EXPLORING THE IMPACT OF REDUCED HYDRO CAPACITY AND LIGNITE RESOURCES ON THE MACEDONIAN POWER SECTOR DEVELOPMENT

by

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The reference development pathway of the Macedonian energy sector highlights the important role that lignite and hydro power play in the power sector, each accounting for 40% of total capacity in 2021. In 2030, this dominance continues, although hydro has a higher share due to the retirement of some of the existing lignite plants. Three sensitivity runs of the MARKAL-Macedonia energy system model have been undertaken to explore the importance of these technologies to the system, considering that their resource may be reduced with time: (1) Reducing the availability of lignite from domestic mines by 50% in 2030 (with limited capacity of imports), (2) Removing three large hydro options, which account for 310 MW in the business-as-usual case, and (3) Both of the above restrictions. The reduction in lignite availability is estimated to lead to additional overall system costs of 0.7%, compared to hydro restrictions at only 0.1%. With both restrictions applied, the additional costs rise to over 1%, amounting to 348 M€ over the 25 year planning horizon. In particular, costs are driven up by an increasing reliance on electricity imports. In all cases, the total electricity generation decreases, but import increases, which leads to a drop in capacity requirements. In both, the lignite and the hydro restricted cases, it is primarily gas-fired generation and imports that "fill the gap". This highlights the importance of an increasingly diversified and efficient supply, which should be promoted through initiatives on renewables, energy efficiency, and lower carbon emissions.

Key words: *MARKAL energy system modeling, lignite resources, hydro power plants*

Introduction

Energy as the prime mover of economic growth and the electricity production is the key component that provides the energy required for technological and economic development. The worldwide mix of primary fuels used to generate electricity has changed a great deal over the past four decades. Coal continues to be the fuel most widely used in electricity generation, although generation from nuclear power increased rapidly from the 1970s through the 1980s, and natural gas-fired generation grew rapidly in the 1980s, 1990s, and 2000s. The use of oil for electricity generation has declined since the late 1970s, when oil prices rose

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sharply. Beginning in the early 2000s, high fossil fuel prices in combination with concerns about the environmental consequences of greenhouse gas emissions resulted in interest in developing alternatives to fossil fuels for generation – specifically, nuclear power and renewable energy sources [1].

Even in the West Balkan (WB) region the power generated by fossil power plants accounts for about 59% (52% from coal, 4% from oil, and 3% from gas). Most of the fossil power plants currently in operation in WB were constructed between 1955 and 1990, during lower emission restrictions, and after 1991 the power generation technology and the environmental characteristics of the operating fossil fuel-fired plants in this region had not been improved considerably, mainly due to poor maintenance and lack of investments in the energy generation sector [2]. The other problems that WB countries are facing are changing ownership structure, reorganization and redefining position and functioning of energy complexes. Special types of problems arise when it comes to coal exploitation such as: out dated technology, low efficiency, difficult working conditions, non-lucrative production, social issues, *etc.*, on one side, and obvious need for coal of higher quality on the local market, on the other. Some mines will definitely not be able to continue with operations, while others will have to go through the process of adapting to harsh conditions of market operations [3].

Nevertheless, coal is generally expected to continue to play a key role in the future energy mix as the most abundant and cheapest fossil fuel source. However, the increase of plant efficiency and the minimization of the respective CO_2 emissions are some of the main challenges that the coal industry faces nowadays, raised by the targets of Kyoto protocol towards the reduction of greenhouse gases (GHG) emissions and the mitigation of climate change [4]. On the other hand, there are also many countries where hydropower is the primary form of generation, such as Brazil, Canada, Colombia, Venezuela, New Zealand, Switzerland, and Norway [5]. Hydro power is currently favoured as a source of clean energy with several desirable features including no carbon emissions, low operating costs, the ability to meet peak demands, significant operational flexibilities and high reliability. In an era of deregulated electricity markets, global warming and volatile prices for fossil fuels, these key features of hydro power become extremely valuable [6].

The aim of this paper is to explore how the reduction of lignite and hydro resources will impact the electricity production in case of the Republic of Macedonia, where 77.2% of electricity generation (in 2009) is from lignite power plants and 19.8% is from hydro power plants. For this purpose a set of scenarios are modelled in MARKAL-Macedonia optimisation model for the planning period 2006-2030.

Methodology

MARKAL is a bottom-up, linear programming energy systems analysis modelling framework that is convenient to examine interlocking uncertainties through a systematic approach. The MARKAL/TIMES models produce robust, scenario-based projections of a country's energy balance, fuel mix and energy system expenditures over time. The models relate economic growth to the necessary energy system resources, trades and investments, while satisfying national environmental standards (or goals), to identify the least-cost energy future for the country that satisfies all the requirements [7]. Thus, the models provide a comparative framework for examining the impact of variations in key assumptions (*e. g.*, fuel price, use of nuclear, availability of natural gas), policies (*e. g.*, RE targets, climate change mitigation goals) and programs (*e. g.*, National Energy Efficiency Action Plan, National Renewable Energy Action Plan) to advise informed decision-making and policy formulation.

The MARKAL objective is to minimize the total cost of the system, adequately discounted over the planning horizon. The objective function (eq.1) is the sum over all regions of the discounted present value of the stream of annual costs incurred in each year of the horizon. Therefore:

$$NPV = \sum_{t=1}^{R} \sum_{t=1}^{NPER} (1+d)^{NYRS(1-t)} ANNCOST(r,t)[1+(1+d)^{-1}+(1+d)^{-2}+...+(1+d)^{1-NYRS}] \quad (1)$$

where *NPV* is the net present value of the total cost for all regions, *ANNCOST* (*r, t*) – the annual cost in region *r* for period *t*, discussed below, *d* – the general discount rate, *NPER* – the number of periods in the planning horizon, *NYRS* – the number of years in each period *t*, and *R* – the number or regions.

The total annual cost *ANNCOST (r, t)* is the sum over all technologies, all demand segments, all pollutants, and all input fuels, of the various costs incurred, namely: annualized investments, annual operating costs (including fixed and variable technology costs, fuel delivery costs, costs of extracting and importing energy carriers), minus revenue from exported energy carriers, plus taxes on emissions, plus cost of demand losses.

MARKAL analyses not only show what is to be constructed (and also what is not), but also when and for how much [7]. Based on the engineering and economic representations of energy supply, conversion plants and end-use devices in each country (mines, power plants, heat and power facilities, air conditioners, furnaces, light bulbs, *etc.*) the least cost energy supply and demand balance that can satisfy the physical and policy requirements can be explored by national experts.

MARKAL/TIMES is widely used planning tool, not just in several major international and global applications, but also in dozens of developed and developing countries for national strategic planning (see *e. g.* [8-10]), including analysis of changes in fuel consumption [11], energy saving potential [12], renewable energy policies [13-16] and low-carbon policies [17-19].

Case study: Macedonian power sector

The total installed capacity for electricity generation in Macedonia is 1,591 MW with a maximal annual production of around 7,900 GWh. Major producers of around 6,500 GWh annually are the thermal power plants (TPP), which have an installed capacity of 1,010 MW and out of which 800 MW are using domestic lignite. With an installed capacity of 675MW and an annual output of 4,600 GWh, the TPP Bitola provides about 70% of Macedonia's electricity supply. The main lignite mine is Suvodol, but its reserves have been depleted and exploitation costs increased 4 to 5 times. The TPP Negotino, which uses residual oil, is not in operation regularly because of the high fuel price. Depending on the hydrological conditions, 15 to 20% of the annual electricity production in Macedonia comes from hydro power plants (HPP). There are eight large HPP with total net capacity of 536 MW and 22 small HPP with total net capacity of 44 MW [20].

To assess the impact of different energy strategies or policies in Macedonia, a Reference scenario was developed, providing an outlook for the energy system based on current policies. The Reference scenario takes into account specific characteristics of the national energy system, such as existing technology stock, domestic resource availability and import options, and near term policy interventions.

To explore the importance of lignite and hydro technologies to the Macedonian energy system, the following three sensitivity runs have been undertaken:

– reducing the availability of lignite available from domestic mines by 50% in 2030 (with limited capacity for imports),
– removing three large hydro options of Galiste, Gradec, and Veles, which account for 341 MW in the Reference case (or 22% of 2030 hydro capacity), and
– combining both of the above restrictions.

It is important to highlight that this would be the first time to analyse what will happen if there is a limitation of both key resources for electricity supply in Macedonia. Most of the publications for Macedonian energy sector development are analysing implementation of different policies and programs that promote energy efficiency and renewable energy [21, 22] or take into account the environmental aspect of different development scenarios [23-25].

Results

Reference scenario

For development of the Reference scenario the available National Strategies [26, 27] were used, from which the energy resource potential of the country was developed. Also, all other available national data sources (State Statistical Office, National energy balances, *etc.*) as well as some International databases (IEA Databases [28]) were considered. The key assumptions and constraints for the Reference scenario are given in tab. 1. One thing that should be noted here is that the transport sector is not included in this analysis.

Table 1. Key assumptions and constraints for the reference scenario

Category	Assumption
GDP growth rate	*e. g.* 6.73% (2006-2020), 5.87% (2020-2030)
Population growth rate	–0.16%
Sector/issue	Constraint
Resource supply	
Domestic resources	
Coal (lignite)	Production price vary between 3.6-13.5 €/MWh Relatively high price for imported coal, running from 14.8-26.1 €/MWh
RES potential	
Hydro	Limited potential for small hydro power plants (up to 200 MW by 2020)
Wind	Limited potential for wind power plants (up to 360 MW by 2030)
Solar	Limited potential for PV installation (up to 40 MW)
Imports/exports	No limit Prices for imported electricity running from 59.3-92.5 €/MWh
Electricity generation	Feed-in-tariffs (FiT) for small hydro (100 €/MWh), wind (97 €/MWh*) and PV (420 €/MWh), with associated potential
Technology availability	Nuclear generation is not available The location and the capacities of the large hydro power plants are limited (based on the available National Studies of the hydro potential in the country)
End use sectors	Limited penetration of advanced technologies (max 10% of new devices purchased each year by 2030)
	Limited fuel switching allowed (max 10% fuel share deviation from base year by 2030)

* The tariff has been set at €89/MWh, plus €8/MWh for the incorporation of wind power in the system (for the spinning reserve and balancing). This €97/MWh is thus the purchase price of the electricity generated from wind power plants (qualified as preferential producers).

The characteristics of the key new power plants that are available in the model are shown in tab. 2. The characteristics of the large power plants are based on the future investment plans of the JSC "Macedonian Power Plants" (AD ELEM). In the case of wind power plants there are two alternatives introduced in the model, taking into account the Decision of the Government to provide FIT of 97 €/MWh for maximum 150 MW of wind power plants.

Table 2. Characterization of key power plant options

Power plant type	Start date	Life-time	Effi-cien-cy*	Availability factor	Investment cost [mln €/GW]	Fixed O&M [mln €/GW]	Variable O&M [€/MWh]	Capacity [MW]
Lignite fired	2021	30	0.4	0.8	1,417	23.72	1.2	max 900
Natural gas CCGT	2015	35	0.58	0.85	440	18	1.53	300
Gas CHP**	2010	20	0.5	0.85	735	7.57	0.36	max 560
Hydro – SvPetka	2012	50	1	0.19	1,500	4.19	0.19	36.4
Hydro – Boskov most	2017	50	1	0.22	1,217	4.19	0.19	68.2
Hydro – Galiste	2024	50	1	0.16	1,344	4.19	0.19	193.5
Hydro – Lukovo Pole***	2018	50	1	0.32	10,600	4.19	0.19	5
Hydro – Gradec	2021	50	1	0.51	3,718	4.19	0.19	54.6
Hydro – Veles	2024	50	1	0.37	3,505	4.19	0.19	93
Pumped hydro – Chebren	2020	50	0.64	0.29	1,243	4.19	0.19	333
Small hydro	2012	30	1	0.29	1,600	4.19	0.19	max 200
Wind (central), with FIT	2015	20	1	0.14-0.32	1,400-1,500	30	2	max 150
Wind (central)	2015	20	1	0.14-0.32	1,414-1,515	30	2	max 210
Solar PV (decentralized)	2009	30	1	0.098-0.175	2,000-2,950	29.4	0	max 40

* Total plant efficiency for CHP plants
** Ratio of electricity to heat (REH) is 8.0 for natural gas plant
*** The investment costs for the HPP Lukovo Pole include the costs for building the storage capacity (build as cascade to four existing hydro power plants), which together as a hydro system give additional 163 GWh to the power system

Under the Reference scenario, energy consumption is projected to grow significantly, by 105% in terms of final energy by 2030, driven by strong gross domestic product (GDP) growth and increasing per capita consumption. This will require more than doubling electricity generation capacity from 1,470 to 3,252 MW and results in higher import levels, as well as growth in CO_2 emissions. Key indicators from the Reference scenario are shown in tab. 3.

Primary energy consumption is projected to grow almost 80% by 2030, and becomes more diverse with increased share of natural gas at the expense of coal, oil and electricity imports. The Reference scenario also suggests that the share of renewable energy sources will increase to 8% in 2030. The increase is due to further investment in hydro generation and attractive feed-in-tariffs for wind. Without these feed-in tariffs wind would not enter the Reference scenario on a least-cost basis.

Table 3. Key indicators for the reference scenario

Indicator	2006	2030	Annual growth rate [%]	Overall growth [%]
Primary energy [ktoe]	2,616	4,656	2.4%	79%
Final energy [ktoe]	1,646	3,371	3.0%	105%
Power plant capacity [MW]	1,470	3,252	3.4%	121%
Imports [ktoe]	1,184	2,584	3.3%	118.3%
CO_2 emissions [kt]	8,359	13,253	1.9%	59%
Final energy intensity [toe/€000 GDP]	0.324	0.150	–3.2%	–54%
Final energy intensity [toe/capita]	0.808	1.722	3.2%	113%

Whilst growing GDP and increasing household energy intensity are driving up energy demand, it is also important to note that energy intensity per unit of economic output is significantly lower than observed in 2006 – estimated to be 0.15 toe/1,000 € in 2030, a reduction of around 54%. This is a result of the continuation of current structural changes in the Macedonia economy and natural technological progress underway internationally.

New power generation capacity additions in each three-year period are shown in tab. 4. Coal power plants remain the main producers of electricity with new installed capacity of 900 MW between 2021 and 2027. The highest level of investment is in hydro power, with a cumulative additional capacity of 944 MW by 2030, while new gas power plants have a cumulative installed capacity of 619 MW. Wind and solar (under Renewable and Other category) also make an important contribution, (340 MW) where wind is primarily incentivized by a feed-in tariff. Capacity additions and the retirement of old power plants results in 3,252 MW of total installed generation capacity in place in 2030, of which 2,803 MW are new capacities.

Table 4. New power plant capacity additions [MW]

Plant type	2012	2015	2018	2021	2024	2027	2030	Total
Coal	0	0	0	300	300	300	0	900
Gas	260	300	0	0	0	0	59	619
Hydro	61	23	96	360	359	23	23	944
Renewable and other	4	32	32	32	30	156	54	340
Total new capacity	325	355	128	692	689	479	136	2,803
[%] of installed capacity	18.1%	18.2%	6.2%	25%	21.9%	14%	4.2%	

The Reference scenario evolution of the Macedonian energy system results with increase of CO_2 emissions from 8,359 kt to 13,253 kt, corresponding to 59% increase over the planning horizon.

Scenarios with reduced hydro capacity and lignite resources

The Reference case highlights the important role that lignite and hydro power generation plays in the Macedonian power generation sector. In 2021, each accounts for 40% of total capacity, or 80% combined. In 2030, this dominance continues, although hydro has a higher share due to the retirement of some of the existing lignite capacity.

Three sensitivity runs have been undertaken to explore the importance of these technologies to the system – Lignite Resource Limit, Hydro Resource Limit and Lignite + Hydro Limit.

Table 5 summarizes the key cumulative metrics for these technology sensitivity cases. The reduction in lignite availability is estimated to lead to additional costs of 0.7%, compared to hydro restrictions at only 0.1%. With both restrictions applied, the additional costs rise to over 1%, amounting to 348 M€ over the 25 year planning horizon. In particular, costs are driven up by an increasing reliance on electricity imports.

Table 5. Cumulative impacts of lignite resource, hydro capacity and lignite + hydro limits on the energy system (compared to reference scenario)

Indicator	Units	Reference	Lignite resource limit		Hydro capacity limit		Lignite + hydro limit	
Total discounted energy system cost	2006 mln €	36,316	271	0.7%	44	0.1%	348	1.0%
Primary energy supply	ktoe	97,045	–2,653	–2.7%	297	0.3%	–2,441	–2.5%
Imports	ktoe	48,667	3,602	7.4%	955	2.0%	4,447	9.1%
Fuel expenditure	2006 mln €	25,807	715	2.8%	479	1.9%	1,055	4.1%
PP new capacity	MW	2,803	–19	–0.7%	–247	–8.8%	–314	–11.2%
PP investment cost	2006 mln €	3,773	–219	–5.8%	–720	–19.1%	–967	–25.6%
Demand technology investment	2006 mln €	10,811	–10	–0.1%	0.5	0.0%	–48	–0.4%
Final energy	ktoe	62,960	–9	0.0%	1	0.0%	–23	0.0%
CO_2 emissions	kt	293,805	–22,524	–7.7%	1,602	0.5%	–20,394	–6.9%

Most of the differences are of course, related to the power generation sector, and are highlighted in fig. 1. In all cases, the total generation decreases. In the lignite cases, it is primarily gas fired generation and imports that *fill the gap*. The same is also true in the hydro restricted case, albeit the relative change is much smaller. The limitation of the lignite resources reduces the generation of the coal power plants up to 41%, and consequently increases the production of gas-fired generation for almost 2.5 times (or 3 times in the scenario with limitation of lignite resources and of hydro capacities) and the electricity import for almost 6 times, in comparison to the Reference scenario.

This overall decrease in electricity generation but increase in imports leads to a drop in capacity requirements, as shown in fig. 2. In comparison to the Reference scenario, the limitation of the lignite resources results in 300 MW less capacity of coal power plants in 2030, which are replaced with additional 281 MW of gas power plants. In the case of hydro capacity limit, the 341 MW of hydro power plants built in the Reference scenario are replaced with 94 MW of gas power plants, resulting in 247 MW less cumulative capacity in 2030 compared to the Reference case, while the rest of the electricity needs will be covered through import. In the combined constraint case, the cumulative capacity drops by over 11% compared to the Reference case, or by 314 MW. Indeed, in this scenario only 318 MW of gas power plants are built in difference to Reference scenario where 290 MW of coal power plants and 341 MW of hydro power plants enter the power system. In all three cases, wind power plants without any incentives are shifted earlier in the planning period.

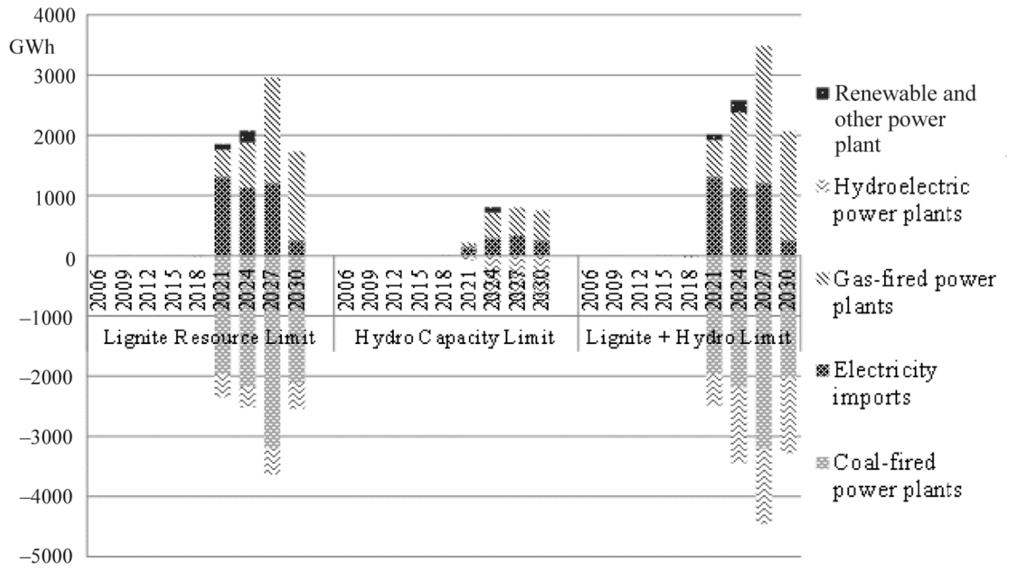

Figure 1. Change in electricity generation by type under power sector sensitivity cases

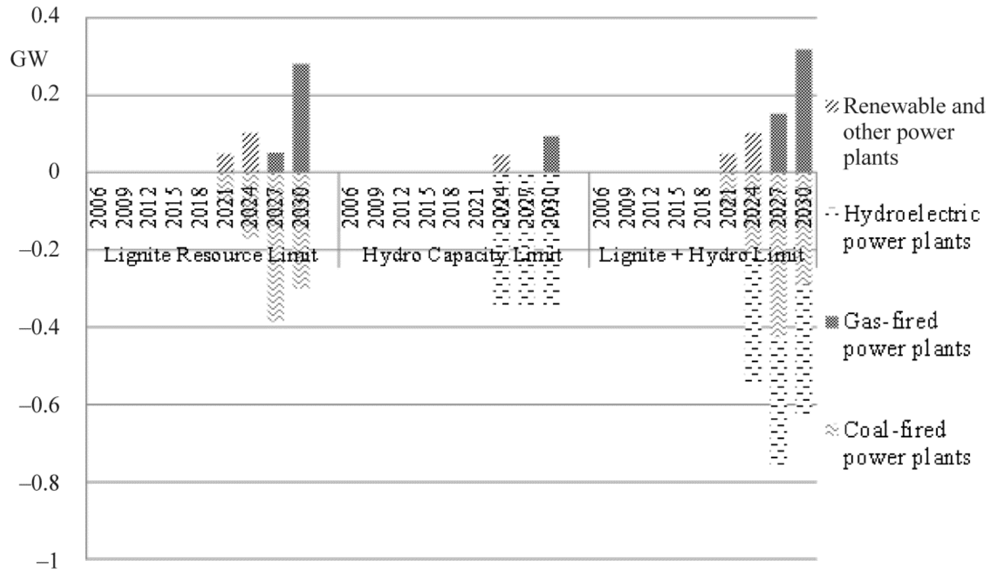

Figure 2. Change in electricity generation capacity by type under power sector sensitivity cases

Conclusions

The Reference development pathway of the Macedonian energy sector emphasizes the importance of the lignite and hydro power generation, both accounting for around 80% of total capacity in 2021 and keeping their dominance even in 2030 (with shares of 74%), even with the retirement of the existing lignite power plants.

From the analyses in this paper it is clear that lignite in particular has a very important role in keeping overall energy system costs down. However, it is clear that this role will be alleviated with the possible introduction of carbon price. Therefore, future uncertainties concerning resource availability and carbon prices could have a significant impact on costs. Combined with lack of investment in new larger hydro plant, costs could be even higher, particularly if there is additional reliance on imported electricity. This highlights the importance of an increasingly diversified and efficient supply, which should be promoted through initiatives on renewables, energy efficiency and lower carbon emissions. Therefore, the key areas for future analysis should include how best to design feed-in-tariffs (FiT) to encourage renewable development, and developing targeted energy savings policies, including standards and appliance and retrofit subsidies.

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