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**STUDY FOR THE EVALUATION OF THE IMPACT OF THE NATIONAL  
ENERGY AND CLIMATE PLAN IN THE UTILIZATION OF LIGNITE AND  
HYDRO-PUMPED STORAGE UNITS BEFORE AND AFTER YEAR  
2030,**

**THROUGH SIMULATION OF THE GREEK WHOLESALE AND  
BALANCING MARKETS AND THE OPERATION OF THE GREEK  
POWER SYSTEM DURING THE PERIOD 2020-2030**

Implemented by AUTH after assignment by the  
ASSOCIATION OF ENGINEERS OF PPC GROUP

**ATHENS**

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## **CONTRACT**

### **FOR THE STUDY FOR THE EVALUATION OF THE IMPACT OF THE NATIONAL ENERGY AND CLIMATE PLAN IN THE UTILIZATION OF LIGNITE AND HYDRO-PUMPED STORAGE UNITS BEFORE AND AFTER YEAR 2030**

**between**

**the Aristotle University of Thessaloniki and the  
ASSOCIATION OF ENGINEERS OF PPC GROUP and  
Associate Professor Pandelis Biskas**

January 2020

**FOR AUTH**

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Research Committee**

**FOR THE RECEIVER**

**The Legal Representative  
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## **Executive Summary**

This report is the first Deliverable of the project carried out on behalf of the Association of Engineers of PPC & ADMIE Group. The scope of the report is:

- a) the investigation of the System's adequacy in the event of the total decommission of the existing lignite units, in accordance to the approved revised National Energy and Climate Plan (NECP),
- b) the investigation of whether it is more financially efficient to introduce new gas-fired units in the System or extend the operation of some newer lignite units (e.g. PTOLEMAIDA 5 and/or AG. DIMITRIOS and/or MELITI) beyond 2028, considering the delignitization/decarbonization timelines of other European countries, and
- c) the investigation of the financial efficiency of technologies (e.g. pumping stations, new CCGT units) that could be used to counterbalance the consequences of the forward-facing national delignitization.

In order to investigate the above-mentioned matters, a long-term analysis of the operation of the Greek Wholesale Electricity Market, the Balancing Market and the Power System was performed. Ten (10) simulation scenarios of the Greek electricity markets were formulated (Day-Ahead Market, Integrated Scheduling Process and Real-Time Balancing Market using one-hour, 30-minute and 15-minute time steps respectively) considering the evolution of various parameters, e.g. system load, installed Renewable Energy Sources (RES) capacity, natural gas prices, CO<sub>2</sub> emissions costs, as well as the future availability of lignite and gas-fired units in the System, etc. Other operation parameters expected to be implemented in the following years (e.g. the interconnection of Crete and the rest of the insular systems with the mainland System) were considered appropriately throughout the study.

The ten (10) formulated scenarios (that are briefly presented in the following table) aim to investigate:

- a) the impact of the future energy mix in the capacity adequacy of the Greek Power System,
- b) the financial efficiency of the use of existing and new PSPs under conditions of high RES penetration,
- c) the financial efficiency of converting the to-be decommissioned lignite units AMYNTAIO 1 and 2 as well as one of the to-be decommissioned units of AG. DIMITRIOS in modern gas-fired units, and
- d) the upgrade of the new lignite unit «PTOLEMAIDA 5» with a CO<sub>2</sub> emissions reduction system.

Scenario	Availability of PSPs	Are PSPs' offers based on economic criteria?	Construction of gas-fired AMYNTAIO & AG. DHMHTRIOS units (from 01/01/2025)	Operation of PTOLEMAIDA 5	Extension of operation of AG. DHMHTRIOS 5 & MELITH until 31/12/2030
S1	2 PPC + 3 IPPs	NO	NO	Until 31/12/2030	NO
S2	2 PPC + 3 IPPs	YES	NO	Until 31/12/2030	NO
S3	2 PPC	YES	NO	Until 31/12/2030	NO
S4	3 IPPs	YES	NO	Until 31/12/2030	NO
S5	-	-	NO	Until 31/12/2030	NO
S6	2 PPC + 3 IPPs	YES	NO	Until 31/12/2030	NO
S7	2 PPC + 3 IPPs	YES	YES	Until 31/12/2030	NO
S8	2 PPC + 3 IPPs	YES	NO	Until 31/12/2030	YES
S9	2 PPC + 3 IPPs	YES	NO	no time limitation, with installation of CO <sub>2</sub> emissions reduction system	NO
S10	2 PPC + 3 IPPs	YES	YES	no time limitation, with installation of CO <sub>2</sub> emissions reduction system	NO

Specifically, the simulation scenarios are characterized by the following basic assumptions:

- **Scenarios 1-5:** All the existing lignite units are decommissioned following the forward-facing delignitization timeline included in the revised NECP which is presented in detail in the following table. The new lignite unit “PTOLEMAIDA 5” is considered to be commissioned by the end of 2021 and is fully available throughout the years 2022-2030<sup>1</sup>. The main differentiation of these scenarios lies in the availability of the existing PPC’s pumped-storage plants (PSPs) (SFIKIA, THISAUROS) and the three new PSPs that are expected to be constructed and operated in early 2024. The main aim of these scenarios is the investigation and the quantification of the contribution of PSPs (both PPC’s and IPPs’) in the provision of flexibility services that ensure the reliable and smooth operation of the System, especially under conditions of high RES penetration. It is noted that Scenario 2 is used as a Baseline Scenario for the comparison with Scenarios 6 – 9 (which are Sensitivity Scenarios).
- **Scenario 6:** The difference between this scenario and the Baseline Scenario (Scenario 2) lies in the assumption of the early decommission of the new lignite unit “PTOLEMAIDA 5” by the end of 2028, in accordance with the national delignitization

<sup>1</sup> In the context of this study it is assumed that the unit “PTOLEMAIDA 5” might operate using a different fuel (e.g. biomass) in the years 2029-2030, which is assumed to not affect the operation of the unit (technical characteristics, variable operation cost, etc.).

plan, essentially foregoing the possibility of the operation of the unit using an alternative fuel. The aim of this scenario is the investigation of the impacts of this strategy in the Energy Production System's ability to fully cover both electricity demand and flexibility requirements that are continuously increased due to the shift in the energy mix with increased RES injections.

- **Scenario 7:** The difference between this scenario and the Baseline Scenario (Scenario 2) lies in the assumption that PPC proceeds to the construction and operation of a new 660 MW gas-fired unit that replaces the to-be decommissioned lignite units of AMYNTAIO 1 and 2, as well as the construction and operation of an identical 660 MW gas-fired unit that replaces one of the to-be decommissioned lignite units of AG. DIMITRIOS. Regarding the second gas-fired unit, it is considered that it will be constructed and operated instead of a gas-fired unit that, in the rest scenarios, is considered to be constructed and operated by some IPP. The aim of this scenario is the investigation of the financial efficiency of the aforementioned investments by PPC, taking into account all the possible revenue streams of the Company from the operation of the units (wholesale market, balancing market, capacity adequacy mechanism, district heating provision).
- **Scenario 8:** The difference between this scenario and the Baseline Scenario (Scenario 2) lies in the assumption that the extension of the operation of the nation's two most modern lignite units is achieved, namely AG. DIMITRIOS 5 and MELITI, until 31/12/2030, instead of their premature decommission in 31/12/2023. The aim of this scenario is the investigation of the impact of this extension of their operation in the capacity and flexibility adequacy metrics of the System (improvement or deterioration).
- **Scenario 9:** In this scenario it is assumed that the new lignite unit "PTOLEMAIDA 5" is upgraded with the installation of a CO<sub>2</sub> emissions reduction system from the beginning of its commercial operation. The aim of this scenario is both the investigation of the operation of the unit in the wholesale electricity market and the balancing market, given its significantly lower variable cost and CO<sub>2</sub> emissions following the upgrade (the latter makes the unit eligible for compensation via future capacity adequacy remuneration mechanisms) and the financial evaluation of the additional investment, namely the quantification of the positive impact of such an investment in the financial results of the Company.
- **Scenario 10:** In this scenario it is assumed that the new lignite unit "PTOLEMAIDA 5" is upgraded with the installation of a CO<sub>2</sub> emissions reduction system from the beginning of its commercial operation and at the same time PPC proceeds with the construction and operation of a modern 660 MW gas-fired unit that replaces the to-be decommissioned lignite units AMYNTAIO 1 and 2, as well as the construction and operation of an identical 660 MW gas-fired unit that replaces one of the to-be decommissioned lignite units of AG. DIMITRIOS. Regarding the second gas-fired unit, it is considered that it will be constructed and operated instead of a gas-fired unit that, in the rest scenarios, is considered to be constructed and operated by some IPP. This scenario is essentially the combination of Scenarios 7 and 9, and it is used to investigate

the impact of the implementation of the three aforementioned business plans both in the context of the operation of the units in the Day-Ahead and the Balancing Markets and the financial results of the Company.

The following table sums the new unit commitment and decommitment schedule and was used as an input in the simulations performed.

For the purposes of this report, an analysis of the Greek electricity market has been performed using the specialized software platform “Long-Term Scheduling” (LTSx) of the Power Systems Lab of Aristotle University of Thessaloniki. This software simulates the Greek wholesale market and the Balancing Market in a mid-/long-term horizon, ranging from one month to several years in the future.

Unit Name	Fuel	Net Capacity [MW]	Start of commercial operation	Unit Name	Fuel	Net Capacity [MW]	Withdrawal date
Ptolemaida 5	Lignite	615	01/11/2021	Ag. Dimitrios 1	Lignite	274	31/12/2022
New CCGT MYT	NG	790	01/07/2022	Ag. Dimitrios 2	Lignite	274	31/12/2022
New CCGT 1 (IPP)	NG	790	01/01/2024	Ag. Dimitrios 3	Lignite	283	31/12/2022
New CCGT 2 (IPP)	NG	660	01/07/2024	Ag. Dimitrios 4	Lignite	283	31/12/2022
New CCGT 3(PPC)	NG	660	01/01/2025	Ag. Dimitrios 5	Lignite	342	31/12/2023
				Kardia 3	Lignite	280	31/12/2021
				Kardia 4	Lignite	280	31/12/2021
				Megalopoli 3	Lignite	255	31/12/2022
				Megalopoli 4	Lignite	256	31/12/2023
				Amyntaio 1	Lignite	273	30/04/2020
				Amyntaio 2	Lignite	273	30/04/2020
				Meliti	Lignite	289	31/12/2023
<b>Sum</b>		<b>3.515</b>		<b>Sum</b>		<b>3.362</b>	

Given the forward-facing delignitization timeline included in the revised NECP, and according to the simulation results, the generation mix of the Greek System undergoes major change during the duration regarding this report, since the national forward-facing delignitization leads to reduction of lignite units’ production by 80-90%, from 8-9 TWh per year during the years 2020-2022 to 1,5-2 TWh per year during the years 2028-2030 (see the Figure below), assuming that the unit PTOLEMAIDA 5 will continue its operation as a lignite unit during the years 2029-2030. **The possible extension of the operation of the units AG. DIMITRIOS 5 and MELITI until 2030 (see Figure below, Scenario 8) seems to curb the sharp decline of the lignite units’ production during the decade, contributing to the System’s capacity adequacy with the use of domestic power sources, and leads to a smoother transition to the new energy landscape**, where RES units are expected to play a prominent role during the duration of the study, since their production share is expected to rise from the current levels of 20% to 60% by 2030, based on the targets included in the approved NECP

In the new energy landscape, the continuously growing production from fluctuating RES units (wind parks, PV plants) is expected to significantly increase the System’s requirements for capacity and flexibility provision in order to balance the System in real-time.

Suitable units for provision of reserves and balancing services are the fast and flexible gas-fired units, the pumped-storage plants (PSPs), and the hydro units.

Simulation results indicate that there will be suitable grounds for the extensive operation of PSPs (SFIKIA, THESAUROS and new PSPs by IPPs), due to the increasing needs for System balancing due to both the forward-facing plan for the withdrawal of lignite units by 2023 and the continuously increasing (fluctuating and volatile) injections by RES units, especially during the years 2024-2030. It is also clear that **PPC's PSPs have a higher utilization factor compared to IPPs' PSPs, despite their lower installed capacity**. This can be mainly attributed to the larger capacity of the downstream reservoirs of PPC's PSPs (especially PSP THISAUROS) compared to the IPPs' PSPs. Moreover, the simulation results indicate that **PPC's PSPs, are more flexible and allow for the pumping (and consequently the injection) of larger volumes of water on a daily basis, contributing this way more to the reliable and smooth operation of the System compared to the IPPs' PSPs**. It is also noted that when the operation of PSPs does not follow a strict economic criteria, but is in the basis of solving management problems of the Power System by ADMIE, e.g. the avoidance of power cuts from RES units, peak-load coverage, contribution in reserve provision, etc., both the annual hydro production and the pumping load are significantly increased, since PSPs are used more intensively to counterbalance the fluctuations of the production of RES and smoothen the operation of the System in real-time, as shown in the bellow Figure (Scenario 1). **The importance of PSPs can be seen under conditions of high RES penetration**, where both the use of PSPs in pumping mode is experienced, in order to absorb the surplus energy from RES production.

The financial results of PSPs indicate that in case PSPs are used for the solution of System's management problems by ADMIE and not following economic criteria (Scenario 1), it leads to significantly lower gross profits (even in possible losses) compared with the rest scenarios, in spite of the larger pumping load they absorb, since their operation does not aim in the maximization of their profits but in covering the System's balancing needs. This means that **if PSPs are used without economic criteria by the System Operator for System balancing (e.g. Scenario 1), then additional remuneration mechanisms should be introduced either through compensation for ancillary services provision or as revenues from the Permanent Capacity Adequacy Mechanism (PCAM)**,

**PPC's PSPs, during the years 2020-2023 yield the highest annual gross profits of the period 2020-2030**, since they operate without any competition from PSPs by IPPs and at the same time cover in part the void resulting from the premature withdrawal of lignite units. The commission of PSPs by IPPs combined with the operation of two new gas-fired units in 2024 leads to a significant decrease in the annual gross profits of PPC's PSPs in all the examined scenarios during the period 2024-2030, as the competition between flexible units for the provision of flexible power to the System grows. **In case PSPs by IPPs are not commissioned in the System, the annual profits of PPC's PSPs will continue growing until 2030**.

Imbalance prices are highly dependent on the availability of PSPs. Specifically, **absence of PSPs would lead to excessively high imbalance prices**, since the System would have to resort in very expensive solutions in order to ensure that it has the required power and flexibility sources to cover the System's imbalances in real-time. **Similar excessively high**

**imbalance prices at the level of 200 €/MWh are observed during the period 2020-2023 in the case of non-operation of the existing PPC's PSPs (SFIKIA, THESAUROS).** It is noted that imbalance prices are expected to play a significant role in the operation of new markets, since those will be the prices at which all the imbalances of the contracting parties with balancing responsibilities will be charged/credited, in which new RES units are included from now on. Consequently, **the intensive exploitation of PPC's PSPs during the following time period (and especially during the years 2020-2023) will lead to a containment of the market's clearing prices at reasonable levels in the interest of the System and the end-customers.**

In the context of investigating the impact of the national forward-facing delignitization on the System's ability to fully cover both electricity demand and flexibility requirements due to the shift of the energy mix towards energy sources with fluctuating levels of production (RES units), the calculation of the relevant capacity (LOLE and EUE) and flexibility (IRRE, EURE) adequacy metrics proves that **in the case of extensive PSP use without strict economic criteria is the optimal choice, since all the reliability metrics have their lowest annual values compared to all the rest simulation scenarios.** This confirms the **importance of the contribution of the storage of electrical energy in the capacity and flexibility adequacy, especially when combined with high penetration of stochastic and fluctuating throughout the day injections by RES units.**

**The possible decommission of the unit PTOLEMAIDA 5 by the end of 2028 leads to a significant deterioration in the values of LOLE, while the possible commission of a gas-fired unit by PPC in Amyntaio and the extension of the operation of the lignite units AG. DIMITRIOS 5 and MELITI until 2030 lead to an improvement of LOLE, thus proving their contribution to the System's capacity adequacy.**

Regarding the flexibility adequacy metrics (IRRE and EURE), it is noted that **the gradual delignitization that happens during the years 2020-2022 leads to a significant increase of their values, which can be interpreted as the contribution of the existing lignite units in the System's flexibility adequacy.** In spite of these, the extension of the operation of the lignite units AG. DIMITRIOS 5 and MELITI until 2030, combined with high RES penetration leads to a deterioration of the metrics for the years 2024-2030. **This proves that the existence of lignite units combined with high RES penetration that fluctuates greatly throughout the day (e.g. PV plants) poses problems to the System Operator.** Essentially, **high RES units' penetration, whose production fluctuates greatly throughout the day poses a major challenge to the System Operator,** as it leads to:

- i. great energy surplus during the day,
- ii. problems in the coverage of load peaks and reserve requirements, especially in the hours when RES units do not produce electricity and especially during the afternoon peak, and
- iii. significant RES units power cuts during the day, even while PSPs are in operation (both PPC's existing and new IPPs' plants).

Operation of batteries of high nominal capacity from 2030 and onwards can contribute to the solution of the above problems, but off-the-market mechanisms are required to cover the investment cost of said batteries. **In order to solve the aforementioned problems of the**



**system's operation and the RES power cuts it is required that (beyond the two existing PPC's PSPs and the three new IPPs' PSPs that are expected to be constructed) a total of 1.650 MW of batteries able of storing four times this energy amount (4 hours of consecutive storage) be installed, with a total investment cost of over 1,15 billion euros.**

Moreover, in the context of the investigation of the construction of two (2) new CCGT units by PPC in order to replace the to-be decommissioned lignite units of AMYNTAIO and AG. DIMITRIOS, respectively, it turns out the specific location choice of both units constitutes the optimal choice for the Company since it allows for the exploitation/upgrade of the existing facilities, it neighbors with TAP's routing, and benefits from lower DESFA transportation fees. Moreover, the positive financial figures of the two business plans

**a) NPV=199,7 m.€ IRR=11,9%**

**b) NPV=176,0 m.€ IRR=11,1%**

indicate that the **construction and operation of these new CCGT units in 2025 constitutes an advantageous investment for cementing the company's position in the new landscape** that is characterized by the national forward-facing delignitization, the increasing penetration of RES in the energy mix and the operation of new Electricity Markets, ensuring at the same time the continuation of district heating provision in the municipalities of Kozani and Amyntaio.

Regarding the possibility of the extension of the operation of the unit PTOLEMAIDA 5 beyond 2028 using lignite as its fuel, initially an overview of the new European energy policy is presented, regarding the energy transition and the so far published practices of decarbonization followed by European countries.

The European Green Deal announced in late 2019 by the leadership of European Union (EU) is the continuation of its earlier commitments for immediate act to combat climate change, as committed in the Paris Agreement in 2015. The new Deal is essentially a roadmap for the transformation of the European Union until 2050 to a modern, viable and climate neutral economy, with the zeroing of greenhouse gasses, dominance of renewable energy sources and maximization of energy savings. In order to achieve this energy transition with the fairest and most just way, EU offers financial and technical support in order to enable people, companies and regions affected by it via the Just Transition Mechanism. This Mechanism provides support of at least 100 billion euros to the regions most affected by this transformation during the period 2021-2027.

The total independence from carbon/lignite for energy production is amongst the main initiative towards achieving a climate neutral economy by 2050. In this context, a sufficient number of European countries have so far officially announced a binding end-date for the decommission of the entirety of their lignite and coal units, as shown in Figure 1<sup>2</sup>

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<sup>2</sup> <https://www.ft.com/content/ba190c72-f590-11e9-b018-3ef8794b17c6>

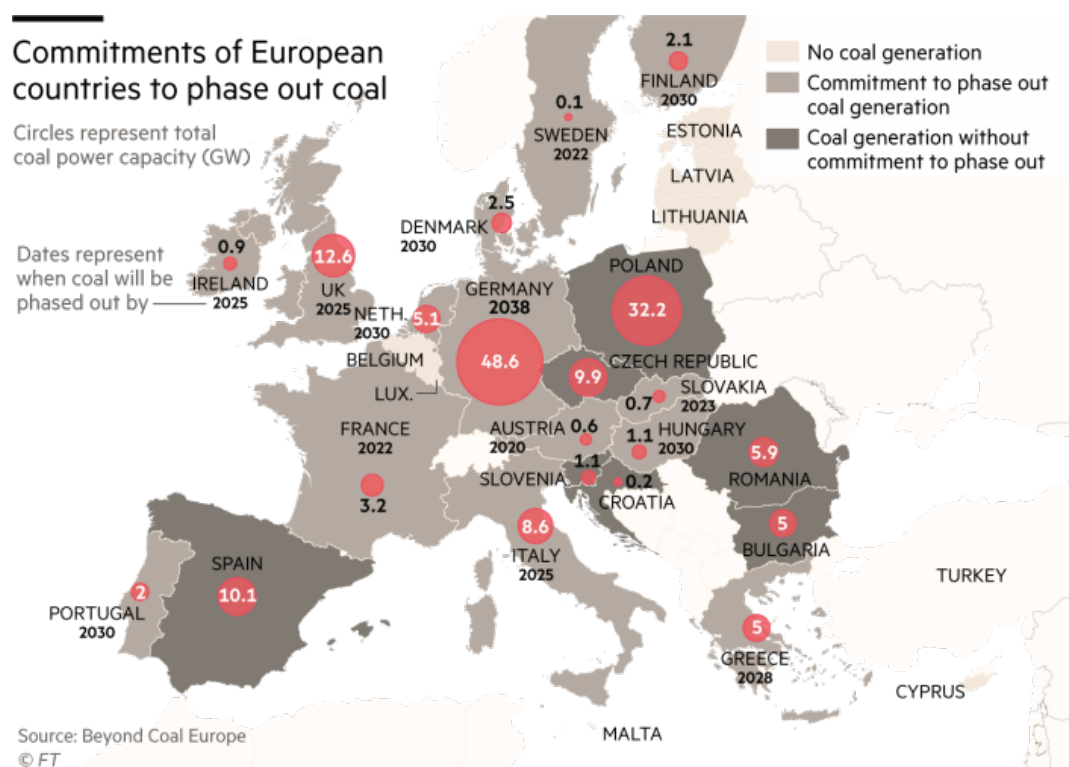


Figure 1. The binding timeline of decommissioning of lignite/carbon units

Greece has committed (via the revised National Energy and Climate Plan (NEPC) that was submitted in the European Commission in late December 2019) for the total independence from lignite generation by 2028, while it intends to apply an intensive and forward-facing plan for the decommission of twelve (12) existing lignite units by the end of 2023. Essentially, during the period 2024-2028 only the new lignite unit PTOLEMAIDA 5 will be in operation, with an installed capacity of 660 MW. It is remarkable that **the decommission timeline of the existing Greek lignite units leads by 7 years (considering that 2023 is a milestone-year for the Greek independence from lignite production) compared to that of more advanced European countries (e.g. Denmark, Holland, Hungary, Finland etc.).**

It should also be noted that countries whose share of coal and/or lignite in the electricity generation mix is large (see Figure 2), have either announced a binding end-date for the decommission of such units that either at a much later date (e.g. Germany by 2038), or have postponed so far such announcements regarding the decommission of coal/lignite units (e.g. Poland, Czech Republic, Spain, Bulgaria, Romania, Slovenia, Croatia, etc.).

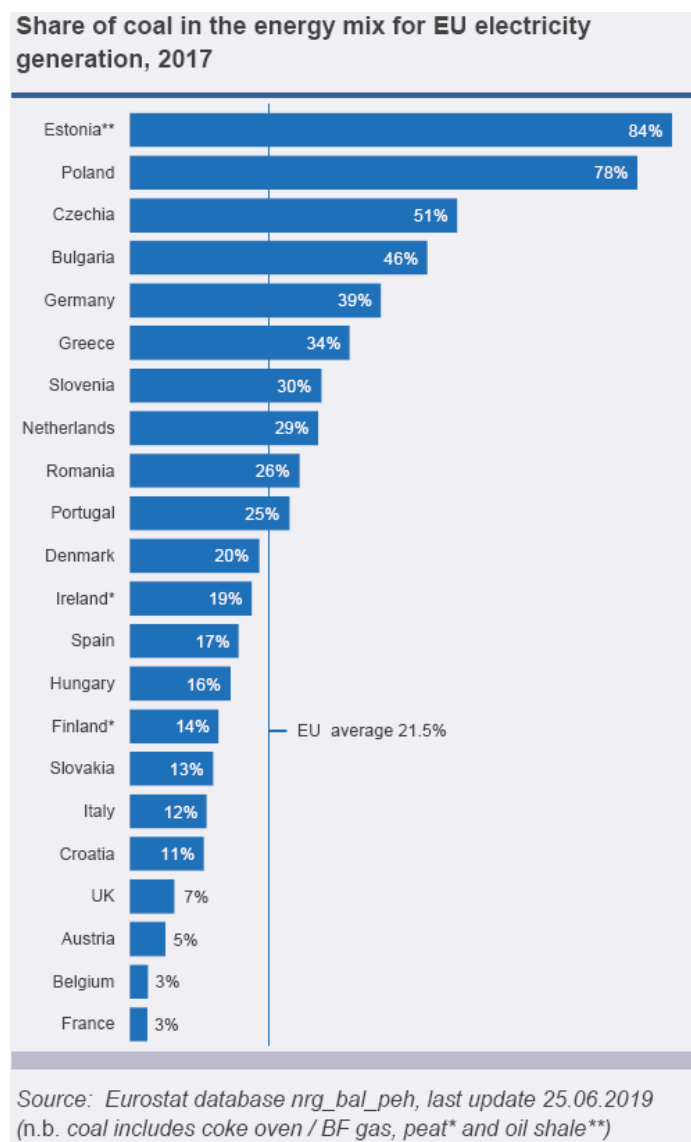


Figure 2. Share of coal in the energy mix for EU electricity generation<sup>3</sup>

Main reasons behind the postponement of the process of coal/lignite independence are<sup>2</sup>:

a) sufficient existing coal and lignite reserves in many members of the European Union combined with a lack of an alternative domestic source of fuel that can be used by conventional units, since natural gas is an imported fuel for most European countries,

b) the coal industry in its entirety (coal mines, supply lines of units, electricity production) contributes to the preservation of thousands of jobs with pay-grades significantly above the average pay-grades of the countries, contributing at the same time to the national budgets via tax, contributions, etc., and

c) coal/lignite units can contribute (to a lesser extent compared to gas-fired units) in the provision of reserves and balancing services for covering the System's imbalances that result from the continuously increasing penetration of the volatile RES units (wind farms and PV plants).

<sup>3</sup> Coal industry across Europe, European Association for Coal and Lignite, 7<sup>th</sup> Edition, 2020

In order to formulate the decarbonization plan and investigate the possible consequences in the economy and the society, Germany has established a special Coal Commission, whose findings (published in January 2019) include specific recommendations for the smoother transition towards a “greener” energy system. The basic proposals are<sup>4</sup>:

a) the gradual and long-term decommission of coal and lignite units until 2038 (with an intermediate evaluation in 2032 in order to investigate whether the speed-up of the total decarbonization can be achieved in 2035, but in no case sooner),

b) the support in the transition of the affected areas by promoting new investments and creating new jobs, the modernization of transportation system and energy facilities, encouragement of R&D and innovations, etc.,

c) the modernization of the power system with the introduction of new, more efficient and flexible cogeneration and storage plants, while at the same time ensuring the security of the energy supply by putting in place appropriate capacity adequacy mechanisms, in case that the existing mechanisms (wholesale market) cannot provide the appropriate incentives for the construction of new units in the future,

d) targeted compensations towards end-customers (both industrial and household) that are expected to face an increased price of electricity, as well as towards the owners of lignite units in order to counterbalance the early decommission of their units from the system,

e) the support of workers directly employed in the coal industry, through targeted benefits,

f) continuous monitoring of the decarbonization process with intermediate progress reports every three years (2023, 2026, 2029, 2032).

In addition to the above proposals, since February 2018 EU has approved the transitional capacity adequacy mechanism for Germany in the form of strategic reserves. According to EU’s approval decision<sup>5</sup>, the System Operator conducts an auction every two years for the provision of 2 GW of reserve capacity. The selected units are withdrawn from their daily participation in the wholesale market and have to be put in operation only to follow the Operator’s orders in emergency situations, when the demand exceeds the available supply. This way, the day-to-day operation of the electricity market is not affected, a reduction in CO<sub>2</sub> emissions is achieved and a certain number of conventional units is kept in reserve ensuring the system’s capacity adequacy.

As already mentioned, a number of European countries have not yet announced any plans regarding the decarbonization of their electricity sector<sup>3</sup>. Amongst them, Poland, whose economy heavily relies on coal, is not only limiting the installed capacity of coal/lignite units, but is in the process of constructing five (5) new coal/lignite units of 4,3 GW net capacity, that will replace existing aged units that have much higher CO<sub>2</sub> emission factors. According to government statements, these coal/lignite units will be the last of this technology to be constructed in Poland. Despite this, the production of coal/lignite units is expected to be kept at today’s levels until 2030.

Similarly, Bulgaria has set as a priority in its energy strategy until 2030 that is being currently drawn up the safeguarding of the energy supply and the financial stability of the

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<sup>4</sup> Agora Energiewende und Aurora Energy Research (2019): The German Coal Commission. A Roadmap for a Just Transition from Coal to Renewables.

<sup>5</sup> [https://ec.europa.eu/competition/state\\_aid/cases/269083/269083\\_1983030\\_171\\_2.pdf](https://ec.europa.eu/competition/state_aid/cases/269083/269083_1983030_171_2.pdf)

companies of the sector. In this context, and since no other reliable and financially acceptable alternative source could replace lignite in the foreseeable future, any plans to decrease lignite production and/or totally decommission lignite units is postponed for after 2030 or whenever the new nuclear plant in Belene is commissioned.

Romania's intentions appear to be in the same direction, since in its recently developed energy strategy (November 2018) for the period 2019-2030 in view of 2050, keeping the same level of diversification of the domestic primary energy sources (coal, lignite, natural gas, oil) is set as a main priority. In this context, it plans and incentivizes the replacement of the existing aged units that are nearing the end of their useful life with modern, highly efficient and with low emissions conventional units.

Czech Republic also aims to maintain the same levels of use of domestic fossil fuels (carbon, coal), and has already engaged in an extensive upgrade and modernization program of its coal units in Northern Bohemia, achieving both a significant decrease in CO<sub>2</sub> emissions and prolonging the useful life of these units beyond 2030.

While the basic characteristic of the energy policy of Slovenia appear to be aligned with the EU's basic priority for energy and climate (increase of RES penetration and energy efficiency) in the electricity production industry the country is expected to proceed to a partial only replacement of its coal/lignite production with energy coming from renewable sources. In the long-term, the coal mine Premogovnik Velenje (that ranks amongst the largest and most modern underground mines in Europe) is expected to continue its operation and the supply of the accompanying lignite stations until 2054, in the context of keeping a well-balanced energy mix that ensures the energy security of the country. Moreover, recently (2015) the country's public power company (HSE) constructed a state-of-the-art thermal unit of 43% efficiency, achieving both the replacement of old units and a reduction in CO<sub>2</sub> emissions by 35% and the stabilization of electricity prices with an improved environmental footprint, in spite of the increased demand.

Based on the above, it is obvious that the **Greek State's recent proposal to be amongst the first 4-5 European countries (see Figure 1) regarding the speed of the decommission of its domestic coal/lignite units is unsubstantiated, taking into account the extent and the future potential contribution of the domestic lignite generation in formulating a diversified energy mix that will enhance the safety of the energy supply of the country.** Given that as of today a Union regulatory framework that obliges Member States to immediate and total decarbonization of the electric generation (as also established by the above analysis) does not exist, the necessity of the extension of Greece's decarbonization process until 2030 or later is enhanced by the possible delay or cancelation of the construction and operation of the CCGT units expected to be commissioned in the Greek Power System by 2024 in combination with a possible prevalence or a more gradual rate of commission of new RES units, that would lead to a significant deterioration of the capacity adequacy metrics, putting in danger the capacity adequacy of the Greek Power System in the long-run. In case this extension is decided upon, in order to avoid the loss-making operation of lignite units given the increasing missing money problem they face in the wholesale market, due to the significant decrease of the Market Clearing Price (MCP) caused by the injections of RES, it is necessary that **they operate under mechanisms that fully cover their operational costs, combined with payments via the permanent capacity adequacy mechanism (in effect**

**until 2025 for existing lignite units**, based on the provisions of the recently approved European Regulation 2019/943 regarding the internal energy market). **Adopting a capacity adequacy mechanism in the form of strategic reserves in accordance to the German mechanism, in which the to-be decommissioned lignite units are able to participate would be an equivalent alternative solution, which would contribute significantly to the safeguarding of the capacity adequacy, simultaneously avoiding the day-to-day loss-making operation of lignite units and limiting the environmental impact.** In order to minimize the burden of the end-customers, **the needed sources for financing such a capacity adequacy mechanism could come from the aforementioned Just Transition Mechanism**, supporting this way the areas of Western Macedonia and Megalopoli that are expected to be affected in a major way by the proposed energy transition.

In case the extension of the operation of the existing lignite units and/or the new lignite unit “PTOLEMAIDA 5” beyond 2028 is not made possible, **the upgrade of the new lignite unit “PTOLEMAIDA 5” with a CO<sub>2</sub> emissions reduction system** was investigated. The main benefits of this upgrade are:

- (a) a significant reduction in the CO<sub>2</sub> emissions factor from 1,05 to 0,37 tn CO<sub>2</sub>/MWhe,
- (b) a significant decrease in the emissions cost allowing the unit to gain a significant competitive advantage in its participation in the new energy markets, and
- (c) guaranteed participation in the capacity remuneration mechanisms, ensuring this way significantly increased annual revenues.

In the context of the financial evaluation, it is evident that **the upgrade of the lignite unit with the installation of a CO<sub>2</sub> emissions reduction system constitutes a particularly advantageous investment for the Company, since it greatly improves the future cash flows of the unit**, even if the investment cost of the upgrade is over 1,5 b€ Therefore, **the realization of the upgrade under consideration is imperative in order to both significantly increase the unit’s operating hours achieving an improved environmental footprint and to significantly improve the unit’s financial results.** Moreover, this upgrade will lead to the lignite unit’s operation without any time constraints.

Beyond the above financial evaluation, in the scenario where the upgrade of the new lignite unit “PTOLEMAIDA 5” with the installation of the CO<sub>2</sub> emissions reduction system takes place at the beginning of its commercial operation, while at the same time PPC proceeds to the construction and operation of a modern 660 MW gas-fired unit that replaces the to-be decommissioned lignite units AMYNTAIO 1 and 2 and an identical gas-fired unit of 660 MW that replaces one of the to-be decommissioned lignite units of the Ag. Dimitrios station (Scenario 10), the combination of the three business plans leads to:

- a) an increased Net Present Value for all three investments, but
- b) a decrease in the financial efficiency of the Company’s total financial results for each investment separately, compared to the Scenario of the implementation of just one of the two investments (namely just the upgrade of the unit “PTOLEMAIDA 5” or the construction of the two CCGTs units AMYNTAIO and AG. DIMITRIOS).

In any case, **the implementation of all three investments represents the best-case scenario for the company.**

In conclusion, the main aim of this report is the documentation and the analysis of all the challenges PPC is expected to face in its production department within the next decade, considering both the projections of the revised National Plan for Energy and Climate and the new conditions that prevail worldwide on a political and technological level, such as the expected gradual increase of CO<sub>2</sub> emissions costs, the commission of new gas-fired units, the steep increase in the installed capacity of RES units – mainly wind farms and PV plants-, the extensive use of pumped-storage stations and other storage stations for managing the daily generation profile of RES units (mainly PV plants), etc.

In the new environment caused by the energy transition, PPC can play a prominent role shaping to a large extent the domestic generation mix of the following years. This can be achieved by:

- a) increasing the Company's RES production, with plants ideally installed in the regions of Western Macedonia and Megalopoli, that would potentially be the most affected areas of the proposed decarbonization. In this context, the construction and operation of innovative hybrid production and storage plants (e.g. a PV plant and battery system), whose financing could come through European Programs, the European Investment Bank and/or the Just Transition Mechanism. Given that this kind of systems are able to provide a guaranteed amount of power at any given time, they could potentially participate in the capacity adequacy mechanisms in the future, maximizing their expected revenues.
- b) the systematic exploitation of the Company's pumped-storage plants (that currently operate for just a few hours per year) in the framework of new electricity markets. The reliability and fast response times of these systems is expected to be necessary in the new conditions established with the increase of the participation share of volatile RES units in the production combined with the maturity of the new Balancing Market, where market participants will be compensated for their balancing services provision,
- c) the construction and operation of modern CCGT units that replace the existing to-be decommissioned lignite units of Western Macedonia. Constructing the units in the said location is the optimal choice for the Company since it allows for the exploitation/upgrade of the existing facilities, it neighbors with TAP, and benefits from lower DESFA transportation fees. These benefits are expected to give a competitive advantage to the new CCGT units against the potential units by IPPs in their participation in the new markets, ensuring at the same time the continuation of the district heating provision (which is currently being provided by the to-be decommissioned units) to the neighboring municipalities, and
- d) the upgrade of the new lignite unit "PTOLEMAIDA 5" with the installation of a CO<sub>2</sub> emissions reduction system. Simulation results suggest that the upgrade constitutes a particularly advantageous investment for the Company, since it greatly improves the future cash flows of the unit. Thus, the realization of the upgrade under consideration is imperative in order to both achieve an improved environmental footprint and to significantly improve the unit's financial results. Moreover, this upgrade will lead to the operation of the unit under lignite fuel without any time constraints, ensuring the

continuation of the operation of several lignite mines in the region of Western Macedonia for its supply.

The Company's main priority should be the its timely adjustment to the new conditions being established in the energy landscape and the immediate of undertaking initiatives, in order to be able to move to the development and operation of innovative energy projects in the interest of the Company, local communities and the national economy.