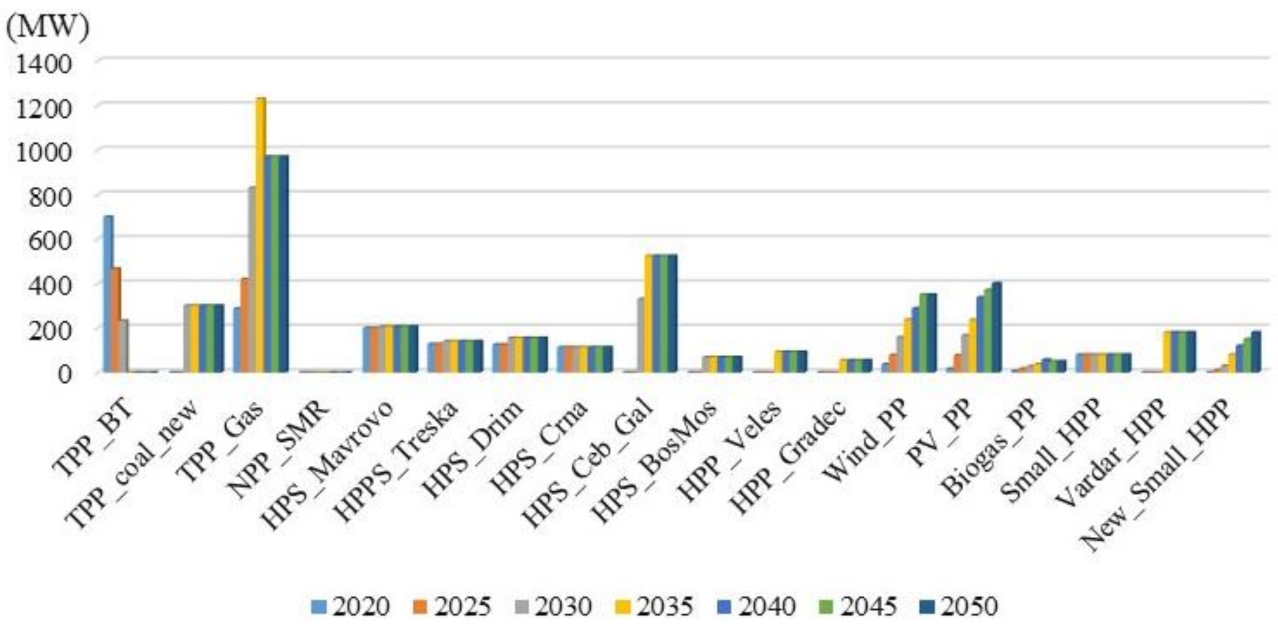


Fig. 4. Available capacities for the planning period for Moderate scenario

RESULTS AND DISCUSSION

In this part of the paper obtained results of both scenarios are presented. Installed capacity for each scenario is given in Figures 5 and 6.

Yearly generated electricity (activity) for each scenario is also obtained. In the base 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. On the next figures (7–9) the energy mix in activity (generated electricity in MWyr and in percentage) for both scenarios for the years 2030, 2040 and 2050 can be compared.

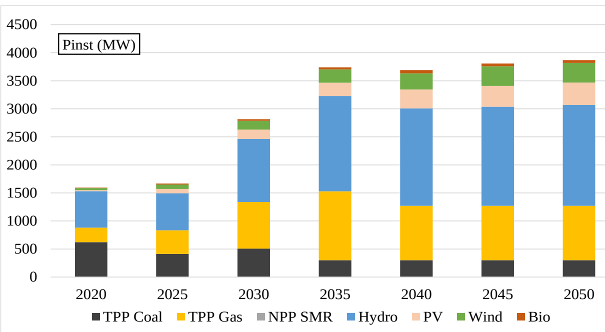


Fig. 5. Installed capacities for Baseline scenario

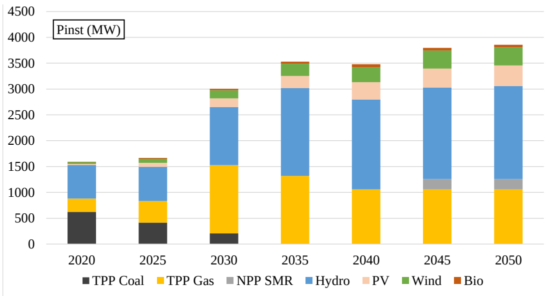


Fig. 6. Installed capacities for Moderate scenario

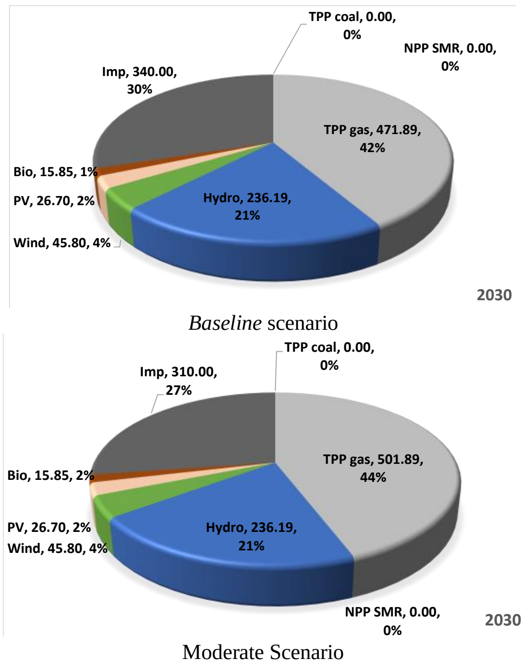
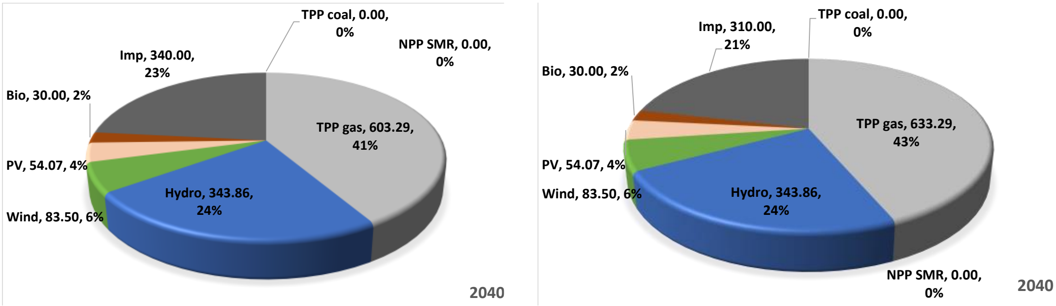
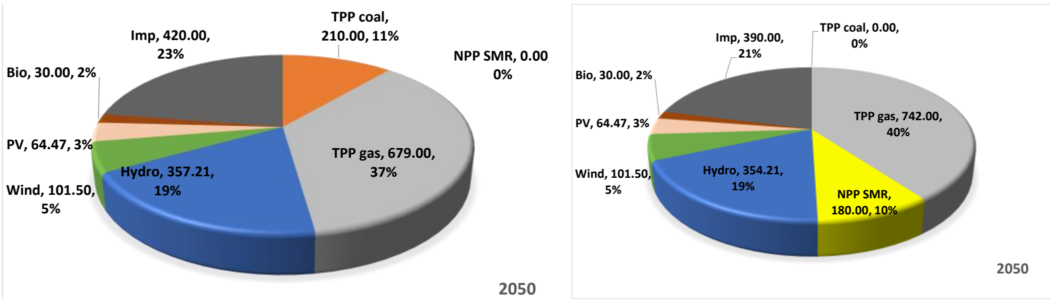


Fig. 7. Energy mix in activity (generated electricity in MWyr and in percentage) for 2030



Baseline scenario — Moderate Scenario

Fig. 8. Energy mix in activity (generated electricity in MWyr and in percentage) for 2040



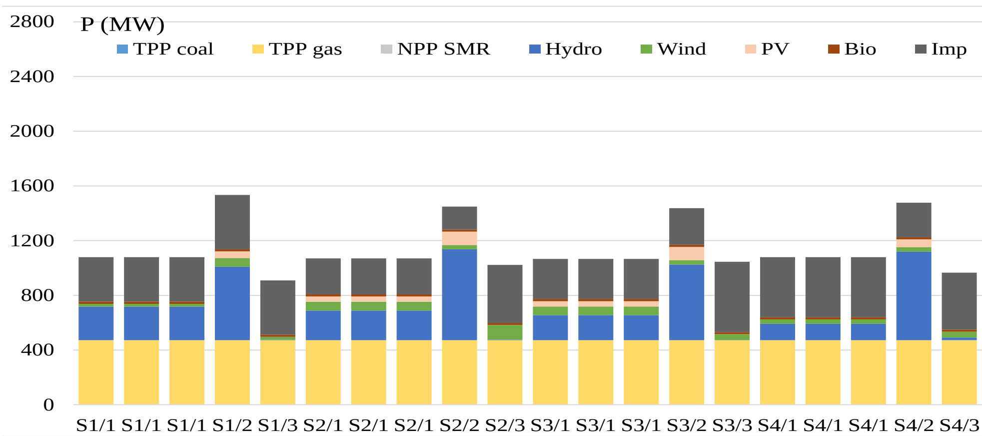
Baseline scenario — Moderate Scenario

Fig. 9. Energy mix in activity (generated electricity in MWyr and in percentage) for 2050

The difference between Baseline scenario and Moderate scenario can be noticed in the last decade where SMR in Moderate scenario replace TPP on coal in Baseline scenario. Anyway it is noticed that in both scenarios, imported electricity have significant part for covering the electricity demand.

Taking into account the load duration curve, the representative day demand and the yearly activity of the power generation system, we can obtain the structure of the covered demand inside of the representative day for each season in each scenario.

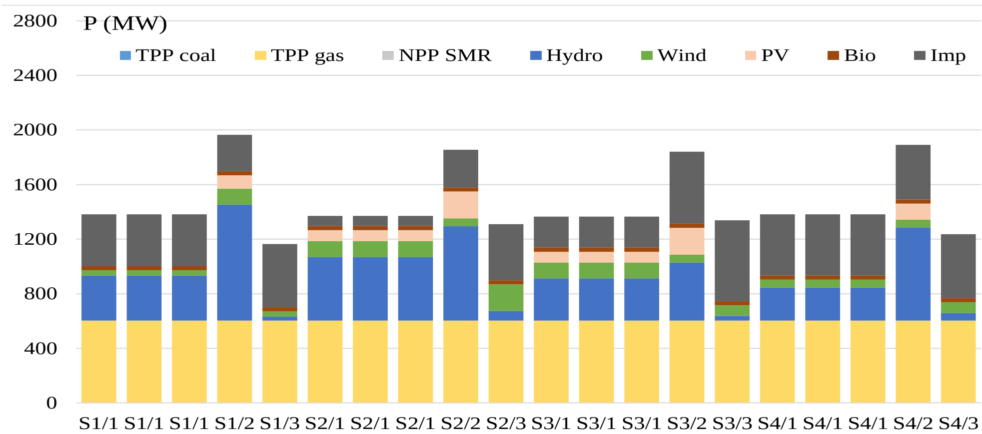
Daily supply of the electricity demand for all representative days, in all 4 seasons in 2030, 2040 and 2050 for the both scenarios is presented in the Figures 10–15. The first base period in a day is three times longer (0.6), than the other two parts (peak and night part) of a day (0.2), so the representative of the first part of a day is presented with 3 bars. While, below the figures short description of the main characteristic of the certain graph is given.



Baseline scenario 2030

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

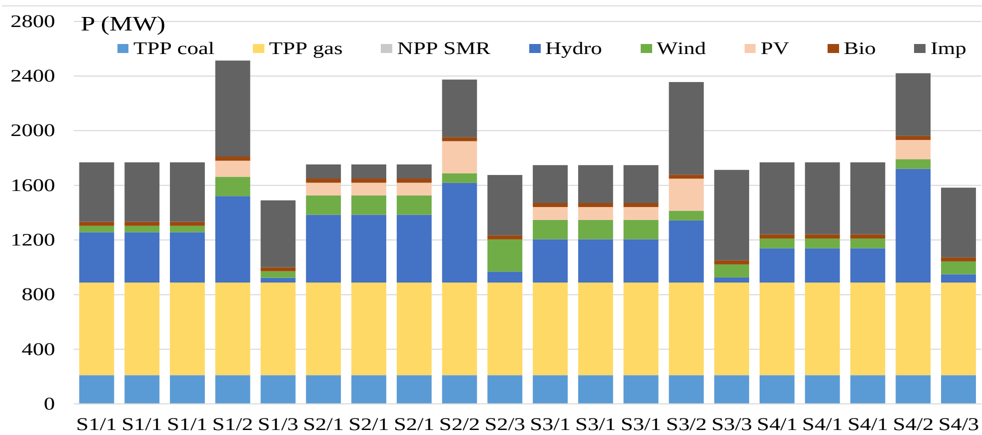
Fig. 10. Daily supplying of the electricity demand for representative days for *Baseline* scenario for 2030



Baseline scenario 2040

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

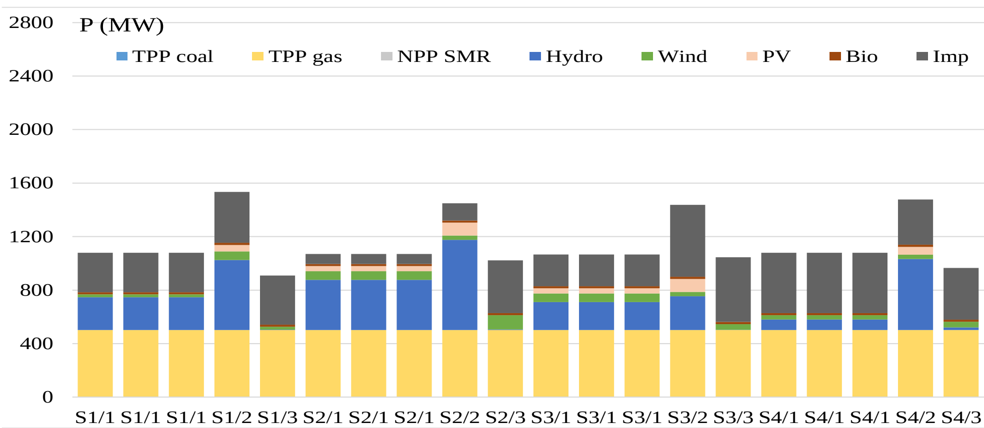
Fig. 11. Daily supplying of the electricity demand for representative days for *Baseline* scenario for 2040



Baseline scenario 2050

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

Fig. 12. Daily supplying of the electricity demand for representative days for *Baseline* scenario for 2050



Moderate 2030

- Similar as *Baseline scenario* 2030
- Base load mainly covered from the gas-fired TPPs,
- Storage hydropower plants covered variable part of electricity demand,
- Significant electricity import

Fig. 13. Daily supplying of the electricity demand for representative days for Moderate scenario for 2030

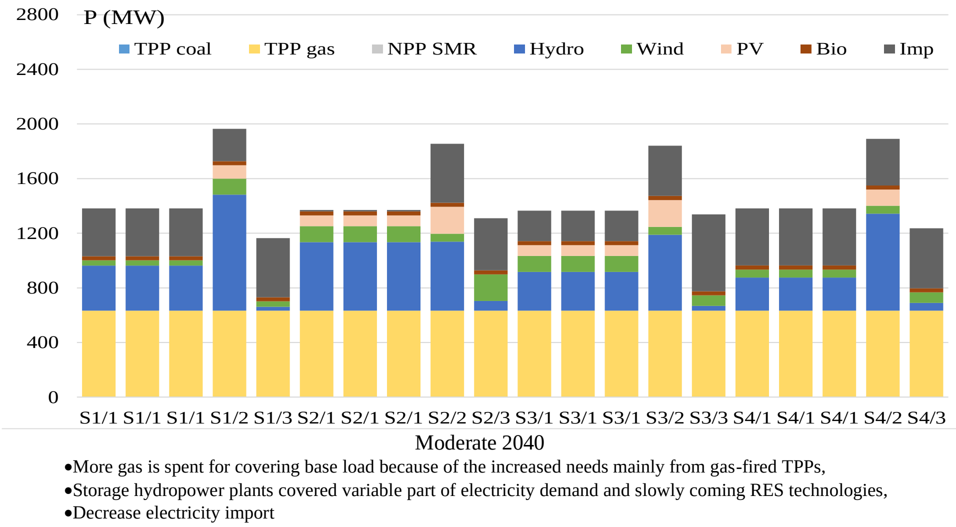


Fig. 14. Daily supplying of the electricity demand for representative days for Moderate scenario for 2040

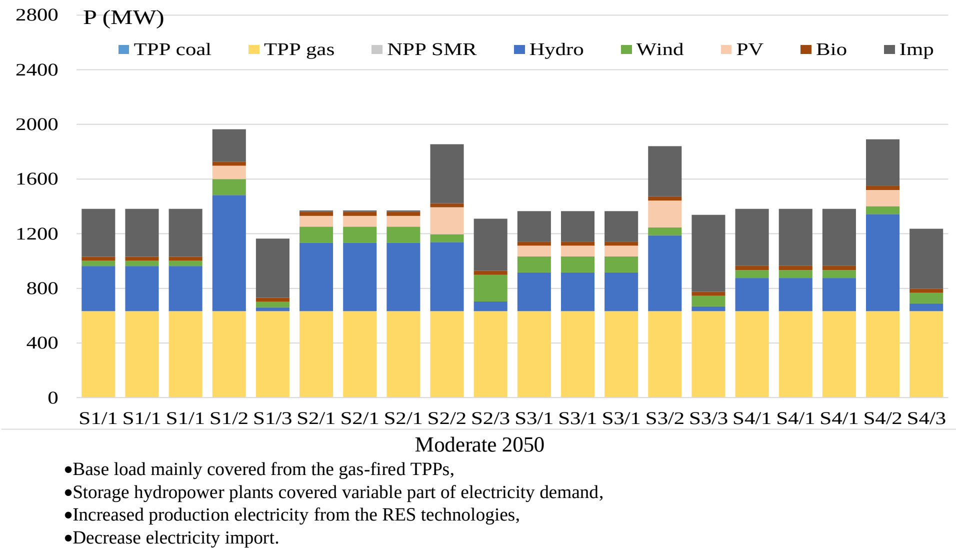


Fig. 15. Daily supplying of the electricity demand for representative days for Moderate scenario for 2050

Environmental impact from CO_2 emission

Carbon emission mainly depend on generated electricity of thermal power plants on fossil fuels (coal and gas). According the results from each scenario, chemical content of fossil fuel and used technology, the CO_2 emission per generated electricity 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.

The yearly generated electricity of thermal power plants on fossil fuels for each scenario is presented in the Figures 16 and 17.

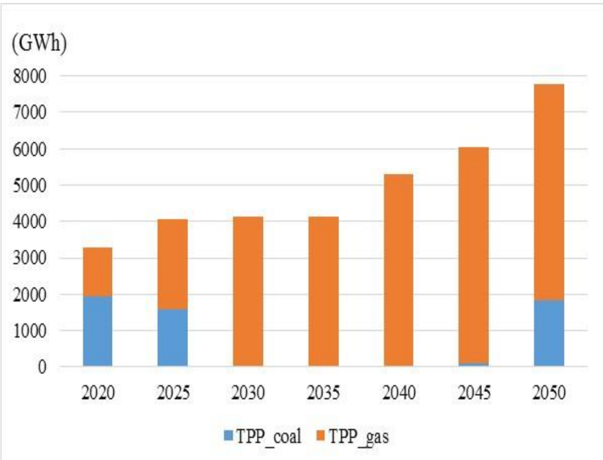


Fig. 16. Yearly generated electricity of thermal power plants on fossil fuels for Baseline scenario

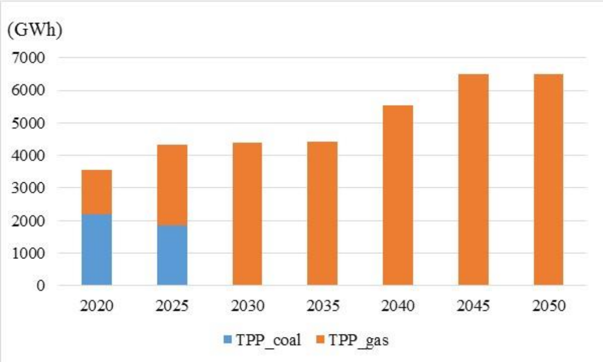


Fig. 17. Yearly generated electricity of thermal power plants on fossil fuels for Moderate scenario

By taking into account the generated electricity and the CO_2 emission per generated electricity, the total CO_2 emission for each scenario are presented in the Figures 18 and 19.

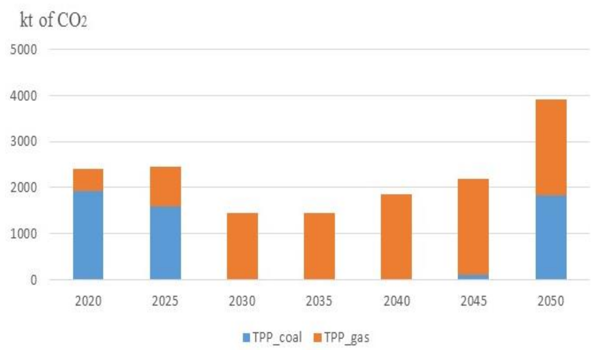


Fig. 18. Yearly total emission of CO_2 for Baseline scenario

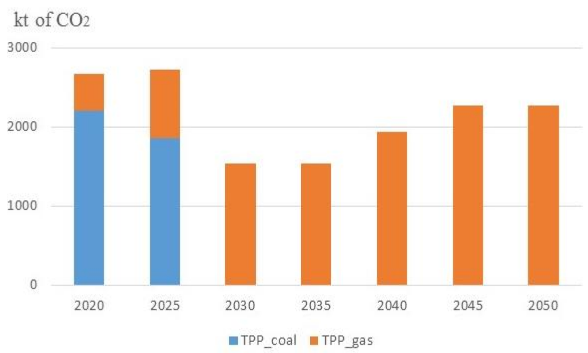


Fig. 19. Yearly total emission of CO_2 for Moderate scenario

CONCLUSION

It is important to have analysis of the current situation of the national electricity generation system taking into account the existing and possible candidates of power plants according the previous studies and documentation. Also, it is necessary to have the national criteria for future power generation 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 from new capacities, available human resources, security supply system for sustainable development, etc.

Reduction of the domestic coal reserves, ageing of the equipment, requirements to reduce emissions from existing coal-fired thermal power plants are some of the reasons for searching for a way to replace them.

One option in the Baseline scenario is to be installed new modern block(s) with imported coal, where would be implemented all desulphurization and deNOx technologies, 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 with an efficiency of about 60%. In case some of them in urban areas to be used as cogeneration plants for electricity and heat production, they would significantly increase the efficiency up to 80% with significantly reduced carbon emissions.

The construction of new gas TPPs and large hydropower plants requires high investment, which is usually provided either by a public-private partnership or by providing funds and loans through international development financial institutions where ESM as a public state-owned energy company guarantees. 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.

It is especially important to find a way to provide investment funds for SMR as nuclear technology from the point of view for new nuclear beginner country. 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. In addition to the necessary investments for the technology itself, additional funds are needed for establishing the national institutional infrastructure and for the education of human resources in nuclear technology.

On the other hand, with the construction of power plants on renewable energy sources such as wind farms, photovoltaics, small hydropower plants, as well as biogas power plants the energy production infrastructure can be further improved and they are mostly private investments that certainly require appropriate conditions and guarantees from national institutions in accordance with the legislation in the energy sector. According the dynamics of construction of power plants on RES, it is important to pay special attention to the rest of the electricity generation system of conventional technologies, in terms of reliable and secure operation of the power system. It is necessary to provide sufficiently flexible capacities of hydro units, reversible hydropower plants or gas power plants that would respond to the dynamic and unpredictable behavior of RES in the energy system.

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