

An Examination of the Economic Prospects of Greek Lignite Plants



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Summary

In this note, an analysis of the economics of the current operation of the lignite plants in Greece has been attempted. This analysis has been based on publicly available information for the financial parameters of the operation of the plants themselves and the mines that provide their fuel.

The results of this analysis (see Table S1) clearly show that the continuation of the operation of the lignite plants in Greece under the current economic parameters and energy market operation (EUA allowance prices of ca €25/tCO₂) would result in substantial losses for PPC, S.A., their owner. The results also demonstrate that NG plants will be at a competitive advantage in a free market as the currently operating lignite plants accrue cumulative O&M losses of over €194Mil annually plus an approximately equal amount to cover capital costs obligations. This advantage of the NG plants remains even with considerable increases (of over 25%) of the NG price. In addition, as most of the operating lignite units do not meet the new BREF emission limit values, additional investment of over €300Mil in anti-pollution facilities would be required to bring them in compliance which would further worsen their already negative financial position.

The dire economics of the lignite plants' operation are seen also in their 2018 performance where they could not show an operating profit even at the relatively low price for EUA allowances paid by PPC, their owner, which, due to prudent hedging, was 25% below market prices and 50% below current prices.

The Greek Government announced in September 2019 that it plans to decommission all lignite plants by 2028. Under its leaked timetable which calls for the gradual cessation of operation starting with the older plants, this would result in an operating loss of ca €835Mil over the 2020-2028 period. This figure will jump to €1109Mil if a EUA price of €27.5/tCO₂ (halfway between the current and the expected price by 2028 by the EC scenario) is considered. Post 2027, only three plants would have not exceeded 40 years of service. All three of them cannot cover their O&M expenses at reasonable ranges of expected wholesale electricity and EUA allowance prices. It is then reasonable to examine their decommissioning as early as possible, even before they reach 40 years of service.

The plan would also entail either the decommissioning or the conversion to alternate fuels of the Ptolemais V 615MW lignite plant currently under construction at a nominal cost of €1.39Bil. Possible alternatives include its conversion to NG or biomass. In view of the funds already disbursed (over €1.04Bil) conversion to NG would result in increased operating profits but not by enough so as to recover its capital costs. It would also require the construction of the pipeline from the nearest point of the national NG grid (a distance of the order of 100km). The biomass option is unrealistic as there is not enough biomass handily available. Other possibilities, not analyzed, might include use of waste derived fuel, and installation of CCS capability.

If the economic basis for the early retirement of the lignite plants that is presented in this note is acted upon, the production gap that it will create can be covered by increased load factors of the existing NG plants together with the new ones already under construction or in the late permitting phase. In this era of very low NG prices, the NG plants have a competitive edge as their LCOE is even lower than that of wind turbine and PV (of the order of €65-68/MWh submitted in the latest RES

capacity auctions of 2018-2019). It is crucial that this price advantage does not result in hindrance of RES installation, if we are to realize the long-term EU target of reaching near zero emissions by 2050.

Table S1: Typical yearly financial results of the PPC lignite plants plus the three configuration of Ptolemais V and the new Mytilinaios NG unit under prevailing wholesale electricity, EUA and NG prices.

Typical year with €25/tCO ₂ EUA and €70/MWh wholesale prices	Net Power (MW)	Load factor	Production (MWh)	Cost O&M (k€/yr)	Income (k€/yr)	Carbon cost (k€/y)	Profit (k€/yr)	Additional Anti poll Loss (k€/yr)	Profit after anti-pol (k€/yr)	Invest Cost (k€/yr)	Profit after anti-poll and invest cost (k€/yr)
Ag. Dimitrios I	274	0.55	1175460	46105	82282	43051	-6874	1084	-7957	23528	-31485
Ag. Dimitrios II	274	0.55	1175460	46105	82282	43051	-6874	1084	-7957	23528	-31485
Ag. Dimitrios III	283	0.6	1324440	49258	92711	48508	-5055	10948	-16003	24301	-40304
Ag. Dimitrios IV	283	0.6	1324440	47631	92711	48508	-3428	10948	-14376	24301	-38677
Ag. Dimitrios V	342	0.7	1867320	71983	130712	68391	-9661	8970	-18631	29367	-47998
Amyntaio	546	0.4	1703520	78055	119246	64862	-23670	31013	-54684	46884	-101568
Kardia I	271	0.4	845520	39324	59186	33377	-13515	0	-13515	0	-13515
Kardia II	271	0.4	845520	39324	59186	33377	-13515	0	-13515	0	-13515
Kardia III	280	0.4	873600	39266	61152	34485	-12599	0	-12599	0	-12599
Kardia IV	280	0.4	873600	39266	61152	34485	-12599	0	-12599	0	-12599
Megalopoli III	255	0.4	795600	52326	55692	36598	-33232	0	-33232	0	-33232
Megalopoli IV	256	0.6	1198080	61632	83866	62390	-40157	4096	-44253	21982	-66235
Meliti	289	0.6	1352520	63863	94676	43754	-12940	1671	-14611	27735	-42347
Total			15355080	674138	1074856	594836	-194118	69814	-263932	221626	-485558
Ptolemais V Lignite	615.7	0.75	3591900	100214	251433	100214	40209	3846	36363	70215	-33852
Ptolemais V Biomass	615.7	0.75	3591900	313683	251433	1796	-64046	3496	-67542	80325	-147868
Ptolemais V NG	615.7	0.55	2634060	107632	184384	27526	49226	1751	47475	60750	-13276
Mytilinaios NG (€615/kW)	804	0.55	3449160	140939	241441	36044	64459	2289	62170	27301	34869
Mytilinaios NG (€400/kW)	804	0.55	3449160	140939	241441	36044	64459	2289	62170	17757	44413

The retirement of the lignite units will result in stranded investments for PPC. These stranded investments after 2027 would include only three plants (Ag. Dimitrios V, Megalopolis IV and Meliti) as the others will have exceeded 40 years of service. Their operation post-2027 under current conditions would result in €477Mil operating losses of which €34.2Mil from Megalopolis IV and €116Mil from Meliti. As the book value on 31 December 2018 of Meliti was €130Mil and of Megalopolis III & IV €140Mil only the Ag. Dimitrios V unit would have some stranded value. This is not the case though for the investment in the mines for which the book value as of 31 Dec 2018 was €1316Mil but in which the value of the lignite in situ should not be counted as it did not cost anything as they assigned to PPC by the Greek State at no cost.

Finally, it should be stressed that the expected retirement of the lignite plants by 2028 according to the Government pledge would entail large upheaval in the local communities where the plants are located. Despite warnings in the past, planning for a Just Transition of these communities to the post-lignite era has not progressed enough so as to propose new viable and substantial activities to replace lost income and more importantly to identify, let alone secure, the funds that would be needed to support the communities throughout the transition period. It is imperative that this planning is completed immediately, and that programs to address the social problems that will result go hand-in-hand with the plan to retire the lignite plants by 2028.

More disaggregated data by plant and mine, would have provided more accurate estimates. Nevertheless, such further disaggregation would not change substantially the results presented which are based on the information available and the use of informed assumptions for some parameters.

As the economic break-even values (Table 22) for a number of core parameters that include wholesale and EU allowance prices are high enough and low enough respectively, it is highly unlikely that these primary findings of substantial losses would be reversed.

1. Introduction

On 24 September 2019, the Public Power Corporation of Greece (henceforth PPC) announced its financial results for the 1st Semester (S1) of 2019 (PPC 2019b). The PPC Group's EBITDA was reduced to €9.3Mil compared to €399Mil of S1 2018, despite an increase of gross income of 4.7%. This picture is also reflected in the companies of the Group that are involved in electricity generation namely PPC, S.A. which owns and operates all lignite power plants three, and Meliti Lignite S.A. (Meliti plant) and Megalopolis Lignite S.A. (which operates the two Megalopolis lignite plants, Megalopolis III and IV, and associated mines).

The picture of reduced EBITDAs and increased operating expenses is replicated in these three companies, namely down to €18.2Mil for PPC, S.A. a 95.2% reduction (compared to S1 2018), a negative €12.5Mil for Meliti Lignite S.A., down 6.8%, and a negative €28.7Mil for Megalopolis Lignite, S.A., down 11.7%.

This is due to the increase of the operating expenses by 24%. A major contributor to this was the increase of the amount paid for the purchase of EUA allowances from €129Mil in S1 2018 to €251Mil in S1 2019 even though the lignite produced electricity was down 16%, with the same amount made up by an increase in NG production which would result in an overall reduction in emissions.

At the same time, on 15 July 2019, PPC announced that the 3rd auction for the sale of the Meliti and Megalopolis lignite plants was unsuccessful (as were the previous 2 attempts) as no binding bids were tabled, indicating that the market has concluded that these facilities were not economically attractive and most likely financially non-viable. This conclusion has been reinforced recently by the analyses of The Green Tank (Mantzaris, 2019) and Carbon Tracker (Gray et al., 2019). The latter estimates that PPC would have a negative €596Mil EBITDA from its operation of the lignite plants in 2019 as would almost all EU lignite plants. The former assuming a €78/MWh electricity wholesale price and a €31/tCO₂ EUA price, estimated that the operation of the lignite plants would result in a €1,3Bil net loss in 2020.

On 27 September 2019 the Greek Government announced at the UN Climate Summit that it intends to decommission all lignite plants by 2028. This announcement is to be reflected in the final Greek NECP to be submitted to the European Commission (EC) by the end of 2019.

This decommissioning would include the Ptolemais V lignite plant with 614MW net power currently under construction and scheduled to start operation in 2021. This plant has a nominal budget of €1.39Bil of which it is estimated that about €1040Mil have already been disbursed. As this investment is sizable, both PPC and the Greek NECP Committee has started investigating alternate plans for its utilization including conversion to natural gas (NG) or other fuel, most likely biomass.

In view of these developments and the on-going work to modify the Greek NECP and hopefully increase its ambition level from 31%, to 35% RES in gross final energy consumption (GFEC) it has been judged useful to revisit the economics of the lignite plants trying to include better informed estimates for fixed and variable costs and also include in this evaluation of the viability of the lignite plants the alternate scenarios for the Ptolemais V unit.

Thus, in this note, following Mantzaris (2019), the net profit (NP) i.e. the gross income from electricity sales minus the fixed and variable O&M costs (FOM and VOM respectively) and minus the cost of allowances, is computed for 2017 and 2018. The annualized cost of capex and anti-pollution installations needed in the older plants to meet the Industrial Emissions Directive (IED) are also accounted for separately. Using the estimates for FOM and VOM, a parametric study of the influence on the prices of EUAs and NG, the load factors and the wholesale price of electricity, the net profit amounts from the yearly operation of all lignite units plus the Ptolemais V with lignite, NG and biomass is carried out to investigate fuel switching points and inform the debate on the fate of the Ptolemais V unit.

2. Lignite Plants

The lignite plants now under operation are shown in Table 1 below. One should note that the Kardia I and II units are already decommissioned (May 2019), while at the present time Megalopolis III is shut because of a Supreme Court decision that found its environmental operation conditions permits have expired. This decision also covers the Megalopolis IV plant which has continued to operate intermittently. In the same Table 1, the timetable for decommissioning of the plants now discussed in the NECP Committee of the Ministry of Environment and Energy (YPEN) for incorporation in the Greek NECP is included.

Table 1: The main specifications and status of the current Greek lignite plants

	Nominal MW	Net MW	Age (end 2018)	Efficiency	CAPEX (€/kW)	Decomm. Date as announced
Kardia I (closed 2019)	300	271	42	28.9%	1700	2019
Kardia II (closed 2019)	300	271	42	28.9%	1700	2019
Kardia III	306	280	37	30.3%	1700	2021
Kardia IV	306	280	36	30.3%	1700	2021
Megalopolis III	300	255	38	30.1%	1700	2020
Megalopolis IV	300	256	28	29.7%	1700	2028
Amyntaio I&II	600	546	31	30.2%	1700	2020
Ag. Dimitrios I	300	274	33	30.7%	1700	2023
Ag. Dimitrios II	300	274	33	30.7%	1700	2023
Ag. Dimitrios III	310	283	32	30.9%	1700	2025
Ag. Dimitrios IV	310	283	32	33.4%	1700	2025
Ag. Dimitrios V	375	342	22	34.7%	1700	2027
Meliti I	330	289	15	35.2%	1900	2028
Total	4337	3904				
Ptolemais V	660	615	Under construction	38.5-41.5%	2260	2029 or alt. fuel after

One should also note that a number of these plants are very close to the 40-year nominal lifetime of such plants (also used in the financial accounts of PPC). As the investment costs and financing schemes of the older plants are unknown, a nominal and very conservative value of €1700/kW was adopted which is the value for lignite plants used in the EC modelling exercises for the 2030 and 2050 GHG emission targets for the European Union (EU). The nominal cost values of the much newer Meliti (Koroneos et al., 2010) and the Ptolemais V under construction are known.

3. Fixed and Variable Costs

To estimate the operating and maintenance costs of the plants, the data included in the Ministerial Decrees in the scope of the NOME auctions that have taken place in 2018 (NOME 2018) and 2019 (NOME, 2019) have been utilized. Information included in the Annual and Periodic Reports of the PPC Group (PPC, 2018; PPC, 2019a; PPC, 2019b) and various other sources such as the Greek Energy Exchange (ENEX, 2019) and the monthly and annual reports of the Greek TSO (ADMIE, 2017; ADMIE 2018) have also been used.

In a number of tabulations for 2018 one should bear in mind that the Meliti and Megalopolis III & IV units have been devolved from PPC, S.A. and transferred to two new companies, Meliti Lignite S.A. and Megalopolis Lignite S.A. which are as of 1 July 2018 subsidiaries of the PPC Group and distinct from PPC S.A. The remaining plants that remain in PPC S.A. are reported under “Continuing activities” in the Group annual report of 2018 (PPC 2019a) and periodic reports of 2019 (PPC 2019b).

3.1. Electricity Production

In Table 2, the production of the lignite plants as published in the December monthly reports of the Greek TSO (ADMIE 2017, ADMIE 2018) are shown together with the associated annual GHG verified emissions as reported in the EU Transaction Log (EC, 2019a).

Table 2: Production and related GHG emissions of the Greek lignite plants for 2017-18.

Lignite Plants	Net Power (MW)	2017 (MWh)	2017 (MWh)	Verified Emissions (t/CO ₂)	EF net (tCO ₂ /MWh) 2017	2018 (MWh)	2018 (MWh)	Verified Emissions (t/CO ₂)	EF net (tCO ₂ /MWh) 2018
Ag. Dimitrios I	274	738236	6092966	8936672	1.467	827915	6062186	9226694	1.522
Ag. Dimitrios II	274	1203311				1138997			
Ag. Dimitrios III	283	1601109				464120			
Ag. Dimitrios IV	283	499992				1478466			
Ag. Dimitrios V	342	2050318				2152688			
Amyntaio I	273	873864	1805763	2751115	1.524	760892	1411206	2421059	1.716
Amyntaio II	273	931899				650314			
Kardia I	271	1113030	4052191	6797011	1.677	719666	3637169	5791829	1.592
Kardia II	271	1234655				851535			
Kardia III	280	1221386				931870			
Kardia IV	280	483120				1134098			
Megalopoli III	255	1426107	1426107	2624012	1.840	1286431	1286431	2449712	1.904
Megalopoli IV	256	1252973	1252973	2609505	2.083	1041847	1041847	2375295	2.280
Meliti	289	1757226	1757226	2273794	1.294	1468199	1468199	1879833	1.280
Total		16387226	16387226	25992109		14907038	14907038	24144422	
M & M34 2nd sem.						2399666		4340818	

The production and GHG emissions of the Meliti and Megalopolis III and IV are given in the main part of Table 2 for the full year. In the last line, their 2nd Semester production and GHG emission during which time the plants have been already transferred to their respective companies, are also provided cumulatively. In the same Table 2 the emission factors that result from the production and verified emissions are also given.

3.2. Variable O&M costs

To specify minimum prices for the NOME auctions that have been agreed between Greece and EC to enhance competition in the retail electricity market in Greece, YPER has issued three Ministerial Decrees of 4 July 2017 (NOME 2017), 21 June 2018 (NOME 2018) and 28 June 2019 (NOME 2019) in which the cost of electricity generated by the PPC lignite and hydro plants is computed. The individual components of this estimate in €/MWh and associated amounts paid are included and are presented in Table 3.

Table 3: NOME information on components of lignite generated electricity cost (the VOM value for lignite purchase refers to Meliti only)

NOME Information	2017		2018 (w/o 2nd sem. Mel & Meg 3&4)	
	€/MWh	€Mil	€/MWh	€Mil
PPC lignite production (MWh)	16386736		12507368	
CO2 emissions (ton)	25029382		19712162	
CO2 ETS future market costs (E/tCO2)	7.64		23.56	
Emission factor (tCO2/MWh)	1.53		1.576	
	€/MWh	€Mil	€/MWh	€Mil
Variable cost - Mines	15.13	247.89	18.13	226.76
Temp personnel costs		47.75		43.20
Consumables		45.88		30.13
Elect purchases		53.01		49.51
Maintenance		99.99		102.92
Contracts		1.27		1.01
Variable cost - Plants	2.94	48.21	3.18	39.77
Consumables		7.28		4.75
Temp personnel costs		3.62		3.28
Maintenance		3.66		2.44
Earth removing		2.38		0.81
Elect purchases		13.23		13.15
Ash and lignite stocks		18.04		15.35
Starting costs	2.40	39.33	2.68	33.46
Lignite Purchase *	31.32	55.04	41.26	24.77
Special lignite levy	2	32.77	2	25.01

One should note that the 2018 data refer to PPC S.A. without the Meliti and Megalopolis plants for the 2nd Semester. One should also note that in the NOME data, there is an amount for lignite purchase from the privately owned Achlada mine to cover the majority of Meliti needs. This amount is purchased by PPC S.A. only in the 1st Semester of 2018. From the 2nd Semester onward the lignite is

purchased by Meliti Lignite S.A. with an additional amount as before secured from the PPC small lignite mine (of only ca 850ha area compared to 4700ha of the nearby Amyntaio one) located nearby in the Florina township. This is reflected in the 2018 NOME data where an almost 55% difference in the purchase between 2017 and 2018 is seen. The €24.77Mil amount in the NOME data refers only to the 1st Semester purchase. In the same Table, the cost for the plants start-ups is also provided. This cost is to be added to the rest of the plant O&M costs.

In view of this anomaly, the specific value for the actual cost of fuel for Meliti shown in the same line (€31.32/MWh and €41.26/MWh) differs from the one in the original NOME tables (3.36/MWh and 1.98/MWh respectively) as the latter values result from dividing the purchase cost with the whole lignite electricity production rather than only the one of Meliti.

Utilizing the information of Table 3, representative VOM costs for future considerations for all the units have been taken to be the average values for the years 2017 and 2018 as shown in Table 3. Again for the Meliti plant, the equivalent value for the mines VOM cost utilized in lieu of fuel cost is a combination of the ones shown in Table 3 and the ones for the rest of the PPC mines taken at a 75-25% ratio of the lignite purchased to the lignite from PPC mines.

This analysis would have benefited by detailed information that would have enabled the estimation of values for plant VOM at a plant-by-plant basis; unfortunately, publicly available information from PPC does not provide enough detail to make this possible.

3.3. Fixed O&M costs

The fixed costs of both mines and lignite plants include a number of items the preponderance of which, if the original investment costs are excluded, is the labor cost of permanent personnel. The additional fixed maintenance costs could not be separated from the variable ones from the information provided in the NOME Ministerial Decrees and as a result they have been included in the VOM cost, thus leaving the labor cost as the only determinant of FOM cost. It should be mentioned that the labor cost of the PPC S.A. management is distributed to the labor cost of the operating units as they appear in the financial accounts of the Annual Report.

With this in mind, an effort was made to estimate the personnel employed by PPC by mine and plant. The breakdown of the actual headcount is not publicly available but data per Prefecture on 31 December of each year as well as the total number employed in mines and plants (not broken down by fuel used) is known (see Table 4). Furthermore, collocation of units in Kardias (units I to IV), Agios Dimitrios (units I to IV) and Amyntaio (units I and II) does not allow a clear breakdown per unit other than a simple division by the number of units. In addition, the number of employees is not constant throughout the year as 50% of the technical personnel is within five years of retirement, so the number used should be considered approximate but with a deviation of less than 5% per plant and less than 2% overall.

Table 4: PPC employees and net hiring in the lignite power stations by region (employees of Megalopolis III & IV and Meliti highlighted in yellow are not counted in the total as they are not PPC SA employees on 31Dec2018)

PPC permanent personnel	2017	2018	2018
	Total	Total	Net Hiring
Arcadia Prefecture	1311	221	-10
Megalopolis III & IV	1090	1080	
Megalopolis V (NG)	221	221	
Kozani Prefecture	3567	3309	-258
Kardia I-IV			
Ag. Dimitrios I-V			
Florina Prefecture	887	613	-34
Amyntaio I - II	647	613	
Meliti	240	240	
Total	5765	5323	
Total Mines (w/o Megalopolis III-IV in 2018)	3445	2569	

The estimate of the compensation of employees in both the mines and the plants was produced based on the total amounts included in the PPC Annual Report for the mines and plants employees. Overtime compensation is included in the VOM costs as is the compensation for non-permanent employees. Finally, the cost of social security, health and other benefits as a percentage of the salary is also derived from data included in the Annual Reports of PPC (PPC, 2018; PPC, 2019a) to be ca 30% as it varies slightly from year to year.

Table 5a: Lignite power stations FOM costs in 2017

2017	Mines				Plants			
	Employees (perm)	Fixed cost (ME/yr)	Fixed cost €/MWh	Fixed cost k€/MW (net)	Employees (perm)	Fixed cost (ME/yr)	Fixed cost €/MWh	Fixed cost k€/MW (net)
Ag. Dimitrios I	235	13.5	6.3	49.2	105	5.64	2.64	20.57
Ag. Dimitrios II	235	13.5	6.3	49.2	105	5.64	2.64	20.57
Ag. Dimitrios III	235	13.5	6.1	47.6	105	5.64	2.55	19.92
Ag. Dimitrios IV	235	13.5	6.1	47.6	105	5.64	2.55	19.92
Ag. Dimitrios V	350	20.1	7.5	58.7	200	10.74	4.03	31.40
Amyntaio I	176	10.1	4.7	37.0	146	7.84	3.68	28.71
Amyntaio II	176	10.1	4.7	37.0	146	7.84	3.68	28.71
Kardia I	230	13.2	6.2	48.7	105	5.64	2.67	20.80
Kardia II	230	13.2	6.2	48.7	105	5.64	2.67	20.80
Kardia III	230	13.2	6.0	47.1	105	5.64	2.58	20.13
Kardia IV	230	13.2	6.0	47.1	105	5.64	2.58	20.13
Megalopoli III	430	24.7	12.4	96.7	125	6.71	3.37	26.32
Megalopoli IV	430	24.7	12.3	96.3	125	6.71	3.36	26.22
Meliti	30	1.7	0.8	6.0	210	11.27	5.00	39.01
Total	3452	197.9			1792	96.2		

Table 5b: Lignite power stations FOM costs in 2018

2018	Mines				Plants			
	Employees (perm)	Fixed cost (ME/yr)	Fixed cost €/MWh	Fixed cost k€/MW (net)	Employees (perm)	Fixed cost (ME/yr)	Fixed cost €/MWh	Fixed cost k€/MW (net)
Ag. Dimitrios I	225	12.69	5.94	46.33	97.00	5.21	2.44	19.01
Ag. Dimitrios II	225	12.69	5.94	46.33	97.00	5.21	2.44	19.01
Ag. Dimitrios III	225	12.69	5.75	44.86	97.00	5.21	2.36	18.40
Ag. Dimitrios IV	225	12.69	5.75	44.86	97.00	5.21	2.36	18.40
Ag. Dimitrios V	350	19.75	7.40	57.74	200.00	10.74	4.03	31.40
Amyntaio I	176	9.93	4.66	36.37	146.00	7.84	3.68	28.71
Amyntaio II	176	9.93	4.66	36.37	146.00	7.84	3.68	28.71
Kardia I	228	12.86	6.09	47.47	88.00	4.72	2.24	17.43
Kardia II	228	12.86	6.09	47.47	88.00	4.72	2.24	17.43
Kardia III	228	12.86	5.89	45.94	88.00	4.72	2.16	16.87
Kardia IV	228	12.86	5.89	45.94	88.00	4.72	2.16	16.87
Megalopoli III	425	23.98	12.06	94.03	125.00	6.71	3.37	26.32
Megalopoli IV	425	23.98	12.01	93.67	125.00	6.71	3.36	26.22
Meliti	30	1.69	0.75	5.86	210.00	11.27	5.00	39.01
Total	3394	191.5			1692	92.4		

Based on the above, in Tables 5a and 5b, the FOM cost per MWh, computed using 7800hr at full net power operation a year which is the typical amount of hours of nominal availability of lignite plants and is also in the design specifications for Ptolemais V (Stamatiou, 2015), are shown.

Table 6: Lignite and NG Power Stations specifications and O&M costs

Lignite units	Net Power (MW)	Investment cost (€/kW)	Efficiency (%)	CO2 EF (t CO2/MWh)	FC-Mines (€/MWh)	FC Plants (€/MWh)	VOM-Mines (€/MWh)	VOM Plants (€/MWh)	Life time (yr)
Ag. Dimitrios I	274	1700	0.307	1.465	6.12	2.44	16.52	5.6	40
Ag. Dimitrios II	274	1700	0.307	1.465	6.12	2.44	16.52	5.6	40
Ag. Dimitrios III	283	1700	0.309	1.465	5.93	2.36	16.41	5.6	40
Ag. Dimitrios IV	283	1700	0.334	1.465	5.93	2.36	15.18	5.6	40
Ag. Dimitrios V	342	1700	0.391	1.465	7.46	4.03	14.61	5.6	40
Amyntaio	546	1700	0.302	1.523	4.70	3.68	16.79	5.6	40
Kardia I	271	1700	0.789	1.579	6.16	2.45	17.55	5.6	40
Kardia II	271	1700	0.289	1.579	6.16	2.45	17.55	5.6	40
Kardia III	280	1700	0.303	1.579	5.96	2.37	16.74	5.6	40
Kardia IV	280	1700	0.303	1.579	5.96	2.37	16.74	5.6	40
Megalopoli III	255	1700	0.301	1.84	12.22	3.37	16.85	5.6	40
Megalopoli IV	256	1700	0.297	2.083	12.18	3.36	17.07	5.6	40
Meliti	289	1900	0.324	1.294	0.76	5.00	30.85	5.6	40
Ptolemais V	614	2264	0.4	1.116	5.5	3.1	12.68	4.5	40
Ptolemais V BM	614	2590	0.39	0.02	0	3.1	77	4.94	40
NG Units	Net Power (MW)	Investment cost (€/kW)	Efficiency (%)	CO2 EF (t CO2/MWh)	FC-Mines (€/MWh)	FC Plants (€/MWh)	Fuel cost (€/MWh)	VOM Plants (€/MWh)	Life time (yr)
Ptolemais V NG	614	1792	0.61	0.418	NA	1.86	35.48	2	30
Mytilinaios	804	615	0.61	0.418	NA	1.86	35.48	2	30

Given the interest on the future of the lignite plants and the timing of their decommissioning, it is useful to choose typical values of the O&M parameters for all plants to be used in estimates of their

financial performance under expected economic and demand needs in the next decade. Taking into account the values of Tables 5a and 5b, the operative values for FOM and VOM costs to be used are given in Table 6. It should be pointed out that the plant VOM values are the same for all units (except the Meliti one with its dependence on purchased lignite), as is the wholesale price per MWh they will be receiving for their production.

In Table 6, the mines' VOM costs of individual plants which are directly related to the amount of lignite consumed, have been derived from the NOME values weighed by their respective efficiency relative to the average of the efficiency of all plants so as to reflect the specific lignite use of each plant.

3.4. Anti-pollution Installation Costs

In a recent study (WWF, 2017), the air pollution emission rates of the lignite plants of Greece have been shown (see Table 7 below) to not meet the IED limits even before the recently adopted more stringent emission limit values (ELV) of new BREFs (75mg/Nm³, 85mg/Nm³ and 5mg/Nm³ for SO₂, NO_x and TSP respectively) which are half of the current ones.

Table 7: Emission rates of SO_x, NO_x and TSPs as estimated in the 2017 Long-term Planning of the Greek electricity System WWF Report

Power Station	SO ₂ Emissions (mg/Nm ³)				NO _x Emissions (mg/Nm ³)				PM Emissions (mg/Nm ³)			
	2013	2014	2015	M.O.	2013	2014	2015	M.O.	2013	2014	2015	M.O.
Kardia I	244	75	115	144,7	326	320	288	311,3	313	253	309	291,7
Kardia II	283	65	185	177,7	284	331	280	298,3	290	421	225	312
Kardia III	305	175	244	241,3	339	336	301	325,3	34	76	49	53
Kardia IV	374	158	170	234	344	360	287	330,3	37	66	50	51
Amyntaio I & II	1144	575	1255	991,3	192,5	194,5	229,5	205,5	25,1	26,8	68,8	40,2
Ag. Dimitrios I & ii	414,9	444,2	313,4	390,8	394,5	333,3	348,3	358,7	20,5	11,7	26,9	19,7
Ag. Dimitrios V	635,6	639	360,9	545,1	363,8	348,6	361,2	364,5	7,9	6,2	9,2	7,8
Ag. Dimitrios III & iV	777,5	512,1	984,5	758	322,3	315,3	302,8	313,5	18,9	10,5	29,3	19,6
Meliti I	108	90,5	121,6	106,7	143	167,7	118	142,9	4,3	2,9	2	3,1
Megalopolis IV	279	151	223,9	218	130	137	114	127	4	5,2	2,6	3,9
Megalopolis III	343	237	194,9	258,3	269	172,3	186	209,1	13,5	9,6	10,1	11,1
Ptolemais V				150				200				10

In the same study an estimation was included of the investment amount needed to bring the lignite plants into compliance together with the O&M costs as percentages of the capex amounts. These are shown in Table 8 below.

Table 8: PPC anti-pollution installation costs as estimated in the 2017 Long-term Planning of the Greek electricity System WWF Report (WWF, 2017)

Lignite Plants	Net Power (MW)	Invest cost (€Mil)				O&M (k€/yr)			
		NOx	SOx	TSP	Total	NOx	SOx	TSP	Total
Ag. Dimitrios I	274	13.7	10.96	4.11	28.77	986	855	164	2006
Ag. Dimitrios II	274	13.7	10.96	4.11	28.77	986	855	164	2006
Ag. Dimitrios III	283	14.15	11.32		25.47	1019	883	0	1902
Ag. Dimitrios IV	283	14.15	11.32		25.47	1019	883	0	1902
Ag. Dimitrios V	342	17.1	119.7	5.13	141.9	1231	5865	205	7302
Amyntaio	546	27.3	131	75	233.3	1583	6419	3000	11002
Kardia I	271				0	0	0	0	0
Kardia II	271				0	0	0	0	0
Kardia III	280				0	0	0	0	0
Kardia IV	280				0	0	0	0	0
Megalopoli III	255				0	0	0	0	0
Megalopoli IV	256	12.8	17.92		30.72	806	878	0	1684
Meliti	289				0	0		0	0

Note that no estimates are provided for the Kardia I – IV units and the Megalopolis III units mainly because due to their age the assumption is made that it would be financially better to decommission these units rather than invest further to upgrade their environmental performance to the point that they could meet the new ELVs. The Meliti unit air pollution performance is considered marginally passable, although it does not meet the new ELVs to which it has to be compliant by 2021.

At the same time, from the PPC periodic and annual reports, the following amounts shown in Table 9 have been contracted or put out for bids for anti-pollution installations in the Ag. Dimitrios units.

Table 9: PPC anti-pollution installation actual contracts or calls for bids for the lignite plants

Known PPC Contracts 2018 (€Mil)				
	NOx	SOx	TSP	Total
Ag. Dimitrios I	6			6
Ag. Dimitrios II	6			6
Ag. Dimitrios III	14.15	48.75		62.9
Ag. Dimitrios IV	14.15	48.75		62.9
Ag. Dimitrios V	15	65		80
Total	55.3	162.5	0	217.8

The total values of Table 9 do not differ substantially from the respective ones of Table 8 for the Ag. Dimitrios units (€217.8Mil vs €250.4Mil) yet as they are the actual ones, they will be utilized to estimate the anti-pollution fixed and variable costs for these 5 plants.

At the same time, if a 40-year lifetime is assumed for all plants at which time they will decommissioned, the years for computing O&M and annual costs of the investment would be the difference between the present age of each plant and the 40-year limit. In accordance with this, no investments for environmental upgrading should be made in the four Kardias I-IV units. The same holds for Megalopolis III.

Table 10: PPC anti-pollution installation O&M and annualized investment costs based on actual contracts or calls for bids for the lignite plants and years left to 40 age.

Anti-pollution costs	Life time (yr left)	O&M (€/MWh)	Annualized invest (k€/yr)
Ag. Dimitrios I	7	0.20	5154
Ag. Dimitrios II	7	0.20	5154
Ag. Dimitrios III	8	2.19	4102
Ag. Dimitrios IV	8	2.19	4102
Ag. Dimitrios V	18	1.60	13108
Amyntaio	9	2.58	34300
Kardia I	0	0	0
Kardia II	0	0	0
Kardia III	0	0	0
Kardia IV	0	0	0
Megalopoli III	0	0	0
Megalopoli IV	11	0.84	3895
Meliti	25	1.10	0

4. Results for 2018

Utilizing the information above, an estimate of the profit (loss) of the operation of the lignite plants has been carried out for 2018. To accomplish this, the cost of EUA prices, the wholesale electricity price in the Greek energy exchange, the tax rate and the discount rate need to be specified.

4.1. Income

In Table 11, the monthly electricity system clearing prices are shown (EnEX, 2019).

Table 11: Wholesale electricity clearing prices, Greek Energy Exchange

Greek Energy Exchange		
Monthly mean values 2018 (€/MWh)		
	Marginal price	Clearing price
Jan	53.5	54.99
Feb	51.63	52.82
Mar	44.28	51.44
Apr	50.35	53.47
May	56.32	57.37
Jun	60.69	61.07
Jul	64.42	65.2
Aug	63.83	64.52
Sept	67.06	68.43
Oct	71.4	71.74
Nov	69.3	71.22
Dec	71.25	73.08
Yearly average	60.34	62.11

In addition to this electricity market remuneration, plants are compensated for balancing and auxiliary services and capacity credit. In Table 12 (Mourtzikou, 2019), these additional payments are shown.

Table 12: Average payment schedule for electricity in the Greek wholesale market

wholesale costs (€/MWh)	2017	2018
Deviation	-0.67	-0.72
Clearing Price (OTA)	57	61.71
Deviation acc Aux. services (ΛΑ2&3)	3.52	4.3
Capacity credit (ΜΔΕΙ)	1.05	0.72
Marginal price RES depression (ΠΧΕΦΕΛ)	7.97	4.84
Total Wholesale price c	68.87	70.85

As of the costs shown in Table 12 only the clearing price and the so-called deviation for auxiliary services and balancing are paid to the producers, the payments for the production of all plants shown in Table 2 for 2018 have been computed (month by month) and are shown in Table 13.

Table 13: Yearly income of the PPC lignite plants from sale of electricity in the Hellenic Energy Exchange (EnEX, 2019) in 2018.

2018 Income from mandatory pool (k€)		
	With Clearing Price	Plus additional services
Ag. Dimitrios I	49397	52957
Ag. Dimitrios II	72622	77519
Ag. Dimitrios III	27930	29926
Ag. Dimitrios IV	93021	99379
Ag. Dimitrios V	134393	143649
Amyntaio	88899	93582
Kardia I	46658	49753
Kardia II	52006	55668
Kardia III	59895	63903
Kardia IV	69168	74045
Megalopoli III	80578	86110
Megalopoli IV	68946	73425
Meliti	93462	99775

In Table 13, the column labelled “Plus additional services” is the result of adding €4.3/MWh to the clearing price to account for the balancing and other auxiliary service remuneration plus capacity credit minus the deviations penalty (see Table 12), uniformly applied to all units.

4.2. EUA allowance purchase costs

The mean spot price of allowances in 2018 was €15.89/tCO₂. PPC, through judicious prior purchases, paid €11.93/tCO₂ for the allowances it required to cover its emissions in 2018 (PPC, 2019a). It should also be noted that the 2018 futures prices (EEX EUA Future Dec-2018) as stated in the NOME Ministerial Decision that is applicable for 2018 are substantially lower at €7.64/tCO₂eq (NOME 2018). The actual mean allowance value in 2018 was €15.89/tCO₂ with the respective futures value for 2019 (EEX EUA Future Dec-2019) applicable in 2019 much higher at €23.56/tCO₂eq (NOME 2019).

4.3. Cost of capital

PPC is called to cover beyond its FOM and VOM costs, its capital expenditure through loans for the construction costs of its power plants. The nominal prices are given in Table 1. As mentioned earlier, the cost is annualized assuming a lifetime of 40 years for the lignite units and 30 years for the NG ones. At the same time, a tax benefit is accrued for amortization at the current rate of 28% (to be reduced to 24% starting in 2020). The discount rate chosen for the annualization is 6% which is a widely used rate for large energy investments. This is also the rate used in the Ptolemais V design considerations (Stamatiou, 2015).

4.4. Results

In Table 14 the results of the operation of the lignite plants are shown. To provide a comparison with a period with much lower EUA prices, results for 2017 were also computed and shown in Table 14a.

Looking at Table 14a, it is clear that the lignite plants produced an operating profit in 2017 when the EUA allowance prices were still low. The cost of allowances in 2017 at €5.71/tCO₂ as paid by PPC was €148.4Mil and the lignite plants showed an operating profit of €124.4Mil. These figures would have been €162.8Mil and €109.8Mil respectively if PPC had paid the EUA average auction price of €6.27/tCO₂

Table 14a: 2017 Financial results for all the PPC lignite plants

2017	Net Power (MW)	Load factor	Production 2018 (MWh)	Cost O&M plus levy(k€/yr)	Income (k€/yr)	Carbon cost (k€/y)	Profit (k€/yr)	Additional Anti poll Loss (k€/yr)	Profit after anti-pol (k€/yr)	Invest Cost (k€/yr)	Profit after anti-poll and invest cost (k€/yr)
Ag. Dimitrios I	274	0.308	738236	37957	44811	6790	64	1242	-1178	22290	-23468
Ag. Dimitrios II	274	0.501	1203311	48320	73041	10080	14641	1305	13336	22290	-8953
Ag. Dimitrios III	283	0.646	1601109	57278	97187	13412	26497	11143	15354	23022	-7668
Ag. Dimitrios IV	283	0.202	499992	33243	30350	4188	-7081	13360	-20441	23022	-43463
Ag. Dimitrios V	342	0.684	2050318	88614	124454	17175	18665	10832	7834	27821	-19988
Amyntaio	546	0.377	1805763	79880	109610	15714	14016	0	14016	44417	-30401
Kardia I	271	0.469	1113030	44884	67561	10658	12019	0	12019	0	12019
Kardia II	271	0.520	1234655	47488	74944	11823	15633	0	15633	0	15633
Kardia III	280	0.498	1221386	48024	74138	11696	14419	0	14419	0	14419
Kardia IV	280	0.197	483120	31669	29325	4626	-6970	0	-6970	0	-6970
Megalopoli III	255	0.638	1426107	66589	86565	14983	4992	0	4992	0	4992
Megalopoli IV	256	0.559	1252973	62429	76055	14903	-1276	4774	-6051	20825	-26876
Meliti	289	0.694	1757226	75505	106664	12984	18174	1615	16559	26276	-9716
Total			16387226	721880	994705	149031	123794	44272	79522	209962	-130440

As can be seen in Table 14b, this is not the case in 2018 during which there was a threefold increase in allowance price.

Table 14b: 2018 Financial results for all the PPC lignite plants

2018	Net Power (MW)	Load factor	Production 2018 (MWh)	Cost O&M plus levy(k€/yr)	Income (k€/yr)	Carbon cost (k€/y)	Profit (k€/yr)	Additional Anti poll Loss (k€/yr)	Profit after anti-pol (k€/yr)	Invest Cost (k€/yr)	Profit after anti-poll and invest cost (k€/yr)
Ag. Dimitrios I	274	0.345	827915	41446	52957	14907	-3396	1242	-4638	22290	-26928
Ag. Dimitrios II	274	0.475	1138997	49461	77519	20508	7550	1305	6245	22290	-16045
Ag. Dimitrios III	283	0.187	464120	32120	29926	8357	-10551	11143	-21695	23022	-44716
Ag. Dimitrios IV	283	0.596	1478466	60531	99379	26620	12228	13360	-1132	23022	-24154
Ag. Dimitrios V	342	0.719	2152688	100265	143649	38760	4624	10832	-6208	27821	-34029
Amyntaio	546	0.295	1411206	75856	94967	28648	-9537	0	-9537	44417	-53953
Kardia I	271	0.303	719666	37552	49753	13554	-1353	0	-1353	0	-1353
Kardia II	271	0.359	851535	40812	55668	16037	-1181	0	-1181	0	-1181
Kardia III	280	0.380	931870	43539	63903	17550	2814	0	2814	0	2814
Kardia IV	280	0.462	1134098	48570	74045	21359	4116	0	4116	0	4116
Megalopoli III	255	0.576	1286431	67154	86110	28976	-10020	0	-10020	0	-10020
Megalopoli IV	256	0.465	1041847	60702	73425	28101	-15377	4774	-20152	20825	-40977
Meliti	289	0.580	1468199	76767	99775	22232	777	1615	-839	26276	-27114
Total			14907038	734774	1001075	285608	-19307	44272	-63579	209962	-273540

Of all the plants, only two, Meliti and Ag. Dimitrios V which are the latest and most efficient operated at load factors above 50%. Three Ag. Dimitrios units (II, IV and V) generated a profit in 2018 which turned into loss after investment costs are factored in. The same holds for Meliti. The Kardia III and IV plants are the only ones that produced profit overall only because the initial investment is already paid off.

Overall, in 2018, the lignite plants had a loss of €19,4Mil. This turns into a large loss if anti-pollution costs (€44Mil) and nominal loan repayment expenses (€210Mil) are taken into account. The cost of EUA allowances reached €285Mil. If the actual mean value of €15.89/tCO₂ for the EUA allowance price were used instead of the €11.93/tCO₂, actually paid, the amount needed to cover it would increase to €371.6Mil and the O&M loss would reach €117.3Mil with only the Ag. Dimitrios II, IV and V units showing profit. No anti-pollution costs have been included for Amyntaio as no such expenses occurred as no contracts have been proclaimed open for bids.

The comparison of the two years makes evident the effect of the allowance price increase. If in 2018 the price paid by PPC were that of 2017 (i.e. €5.71/tCO₂ as opposed to €11.93/tCO₂ actually paid) the operating loss of €19.3Mil would have turned into a profit of €128.5Mil for the same production.

5. Ptolemais V

On 9 March 2013, PPC S.A. signed a contract for a new lignite unit in the Ptolemais valley (Ptolemais V) of 660MW nominal and 614MW net power rating (plus 140MW_{th} for district heating of the Ptolemais Municipality). The nominal cost of the new unit is €1.39Bil or €2264/kW. The unit is designed to consume 291.6ton/s or 1.71ton/MW_{el} of lignite with a nominal new efficiency of 41.5%. The construction started in 2015 with the plant scheduled now to start operation in 2021. Estimates of disbursements including advance payment till now reach €1041Mil.

In view of the large increases in the EU allowance prices in the last year, the economic viability of Ptolemais V has been brought into question. After the September 2019 announcement that delignitization in Greece will be accelerated with a target to be complete by 2028, the fate of Ptolemais V is now actively investigated by PPC. Possible alternatives under examination include its conversion to NG and even to other alternate fuels such as biomass/biogas. It is therefore of interest to utilize the approach already followed for the rest of the lignite plants also to Ptolemais V in 3 different configurations namely (i) using lignite as originally designed, (ii) using NG and (iii) using biomass.

In relation to the 2nd option, the new NG CCGT unit of 826MW nominal power and 63.1% efficiency (new and clean) of the Mytilinaios Group whose construction just started (3 October 2019), will also be included. Even though typical costs for CCGT NG units are of the order of 600-720k€/MW (ASSET, 2016, Aurora 2019) Mytilinaios Group claims that the cost will be of the order of €300Mil only (ca 375k€/MW) possibly because of its collocation with their other two NG units in Ag. Georgios, Euboea, Greece which would result in considerable saving in infrastructure costs.

The conversion of Ptolemais V to NG would possibly require an expenditure of an additional €50Mil of costs beyond the ones already incurred - €1.04Bil as of 31 Dec 2018 (PPC 2019a) - bringing the total to about €1.1Bil. It would also require the construction of the NG pipeline from the nearest point of the high-pressure NG Greek network, a length estimated at ca 100km.

The conversion to biomass may be technically simpler but it would still require additional modifications of about €200Mil bringing the total cost to €1.6Bil. This is in line with the costs of the conversion of the 645MW unit at Drax, UK (Drax, 2016).

For the analysis of both conversions to NG and biomass, an estimate of the fuel cost is required. The NG prices have stayed lately around €22/MWh_{th} and are expected to remain at these levels (€22-25/MWh_{th}) for the next few years.

The cost of biomass on the other hand varies considerably with the location and the transportation and storage costs. In the recent study (Stamatiou, 2015) for a possible co-firing of a 645MW nominal lignite plant the cost of the available biomass from the West Macedonia and neighboring (Thessaly and Central Macedonia) regions is estimated at €35/ton, with additional costs of about €0.5/ton for transport, €19.5/ton for transformation into pellets and an additional €1.0./ton for storage, which would lead to a cost with a 39% plant efficiency to between €41.62/MWh_{el} and €51.95/MWh_{el} depending on the means of harvesting and handling the biomass.

Besides straw, wood pellets from the international market could also be used. The cost of such pellets according to the Drax conversion notification to the EC is 8.94UKP/GJ which corresponds to €35.81/MWh_{th} at a €1.1/UKP exchange rate. Typical prices in the European open market range at about €260/ton (with LHV around 18MJ/kg and about 8% humidity) with local Greek market prices in the range €175 to €250/MWh_{th} (Alpha Woods, 2019). These would translate to about €86.37/MWh_{el} for the Drax price (which is based on their building their own pellet facility in the US) and to €77-110/MWh_{el} for open market wood pellets.

Based on the above, in Table 15, the basic specifications of the three possible versions of operation of the Ptolemais V unit together with the Mytilinaios NG plant under construction - adopted for both comparison and parametric studies of cost variables - are shown. It should be noted that the CAPEX for the Mytilinaios plant is set at €400/kW which is 10% higher than what the company has announced but 33% below the current green field typical rates for EU NG plants. Similarly, the biomass fuel cost has been set at €77/MWh_{el}, that is at the low end of the market wood pellets, as there is considerable uncertainty whether enough straw is available for combustion in the Ptolemais V plant from the neighbouring (ca 200km radius) agricultural areas.

Lately, a fourth configuration for Ptolemais V which would utilize solid recovered fuel (SRF) from solid waste installations nationwide, has been proposed but is not considered here as the logistics and stockpiling aspects involved require a separate analysis.

It should be noted that the FOM cost of the Ptolemais V unit in its NG configuration and that of the Mytilinaios plant have been adjusted to agree with that of the Megalopolis V NG plant (€1.86/MWh).

Table 15: Ptolemais V configuration specifications and O&M costs

	Net Power (MW)	Invest cost(€/kW)	Efficiency (%)	Life time (yr)	CO2 EF (t CO2/MWh)	FC-Mines (€/MWh)	FC Plants (€/MWh)	VOM-Mines (€/MWh)	VOM Plants (€/MWh)
Ptolemais V Lignite	614	2264	0.41	40	1.116	5.95	3.1	13.71	4.5
	Net Power (MW)	Invest cost(€/kW)	Efficiency (%)	Life time (yr)	CO2 EF (t CO2/MWh)	FC Mines (€/MWh)	FOC Plants (€/MWh)	Fuel cost (€/MWh)	VOC Plants (€/MWh)
Ptolemais V Biomass	614	2590	0.39	40	0.02	NA	3.6	77.00	4.94
Ptolemais V NG	615	1789	0.62	30	0.418	NA	1.86	35.48	2
Mytilinaios NG	804	400	0.62	30	0.418	NA	1.86	35.48	2

With these parameters for the operation of the Ptolemais V plant in its three different configurations, it is of interest to see how this plant together with the Mytilinaios plant would fare with 2018 actual load factors for the lignite and biomass configuration at 70% similar to those of Ag. Dimitrios V (72%) and Meliti (59%) and the NG configuration and the Mytilinaios plant operating at 50% again similar to the other NG plants. The results are shown in Table 16.

Table 16 brings out the fact that at 2018 prices of fuel and at ETS allowance prices of only €11.93/tCO₂ as paid by PPC, Ptolemais V with lignite would have been profitable. The biomass configuration cannot even cover its O&M costs which are more than double those of the lignite version because of the very high biomass price. This differential cannot be counterbalanced by the savings of the ETS allowance cost.

Table 16: Financial results for 2018 of all the PPC lignite plants plus the three configuration of Ptolemais V and the new Mytilinaios NG unit.

2018	Net Power (MW)	Load factor	Production 2018 (MWh)	Cost O&M plus levy(k€/yr)	Income (k€/yr)	Carbon cost (k€/y)	Profit (k€/yr)	Additional Anti poll Loss (k€/yr)	Profit after anti-pol (k€/yr)	Invest Cost (k€/yr)	Profit after anti-poll and invest cost (k€/yr)
Ag. Dimitrios I	274	0.345	827915	41446	52957	14907	-3396	1242	-4638	22290	-26928
Ag. Dimitrios II	274	0.475	1138997	49461	77519	20508	7550	1305	6245	22290	-16045
Ag. Dimitrios III	283	0.187	464120	32120	29926	8357	-10551	11143	-21695	23022	-44716
Ag. Dimitrios IV	283	0.596	1478466	60531	99379	26620	12228	13360	-1132	23022	-24154
Ag. Dimitrios V	342	0.719	2152688	100265	143649	38760	4624	10832	-6208	27821	-34029
Amyntaio	546	0.295	1411206	75856	94967	28648	-9537	0	-9537	44417	-53953
Kardia I	271	0.303	719666	37552	49753	13554	-1353	0	-1353	0	-1353
Kardia II	271	0.359	851535	40812	56668	16037	-1181	0	-1181	0	-1181
Kardia III	280	0.380	931870	43539	63903	17550	2814	0	2814	0	2814
Kardia IV	280	0.462	1134098	48570	74045	21359	4116	0	4116	0	4116
Megalopoli III	255	0.576	1286431	67154	86110	28976	-10020	0	-10020	0	-10020
Megalopoli IV	256	0.465	1041847	60702	73425	28101	-15377	4774	-20152	20825	-40977
Meliti	289	0.580	1468199	76767	99775	22232	777	1671	-894	26276	-27170
Total			14907038	734774	1001075	285608	-19307	44328	-63635	209962	-273596
Ptolemais V Lignite	615.7	0.700	3775472	112098	249219	50266	86855	4153	82702	66703	15999
Ptolemais V Biomass	615.7	0.700	3775472	324243	249219	901	-75925	3775	-79700	76308	-156009
Ptolemais V NG	615.7	0.500	2696766	116756	178014	13448	47810	1347	46463	57603	-11140
Mytilinaios NG (€615/kW)	804	0.500	3521520	152463	232456	17561	62432	1761	60671	25864	34807
Mytilinaios NG (€400/kW)	804	0.500	3521520	152463	232456	17561	62432	1761	60671	16822	43849

The comparison of the NG version with that of the new Mytilinaios unit clearly shows the effects of the threefold capex cost disadvantage of Ptolemais V in this configuration. Increases in the ETS allowance price to current levels (ca. €25/tCO₂) would make Ptolemais V in its lignite configuration able to meet its operational and but not loan repayment costs and would not change its relative position vis-a-vis other NG plants but they will further depress the financial performance of the lignite configuration.

6. Typical Future Performance

To inform the on-going discussion on the future of Ptolemais V and the 2028 deadline for decommissioning of the lignite plants as well as the changes in the Greek NECP to reflect the Government announcements of increases of RES to 35% on Gross Final energy Consumption (GFEC), it would be instructive to use the results and insights of the financial parameters of the lignite plants presented above, to examine the benefits of early decommissioning in accordance with the tentative schedule of the reformulated NECP and gage the amount of stranded investment in relation to operating savings.

To this end, a Reference scenario of the basic parameters that affect the economics of the lignite power plants is constructed that assumes that for the next ten years or so, no substantial deviations of the basic parameters from their current levels would occur. Thus, in this scenario, the wholesale price would increase slightly from its current level of €68/MWh to about €70/MWh, the EUA allowance market prices would increase to €25/tCO₂ and earlier hedging reserves of PPC would be depleted (its current reserve on 31 Dec 2018 amounts to 7.69Mil allowances, worth €177.73Bil). This is the average value around which a number of analyses converge in the 2020-2030 period (Marcu et al., 2019). At the same time, NG prices continue at around today's low prices of €22/MWh_{th}. It further considers that the lignite plants would seek to increase their load factor from their current levels of ca 45% to 65% and this so as to decrease starting costs, but also to cover the production capacity loss in view of early decommissioning of some units (for example Kardias).

In this scenario, Ptolemais V in its lignite and biomass configuration is assumed to operate at 70%, similar to current Ag. Dimitrios V levels, while in its NG configuration at 50% as will the new Mytilinaios NG unit. A similar approach has been utilized recently to examine the risk of new coal plant investments in Japan (Takizawa and Okubo, 2019).

The O&M costs and technical characteristics of the plants are taken as those in Table 6.

A sensitivity of the results to the basics parameters of EUA allowance and wholesale price, loading factor and fuel costs is also carried out and is presented in the next Section.

Table 17: Yearly profit from the operation of the lignite plants, Prolemas V in its three configurations and the Mytilinaios NG unit, under the Reference scenario parameters

	w/o investment and anti-pollution costs					with investment and anti-pollution costs						
	Profit (k€/yr)	Profit (€/MWh)	FOM %	VOM %	CO2 %	Profit (k€/yr)	Profit (k€/MWh)	FOM %	VOM %	CO2 %	Anti-Poll %	Invest cost %
Lignite Units												
Ag. Dimitrios I	-4468	-5.05	20%	30%	50%	-29128	-22.81	28%	24%	40%	-11%	19%
Ag. Dimitrios II	-4468	-5.05	20%	30%	50%	-29128	-22.81	28%	24%	40%	-11%	19%
Ag. Dimitrios III	-3801	-4.48	19%	30%	50%	-39321	-29.23	31%	23%	38%	-9%	17%
Ag. Dimitrios IV	-2038	-3.11	20%	29%	51%	-37558	-27.87	31%	22%	38%	-8%	18%
Ag. Dimitrios V	-11416	-6.38	26%	26%	48%	-49513	-28.35	41%	21%	37%	-16%	17%
Amyntaio	-13520	-6.75	19%	30%	51%	-94508	-36.01	35%	22%	37%	-10%	16%
Kardia I	-9616	-8.95	19%	30%	51%	-9616	-8.95	21%	30%	51%	-24%	22%
Kardia II	-9616	-8.95	19%	30%	51%	-9616	-8.95	21%	30%	51%	-24%	22%
Kardia III	-8128	-7.59	18%	29%	52%	-8128	-7.59	20%	29%	52%	-24%	22%
Kardia IV	-8128	-7.71	18%	29%	52%	-8128	-7.71	20%	29%	52%	-24%	22%
Megalopoli III	-32459	-26.98	28%	24%	48%	-32459	-26.98	38%	24%	48%	-28%	18%
Megalopoli IV	-40631	-33.20	26%	22%	51%	-66804	-53.37	53%	19%	43%	-29%	14%
Meliti	-12805	-8.74	13%	46%	41%	-42351	-28.90	20%	37%	33%	-9%	19%
Ptolemas V	34480	14.73	23%	30%	47%	-39580	-7.36	28%	22%	34%	-10%	26%
Ptolemas V BM	-61067	-18.22	7%	93%	1%	-144889	-43.22	13%	72%	0%	-7%	21%
NG Units												
Ptolemas V NG	43940.91	18.35	7%	73%	20%	-18560	-7.75	8%	48%	13%	-3%	33%
Mytilinaios (€615/kW)	57538.26	18.35	7%	73%	20%	27949	8.91	6%	61%	17%	1%	14%
Mytilinaios (€400/kW)	57538.26	18.35	7%	73%	20%	37493	11.96	6%	65%	18%	2%	10%

Looking at the results of the Reference case, it becomes clear (Table 17) that under these conditions none of the operating lignite plants are financially viable, as they cannot even cover their O&M costs, let alone their capital cost repayments. Ptolemas V under its lignite configuration is the only lignite plant that can cover its O&M costs but clearly not its capital cost repayments. The plants with the highest losses are the two Megalopolis units. This is mostly due to their high GHG emission factors and FOM costs of the units themselves, coupled with high lignite costs because of higher employee count in their mines. As a result, they have the highest loss per MWh produced. The next highest are the older Kardia I and II units which also have high emission factors and low efficiencies which though have already ceased operation. All the NG plants including the Ptolemas V NG configuration show a clear overall profit.

In Table 17, the difference between the contributions of costs between lignite and NG plants is clearly shown as is the large difference of the EUA allowance costs which for the lignite plants is the dominant contributor (41%-52%). Of note is also the high cost for the Amyntaio plant for anti-pollution which is almost double that of the others. Here it should be mentioned that for the four Kardia units and Megalopolis III, no anti-pollution cost is shown because as these units are very near or over the 40-year limit and as a consequence are at or very near retirement, additional investment is improbable. All five units are scheduled to be decommissioned in the next 2-3 years with the Kardia I and II ones already shut as of April 2019. For this reason, capital cost repayments are also not included on the premise that the loans have already been repaid.

7. Sensitivity Analysis

As the main parameters that determine the profit of the power plants under consideration are the cost of the EUA allowances and the wholesale electricity price, it is important to examine the effect of their variation around the values of the Reference case. At the same time, as the absolute values and the relation between FOM and VOM costs depend on the production, this sensitivity analysis also includes variations of the load factor. Finally, for the NG plants, for which the cost of fuel is responsible for almost 75% of the O&M cost, the effect of changes of the NG price is examined as well. For the biomass configuration of Ptolemais V, the effect of the cost of biomass is similarly examined. The results are given in Tables 18-21.

Looking first at the effect of the EUA price (Table 18), one sees that at €20/tCO₂, all lignite units except Megalopolis but including Ptolemais V cover their O&M costs but not their loan repayment obligations (except Kardia whose capital investment is already paid of), but show losses at €25/tCO₂. All NG units are profitable even when loan repayments are included, except for the Ptolemais V unit above €35/tCO₂. The biomass configuration of Ptolemais V is not affected by the EUA price but is always at the loss column.

Table 18: EUA allowance prices sensitivity

EUA allowance price (€/tCO ₂)	40	35	30	25	20	40	35	30	25	20
Lignite Units	Profil (k€) w/o investment costs					Profil (k€) with investment costs				
Ag. Dimitrios I	-37549	-24819	-14643	-4468	5708	-62209	-52033	-39304	-29128	-18952
Ag. Dimitrios II	-37549	-24819	-14643	-4468	5708	-62209	-52033	-39304	-29128	-18952
Ag. Dimitrios III	-37951	-24821	-14311	-3801	6709	-73471	-62961	-49831	-39321	-28811
Ag. Dimitrios IV	-35993	-23058	-12548	-2038	8472	-71513	-61003	-48068	-37558	-27048
Ag. Dimitrios V	-49171	-36819	-24117	-11416	1285	-87268	-74567	-62215	-49513	-36812
Amyntaio	-81934	-55680	-34600	-13520	7560	-162921	-141841	-115588	-94508	-73428
Kardia I	-44841	-31311	-20463	-9616	1232	-44841	-33994	-20463	-9616	1232
Kardia II	-44841	-31311	-20463	-9616	1232	-44841	-33994	-20463	-9616	1232
Kardia III	-44396	-30544	-19336	-8128	3080	-44396	-33188	-19336	-8128	3080
Kardia IV	-44571	-30544	-19336	-8128	3080	-44571	-33363	-19336	-8128	3080
Megalopoli III	-70566	-56248	-44354	-32459	-20565	-70566	-58672	-44354	-32459	-20565
Megalopoli IV	-83651	-67667	-54149	-40631	-27113	-109824	-96306	-80321	-66804	-53286
Meliti	-41245	-31765	-22285	-12805	-3325	-70791	-61311	-51831	-42351	-32871
Total (k€)	-654259	-469404	-315249	-161093	-6938	-949423	-795267	-610413	-456257	-302102
Ptolemais V	-17726	-2933	15774	34480	53187	-91786	-73079	-58287	-39580	-20874
Ptolemais V BM	-62073	-61738	-61403	-61067	-60732	-145895	-145559	-145224	-144888.8	-144554
NG Units	Profil (k€) w/o investment costs					Profil (k€) with investment costs				
Ptolemais V NG	28927	33931	38936	43941	48946	-33575	-28570	-23565	-18560	-13556
Mytilinaios (€615/kW)	37878	44431	50985	57538	64092	8288	14842	21395	27949	34502
Mytilinaios (€400/kW)	37878	44431	50985	57538	64092	17833	24386	30939	37493	44046

Turning next to the effect of the wholesale price (in which auxiliary services remuneration but not capacity credit is included), all existing lignite units are seen (Table 19) to generate operating losses for prices below €74/MWh. Ptolemais V in the lignite configuration covers its O&M costs with values as low as €68/MWh. None can cover their capital repayment costs. The NG plants generate profits for all values examined.

Table 19: Wholesale price sensitivity

Wholesale price (€/MWh)	76	74	72	70	68	76	74	72	70	68
Lignite plants	Profil (k€) w/o investment costs					Profil (k€) with investment costs				
Ag. Dimitrios I	3867	1089	-1689	-4468	-7246	-20793	-23571	-26350	-29128	-34460
Ag. Dimitrios II	3867	1089	-1689	-4468	-7246	-20793	-23571	-26350	-29128	-34460
Ag. Dimitrios III	4808	1939	-931	-3801	-6670	-30712	-33581	-36451	-39321	-44811
Ag. Dimitrios IV	6571	3701	831	-2038	-4908	-28949	-31819	-34689	-37558	-42852
Ag. Dimitrios V	-1013	-4481	-7948	-11416	-14884	-39110	-42578	-46046	-49513	-52633
Amyntaio	3089	-2447	-7984	-13520	-19056	-77898	-83435	-88971	-94508	-105218
Kardia I	-1372	-4120	-6868	-9616	-12364	-1372	-4120	-6868	-9616	-15047
Kardia II	-1372	-4120	-6868	-9616	-12364	-1372	-4120	-6868	-9616	-15047
Kardia III	390	-2450	-5289	-8128	-10967	390	-2450	-5289	-8128	-13612
Kardia IV	390	-2450	-5289	-8128	-10967	390	-2450	-5289	-8128	-13787
Megalopoli III	-24702	-27288	-29874	-32459	-35045	-24702	-27288	-29874	-32459	-37469
Megalopoli IV	-32843	-35439	-38035	-40631	-43227	-59016	-61612	-64208	-66804	-71866
Meliti	-4014	-6944	-9875	-12805	-15736	-33559	-36490	-39420	-42351	-45281
Total (k€)	-38320	-74976	-111632	-148288	-184944	-303938	-340594	-377251	-413907	-481262
Ptolemais V	54595	47890	41185	34480	27775	-19466	-26170	-32875	-39580	-42371
Ptolemais V BM	-40953	-47658	-54363	-61067	-67772	-124774	-131479	-138184	-144889	-151594
NG Units	Profil (k€) w/o investment costs					Profil (k€) with investment costs				
Ptolemais V NG	58309	53519	48730	43941	39152	-4193	-8982	-13771	-18560	-23350
Mytilinaios (€615/kW)	76352	70081	63809	57538	51267	46762	40491	34220	27949	21677
Mytilinaios (€400/kW)	76352	70081	63809	57538	51267	56306	50035	43764	37493	31222

In Table 20, the effect of the load factor is shown. Even at 70% load factors, the existing lignite plants cannot cover their O&M costs.

Table 20: Load factor sensitivity

Load factor (%)	0.5	0.55	0.6	0.65	0.7	0.5	0.55	0.6	0.65	0.7
Lignite Units	Profil (k€) w/o investment costs					Profil (k€) with investment costs				
Ag. Dimitrios I	-8076	-6874	-5671	-4468	-6015	-32664	-31485	-30307	-29128	-30700
Ag. Dimitrios II	-8076	-6874	-5671	-4468	-6015	-32664	-31485	-30307	-29128	-30700
Ag. Dimitrios III	-7563	-6309	-5055	-3801	-5369	-42271	-41287	-40304	-39321	-41160
Ag. Dimitrios IV	-6208	-4818	-3428	-2038	-3259	-40915	-39796	-38677	-37558	-39050
Ag. Dimitrios V	-16683	-14927	-13172	-11416	-9286	-54061	-52545	-51029	-49513	-47622
Amyntaio	-19610	-17580	-15550	-13520	-17061	-98744	-97332	-95920	-94508	-98667
Kardia I	-11955	-11175	-10395	-9616	-11726	-11955	-11175	-10395	-9616	-11726
Kardia II	-11955	-11175	-10395	-9616	-11726	-11955	-11175	-10395	-9616	-11726
Kardia III	-10811	-9917	-9022	-8128	-10082	-10811	-9917	-9022	-8128	-10082
Kardia IV	-10811	-9917	-9022	-8128	-10271	-10811	-9917	-9022	-8128	-10271
Megalopoli III	-32923	-32768	-32614	-32459	-34916	-32923	-32768	-32614	-32459	-34916
Megalopoli IV	-39208	-39683	-40157	-40631	-43761	-65097	-65666	-66235	-66804	-70029
Meliti	-13211	-13076	-12940	-12805	-12670	-42339	-42343	-42347	-42351	-42355
Total (k€)	-197091	-185092	-173093	-161093	-182156	-487209	-476892	-466575	-456257	-479001
Ptolemais V	17295	23023	28752	34480	40209	-56766	-51037	-45309	-39580	-33852
Ptolemais V BM	-52131	-55110	-58089	-61067	-64046	-135952	-138931	-141910	-144889	-147868
NG Units	Profil (k€) w/o investment costs					Profil (k€) with investment costs				
Ptolemais V NG	28086	33371	38656	43941	43941	-34415	-29130	-23845	-18560	12858
Mytilinaios (€615/kW)	36777	43698	50618	57538	57538	7188	14108	21028	27949	61839
Mytilinaios (€400/kW)	36777	57538	50618	57538	57538	16732	23652	30572	37493	71383

Ptolemais V in its lignite but not in its biomass configuration also covers its O&M costs but not its capital cost repayment costs. Again, the Mytilinaios NG unit at the Reference wholesale price of

€70/MWh covers all their O&M costs and loan obligations but not the Ptolemais V unit in its NG configuration.

Finally, in Table 21 the sensitivity to the price of NG and biomass is given. All NG plants cover their O&M costs but at higher NG prices Ptolemais V cannot cover its capital cost obligations. The Ptolemais V in its biomass configuration shows a loss over the whole range of biomass costs covered.

Table 21: Fuel cost price sensitivity

NG plants	Profil (k€) w/o investment costs					Profil (k€) with investment costs				
	28	26	24	22	20	28	26	24	22	20
NG fuel Price (€/MWh _{th})										
Ptolemais V NG	21712	30411	39111	47810	56531	-37238	-28539	-19840	-11140	-2419
Mytilinaios (€615/kW)	28352	39712	51072	62432	73820	728	12088	23447	34807	46195
Mytilinaios (€400/kW)	28352	39712	51072	62432	73820	9770	21129	32489	43849	55237
Biomass Plant	Profil (k€) w/o investment costs					Profil (k€) with investment costs				
Biomass fuel Price (€/MWh _{th})	37.5	35.5	33.5	31.5	29.5	37.5	35.5	33.5	31.5	29.5
Ptolemais V BM	-80870	-65306	-49741	-34176	-18611	-160815	-145250	-172989	-114120	-98555

In view of the above, it is interesting to identify the null points between profitability and loss for all three parameters. These values are shown in Table 22.

Table 22: Economic viability null values for the basic parameters of EUA prices, load factors and wholesale prices all plants (Sensitivity to NG and biomass fuel prices in Table 20)

	EUA price (€/MWh)		Load (%)		Wholesale Price (€/MWh)	
	w/o	with	w/o	with	w/o	with
Lignite Units						
Ag. Dimitrios I	22.8	10.7	0.90<	0.90<	73.2	90.9
Ag. Dimitrios II	22.8	10.7	0.90<	0.90<	73.2	90.9
Ag. Dimitrios III	23.2	6.3	0.90<	0.90<	72.7	97.4
Ag. Dimitrios IV	24	7.1	0.90<	0.90<	71.4	96.2
Ag. Dimitrios V	20.5	5.5	0.90<	0.90<	76.6	98.6
Amyntaio	21.8	2.6	0.90<	0.90<	74.9	104.15
Kardia I	20.6	20.55	0.90<	0.90<	77.0	77.0
Kardia II	20.6	20.55	0.90<	0.90<	77.0	77.0
Kardia III	21.4	21.4	0.90<	0.90<	75.7	75.7
Kardia IV	21.4	21.4	0.90<	0.90<	75.7	75.7
Megalopoli III	11.35	11.4	0.90<	0.90<	95.1	95.15
Megalopoli IV	10	0.4	0.90<	0.90<	101.3	121.5
Meliti	18.2	2.7	0.90<	0.90<	78.7	98.9
Ptolemais V	34.2	14.58	0.398	0.90<	59.7	81.8
Ptolemais V BM	25	25	0.90<	0.90<	88.2	113.2
NG Units						
Ptolemais V NG	68.9	6.5	0.1	0.675	51.7	77.72
Mytilinaios (€615/kW)	68.9	46.3	0.1	0.298	51.7	61.1
Mytilinaios (€400/kW)	68.9	53.6	0.1	0.229	51.7	58.05

At €70/MWh wholesale price and 65% load factor, all existing lignite units would show losses when the EUA allowance price goes above €20.5/tCO₂. The NG units would still be profitable with prices up to €32/tCO₂ for the Ptolemais V unit and €58.4/tCO₂ for the Mytilinaios unit. These prices are not expected to be reached before 2030. The load factors needed to break even at €25/tCO₂ EUA and €70/MWh wholesale price for the lignite units are very high, exceeding the actual maximum of 90% load factor (7800hr/yr). At the other extreme, at these EUA and wholesale prices, the NG plants are profitable at much lower levels (67.5% for Ptolemais V and 29.8% for the Mytilinaios unit). This gap is also evident in the wholesale electricity price null point with the NG-fuelled plants able to operate profitably with values as low as €58/MWh (€78/MWh for Ptolemais V). The biomass configuration of Ptolemais V again requires extremely high values of wholesale prices and unrealizable load factors to break even.

8. The Modified NECP Decommissioning Timetable

As mentioned above, the Greek Government announced that the NECP to be submitted by the end of 2019 which has to take into account the recommendations of the EC (EC, 2019b) will also reflect the pledge to decommission all lignite power stations by 2028 (with the possible exception of the Ptolemais V unit which might be converted then to other fuel). The most probable timetable for this is shown in Table 23.

Table 23: The lignite unit probable withdrawal timetable to be incorporated in the Greek NECP and the addition of new NG units which are under construction or in advanced permitting stage and the cumulative profit from their operation in the period 2020-2028.

NECP Decommissioning new Timetable	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Profit O&M (k€)
Ag. Dimitrios I	274	274	274	274	274								-27494
Ag. Dimitrios II	274	274	274	274	274								-27494
Ag. Dimitrios III	283	283	283	283	283	283	283						-30329
Ag. Dimitrios IV	283	283	283	283	283	283	283						-20568
Ag. Dimitrios V	342	342	342	342	342	342	342	342	342				-77287
Amyntaio	546	546											-23670
Kardia I	271												0
Kardia II	271												0
Kardia III	280	280	280										-25199
Kardia IV	280	280	280										-25199
Megalopoli III	255	255	255	255									-99695
Megalopoli IV	256	256	256	256	256	256	256	256	256	256			-361410
Meliti	289	289	289	289	289	289	289	289	289	289			-116464
Ptolemais V				614	614	614	614	614	614	614	614	614	361879
Mytilinaios NG (€615/kW)			804	804	804	804	804	804	804	804	804	804	515668
Elpedison NG				615	615	615	615	615	615	615	615	615	344581
Terna NG					615	615	615	615	615	615	615	615	295355

Based on this timetable, and taking into consideration (i) the very low current load factors of both lignite (43.6%) and NG (36.5%) plants, (ii) the addition of two (Mytilinaios and Elpedison) and possibly a third one (iii) the expected additional 7,500MW of RES installation plus (iv) the small (ca

10%) increase in electricity demand, no production deficit is seen for the whole 2020-2030 period. Under this timetable, both the remaining lignite and the NG units see an increase of their load factor to slightly over 50%. This is the case even if Ptolemais V is completely shut down rather than converted to alternative fuels use.

During the 2020-2028 period, PPC, with today's range of values for wholesale electricity price (ca €70/MWh), EUA allowance price (€25/tCO₂) and load factors ranging from 45% for the older to 70% for the newer units, would incur an operating loss from the lignite units of €834.8Mil and an operating profit of €361.9Mil from Ptolemais V. If a value of €27.5/tCO₂ is considered instead as a mean value between €25/tCO₂ and €30/tCO₂, a likely value in 2028 according to EC the loss will rise to €1109Mil. This calls into question whether based on purely economic consideration, the PPC lignite units should be withdrawn earlier.

In this, other factors also clearly weigh in. Such factors are the cost of contract termination of permanent employees, the renegotiation of long-term supply contracts, the loan structure reorganization, the plant decommissioning costs, the mine area rehabilitation and the pledges to local communities. This would require a more detailed analysis of both financial and organizational aspects by PPC and the Greek Government, its main shareholder.

9. Discussion and Some Concluding Remarks

In this note, an analysis of the economics of the current operation of the lignite plants in Greece has been attempted. This analysis has been based on publicly available information for the financial parameters of the operation of the plants themselves and the mines that provide their fuel. More disaggregated data by plant and mine, for example VOM costs, would have provided more accurate estimates. Never-the-less, such further disaggregation would not change substantially the results presented which are based on the information available and the use of informed assumptions for some parameters.

The results presented above clearly show that the continuation of the operation of the lignite plants in Greece under the current economic parameters and energy market operation would result in substantial losses for PPC, S.A., their owner. The break-even values (Table 22) for a number of core parameters that include wholesale and EUA allowance prices are high enough and low enough respectively that it is highly unlikely that this primary finding of substantial losses would be reversed.

The results also clearly demonstrate that NG plants will be at a competitive advantage in a free market as would RES units which have submitted binding offers in the latest RES capacity auctions of 2018-2019 of the order of €65-68/MWh. At these wholesale prices, no lignite plant would be able to cover its O&M expenses while their operation would result in cumulative O&M losses of over €200Mil annually plus an approximately equal amount to cover capital costs obligations. This advantage of the NG plants remains even with considerable increases (of over 25%) of the NG price.

Most of the operating lignite units do not meet the new BREF ELVs. The anti-pollution equipment installation cost required is considerable. This expenditure is not attractive for plants nearing or even exceeding 40 years of operation. This is an additional reason to their operational losses, for the early decommissioning of the four Kardias units and the twin Amyntaio units which would require an additional ca €200Mil anti-pollution investment.

Post 2027, only three plants would have not exceeded 40 years of service. All of them cannot cover their O&M expenses at reasonable ranges of expected wholesale electricity and EUA allowance prices. It is then beneficial to examine their decommissioning as early as possible, even before they reach 40 years of service.

The Ptolemais V under construction is the only lignite plant that appears to cover its O&M costs and make an operational profit. Yet it does not produce enough income to repay its substantial loan repayment obligation. Options currently under consideration are to convert it to NG or biomass. The biomass option which has the advantage of having no CO₂ costs, is found to be not-viable mainly because of the high cost of biomass which most likely will have to be imported. The option to convert to NG would result in an operating profit but not enough so as to cover even taking into the large capex already sunk in the construction. Comparison to other NG units under construction clearly shows that it would be at a distinct competitive disadvantage. Still, for this option to be realistic, an additional requirement is the construction of the NG pipeline from the nearest convenient point of the Greek gas network to Ptolemais, which is at least 100km away. Such a pipeline was built from Corinth to Megalopolis, over a similar distance and topography, to provide NG for the Megalopolis V unit. A possible alternative may be to modify Ptolemais V to CCS-ready and investigate in the years to 2028 the means to transport the CO₂ to the Prinos depleted oil wells (if they are not converted to NG storage as is currently under consideration by their owner).

If the economic basis for the early retirement of the lignite plants that is presented in this note is acted upon, the production gap that it will create can be covered by increased load factors of the existing NG plants together with the new ones already under construction or in the late permitting phase. In this era of very low NG prices, the NG plants have a competitive edge as their LCOE is even lower than that of wind turbine and PV. There is then a real possibility that the production gap that results from the lignite plant retirement would be filled by the NG plants leaving limited room for the RES units which are estimated in the NECP to reach at least 17.5GW by 2030. In view of the long-term EU target of reaching near zero emissions by 2050, to ensure that RES installation is not hindered, vigilance is required to retain priority dispatching and minimum curtailment of RES generation.

The retirement of the lignite units will result in stranded investments for PPC. These stranded investments include only three plants (Ag. Dimitrios V, Megalopolis IV and Meliti) as the others will have exceeded 40 years of service. These three have 30 years of operation left in total beyond the dates of the modified NECP. Their operation past 2027 for the additional cumulative 30 years under current EUA allowance price would result in €477.7Mil operating losses of which €39.5Mil from Megalopolis IV and €181Mil from Meliti as against a book value on 31 December 2018 for Meliti of €130Mil and of €140Mil for Megalopolis III & IV (PPC. 2019a) Thus, after 2027, only the Ag. Dimitrios V unit would have some stranded value. This is not the case though for the investment in the mines

for which the book value as of 31 Dec 2018 was €1316Mil but in which the value of the lignite in situ should not be counted as they were assigned to PPC by the Greek State at no cost.

Finally, it should be stressed that the expected retirement of the lignite plants by 2028 according to the Government pledge would entail large upheaval in the local communities where the plants are located. Despite warnings in the past, planning for a Just Transition of these communities to the post-lignite era has not progressed enough so as to propose new viable and substantial economic activities to replace lost income and more importantly to identity, let alone secure, the funds that would be needed to support the communities throughout the transition period (Claeys et al., 2019). It is imperative that this planning is completed immediately, and that programs to address the social problems that will result, go hand-in-hand with the plan to retire the lignite plants by 2028.

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