The variability of Greek fly ashes
Estimations for their future evolution

Argiro Kastanaki[1], Dimitrios Sotiropoulos[2], Eleni Papadopoulou[3]

[1] PPC S.A., Thermal Power Plants Operations Department, Solomou 41, Athens 106 82, email: a.kastanaki@dei.com.gr.

[2] PPC S.A., Thermal Power Plants Operations Department, Solomou 41, Athens 106 82, email: d.sotiropoulos@dei.com.gr.

[3] PPC S.A., Thermal Power Plants Operations Department, Solomou 41, 106 82 Athens

Summary

Although the initial Power Plants design was based on their feeding by the near-by lignite mines, during the last years, environmental and energy reasons forced the changing of this strategy with mixing of different qualities from different mines, which led in differentiated fuel mixes in each Power Plant, in order to meet special energy and environmental targets.

The new strategy is strongly bind to the variability of the produced quality of fly ash, but did not changed finally the ranking of these fly ashes to the main two categories (EIT1 and EIT2) described in the Greek Specifications of calcareous ashes.

According to the mines exploitation design plan up to 2054, it is estimated that the fly ash ranking in these two categories will remain at the same levels as today, although the available quantities will be diminished by time.

Keywords: fly ash, quality ash variability, ash classification.

1 Introduction

Lignite is the main energy "fuel" of Greece, as the deployed lignitic power is almost half of the total installed capacity of the mainland’s interconnected electricity grid.

The Basins of Western Macedonia and Megalopolis area are fairly regarded as the energy "hearts" of Greece, since there the seven (7) lignite-fired power plants (TPP) are located. These plants cover 47% of the total installed capacity of the interconnected electricity grid of the country.

All lignite power stations were constructed at very short distances from certain coal-mines, from which, according to their original design, they could be supplied with local fuel (local lignite). During the design phase of these power plants, an estimated average quality of the relevant mine’s deposit, that was available at that time, was used for calculation and design purposes, This estimated quality is known by the term "base fuel" or "design fuel." This quality is specific for each lignite power station, though it may vary significantly from station to station (Table 1).

Particularly in the Ptolemais-Amynteon Basin in Western Macedonia (Figure 1), the deposits of lignite mines are of zebra type, originated by the intense geological tectonism, thus resulting in lignite layers that vary widely both geometrically and in morphological features. As a consequence, the quality of the fuel varies considerably in all timescales (daily, monthly and yearly), as it is reflected indicatively in Charts 1 and 2, that concern SES Agios Dimitrios. In addition, due to the fact that the excavated lignite in different mines was created in completely different geological periods, the intense quality variations always was and still is the normal situation for all the coal used in thermal power plants of the region.

2 The impact of the lignite's quality variation

The term "lignite quality" describes a set of physical/chemical characteristics, which can be categorized into three basic groups: moisture, heat content and inorganic (mineral) content and hence the term variability refers to the variation of all characteristics in each of these three groups. Typically the variations of these groups follow specific qualitative relationships amongst them. For example an increase of the heat content of lignite means respectively an increase of the humidity and a reduction of the mineral content. Moreover, if someone attempts to study in detail the mineral content, he wil find out that there are also existing parallel qualitative relationships, where i.e. calcium "competes" silicon.

2.1 The impact of lignite's variation in the operation of the Power Units

Each of the aforementioned groups has an effect on both the generation process of the Units as well as their environmental behaviour:

The main parameter, that affects the generation process of a Unit and it's efficiency, is the heat content of the fuel (lower heating value or LHV). The inorganic content plays a secondary role.

On the contrary, the main parameter for the environmental behaviour of a Unit is the mineral content of the fuel (mostly ash) and secondarily the heat content. Especially for the performance of Electrostatic Precipitators (ESP) of a unit and consequently for the dust emission of the stack, the amount of free calcium in ash and sulphur in lignite is decisive.

Therefore, in the Units of Western Macedonia area, the quality variation of used coal and the corresponding produced ash, has an impact on the Units' load and efficiency as well as on the dust and sulphur oxides emissions.

As per content, the ash of the thermal power plants in Western Macedonia can be classified into two groups:

- Calcareous ash (TPP Agios Dimitrios - Kardia - Ptolemais) with a content of total calcium (CaO) in the range of 25-50% and silica (SiO2) 20-35%.
- Siliceous ash (TPP Amyntaio - Meliti) with a content of total calcium (CaO) in the range of 5-25% and silica (SiO2) 35-50%

2.2 The development of lignite's management strategy

Since the installed Units in the Western Macedonia region are designed and constructed with specific energy and environmental standards and at the same time are having specific energy and environmental obligations, they should use lignite as possible equivalent to the "design lignite". Due to the wide quality variation of the coal however, this can not be feasible.

To tackle the variability problem in the fuel quality, PPC S.A., since 2008, developed a new lignite management strategy, by a series of methods and actions, that aimed to smooth out quality fluctuations of mined lignite and achieve optimized energy and environmental performance in its Units. An indicative form of this strategy's lignite handling is shown in Figure 2.

The new lignite management aims at the enrichment of calcareous lignite (with low heat content) with low-calcium lignite (with increased heat content), in the lignite yards either of the power plants or of the Mines, and vice versa. In this way, the Power Units that previously were systematically unable to reach their rated load are now fully charged, while Units that previously suffered serious environmental issues (mainly dust emissions) have now significant environmental compliance.

Eventually, in the lignite yard of each TPP, lignite quantities from different sources (mines) with different qualities are stored. This process requires considerable effort by the power plants' personnel, in order to manage and develop specialized expertise on how to mix and exploit the different lignite qualities on an ongoing basis. The power plants manage the following numbers of lignite qualities described in more detail in Table 2:

AGIOS DIMITRIOS	3 different qualities from 3 different mines
KARDIA	10 different qualities from 6 different mines
PTOLEMAIS	4 different qualities from 4 different mines
AMYNTAIO	2 different qualities from 2 different mines
MELITI	6 different qualities from 6 different mines (domestic and foreign)

Although the degree of enrichment and mixing is designed by PPC SA on a monthly and an annual basis, however it is monitored by power plants and mines on a daily basis, in order to implement corrective actions in cases that the expected result is not delivered. Although this method of management increases the handling costs of lignite (mainly due to road transportation), the total operating, energy and environmental benefits are multiple.

The results of fuel mixing strategy are significant and even in some cases (such as TPP Kardia) spectacular. Specifically the problems confronted in each TPP were:

AGIOS DIMITRIOS	nominal load undertaking, reduction of sulfur oxides emissions
KARDIA	nominal load undertaking, significant reduction of dust emissions
PTOLEMAIS	nominal load undertaking, reduction of dust emissions
AMYNTAIO	nominal load undertaking, minor reduction of sulfur emissions
MELITI	Unit charging

3 Variability of produced fly ash

According to the National Technical Specification (Ministerial Decision YPECHODE/281/2007) Greek fly ash is classified into two categories:

- category EIT1, which includes Fly Ashes, offered as collected (crude ash) or disposed after elementary homogenization selectively collected material, for which quality limits can be set depending on the intended use, and
- category EIT2 (processed ash), which includes Fly Ashes that may substitute a percentage of cement CEM I in the concrete of unarmed structures. For the processed ash production a system that includes homogenization, milling, hydrolysis and quality control is required, so that the produced material reaches the provisions of this Specification.

For each of these categories, when the ash is to be used in the cement industry, threshold limits have been set in Fineness (R45), sulphates content (SO3) and free calcium oxide content (CaO_{free}).

The elements (in oxide form) that constitute the ash produced by the thermal power plants of Western Macedonia can be classified (based on content) in three main categories:

- Main elements (> 8%): Calcium (CaO), Silica (SiO_2) and Alumina (Al_2O_3)
- Secondary elements (<8%): Iron (Fe_2O_3), Magnesium (MgO), Sulfur (SO_3), Potassium (K_2O), Sodium (Na_2O), Titanium (TiO_2)
- Trace elements (ppm): Pb, Ni, Cu, Cr, Zn, Cd, Hg, As, V, Mo

From these data, the ones that are important for the exploitation of ash and are tested in order to classify them in the specified categories EIT1 and EIT2 are calcium (in the specific form of free calcium, CaO_{free}) and sulphur (SO_3). Moreover, another element associated with the hardness of the ash and thus with the required energy demanded for milling, is silicon (SiO_2).

The evolution of these parameters is shown in Charts 6, 7 and 8.

3.1 Fineness (R45) and granulometry of Ashes

The ash produced by power plants displays a particle size distribution with two maximums (peaks) at 45 and 95 microns (Chart 3). These maximums are linked to the milling process of the coal in the Units' mills (strong - weak) and to the composition of the ashes, especially with regards to the silica content. Thus, it is observed that in calcareous ash (TPP Agios Dimitrios, Kardia, Ptolemais) the particles size of 45 microns has a higher frequency than the 95 microns, while the opposite occurs in siliceous ash (TPP Meliti, Amyntaio).

The calcareous ashes present fineness R45 at a rate 60-65%, while the silicon at a rate not exceeding 40%.

These distributions did not change with the implementation of the new strategy and are not expected to change in the future, insofar as there are no significant changes in milling equipment of the Power Units.

3.2 Free Calcium Oxide (CaO_{free})

The new management of lignite qualities in the power plants of the Western Macedonia region produced significant differentiation either in the variability or in the mean average of the fly ash CaO_{free}, depending on the scope of the lignite management at each power plant, as shown in the following table:

Mean Avg & Variability CaO_{free}	AGIOS DIMITRIOS		KARDIA		MELITI	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
2005-2007	8,5	2,3	21,7	4,2	<1,5	<0,5
2008-2011	9,1	1,6	15,2	4,0	<1,5	<0,5

Since the TPP Agios Dimitrios environmental issues were related to the variability of free CaO, the effort was focused on reducing its standard deviation. On the contrary the problem at TPP Kardia laid in the increased content of free CaO, so the effort was focused on reducing the average CaO_{free} content (keeping the variability approximately constant). The above are illustrated in the statistical distributions of Chart 4. At TPP Meliti free CaO has always been very low, due to the nature of the fuel used.

3.3 Sulphates (as SO_3)

At the same time, at these power plants, the achievement was a significant variation either in the variability or in the average value of sulphates (SO_3) of fly ash, depending on the purpose of management at each station, as shown in the following table:

Mean Avg & Variability SO_3	AGIOS DIMITRIOS		KARDIA		MELITI	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
2005-2007	4,5	0,9	5,3	0,4	1,5	0,7
2008-2011	3,8	1,1	4,2	0,5	2,1	1,6

At TPP Agios Dimitrios, a part of the environmental issues were related to the high values of sulphate (SO_3), and therefore the effort focused on reducing the SO_3 average value. At SES Kardia, where there was no similar problem, the SO_3 average value reduction came out only as a result of the reduction of ash's free calcium (CaO_{free}). On the contrary at TPP Meliti there was an increase of SO_3 average value and its variability, because the entire management program was exclusively focused on enriching the heat content of lignite fuel, with the use of foreign lignites of increased LHV, which generally have a higher concentration of sulphur than the Western Macedonian lignites.

The distributions of SO_3 are shown in Chart 5.

4 Forecasting of future ash qualities evolution

Given the available reserves of lignite in the region, the studies concerning the future mining exploitation as well as the timescale of withdrawal or inclusion of lignite units, the lignite production until 2054 can be estimated and consequently the expected qualities of the ash to be produced in that period of time.

Based on this analysis, an estimation of the expected quantities and qualities of ash is given in the following table:

SES	Ash Production (10^6 tn)	CaO_{free}		SO_3	
		Range	Standard Deviation	Range	Standard Deviation
AGIOS DIMITRIOS	59,1	6,1 - 14,1	2,6	2,3 - 4,6	0,8
KARDIA	10,9	11,9 - 16,6	1,9	4,1 - 5,0	0,4
PTOLEMAIS 5	32,2	8,2 - 17,2	3,2	3,0 - 5,2	0,7

The estimated evolution of the above sizes is presented in detail in Figures 9, 10 and 11.

The percentages of the ashes produced in the future, that will be between the limits set by the National Standards for Ash are presented in the following table:

Parameter (2012-2054)*	Criterion	TPP AGIOS DIMITRIOS	TPP PTOLEMAIS 5
CaO_{free}	<9,0%	75,0%	13,2%
SO_3	<7,0%	100,0%	100,0%
SO_3	<5,0%	100,0%	50,0%

* SES Kardia is not shown at the Table, since the estimated remaining life of the power plant is much smaller than the other two TPP

The above Table shows that while the ash that will be produced in the future by TPP Agios Dimitrios will continue to have features similar to those presented until now, the ash produced from the new Ptolemais Unit 5 (if constructed) will be much more calcareous and at a large proportion (~ 50%), beyond the national standards.

The estimation of the concentrations distribution, presented in Figure 12, show the absence of concentrations less than 5% of free calcium for TPP Agios Dimitrios and the absence of concentrations less than 3% of sulphates for TPP Ptolemais 5.

5 Conclusions

The original design of lignite power stations was based on their exclusive supply from their near-by mines. However in recent years, energy and environmental reasons called for mixing coal from different mines, to create blends of fuel for each TPP, in order to achieve specific energy and environmental goals at each station.

This strategy is directly connected with the variability in the quality of the produced ash .This variability however does not seem to affect the percentage of the final classification of the ashes of the two categories (EIT1 & EIT2) identified by the Greek Specifications for calcareous ash.

According to the mines studies and exploitation design plan up to 2054, it is estimated that the fly ash ranking in these two categories will remain at the same levels as today, although the available quantities will be diminished by time.

References

- PPC S.A. - General Production Division - TPPOD TPP report accounting years 2005-2011, TPP AGIOS DIMITRIOS
- PPC S.A.- General Production Division - TPPOD TPP report accounting years 2005-2011 TPP KARDIA
- PPC S.A.- General Production Division - TPPOD TPP report accounting years 2005-2011, TPP MELITI
- PPC S.A.- General Production Division - TPPOD, Report of qualitative and quantitative characteristics of TPP ash produced years 2005-2011
- E. Tsiakos, Precursory evaluation of qualitative characteristics of lignite reserves of Mavropigi, South Field and Southwest Field Mines, PPC S.A.- General Division of Mines – DDDM, 2011
- National Technical Specification "GREEK FLY ASH" Ministerial Decision YPECHODE/281/2007, Gov. 551V - 18/4/2007, 2007

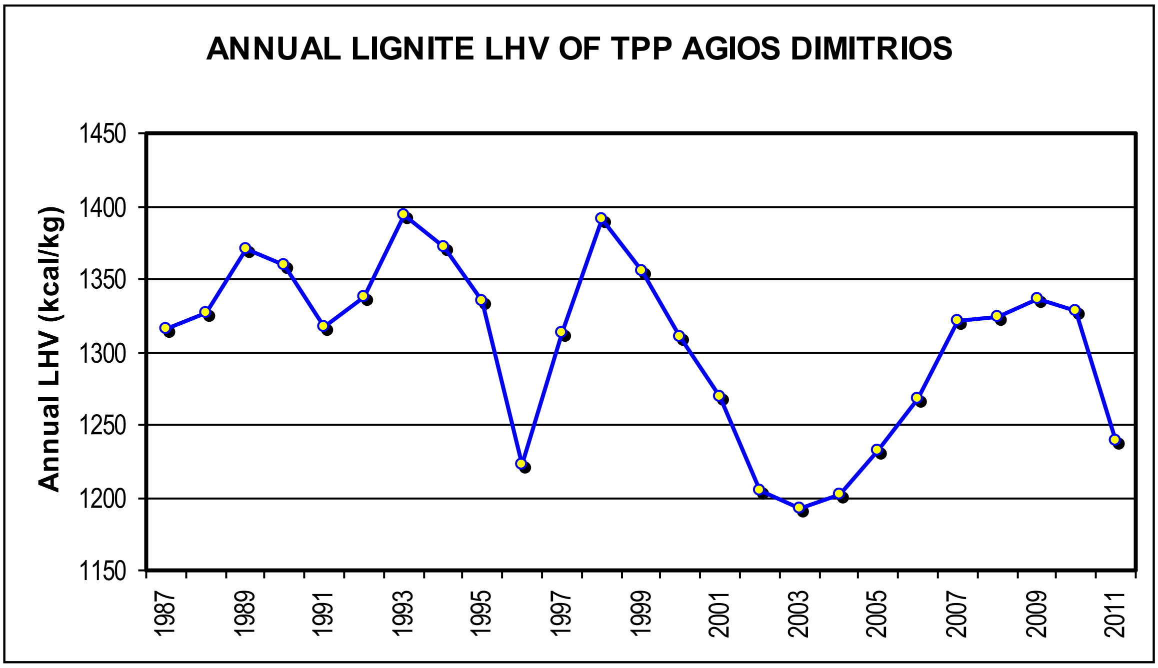
Table 1. Lignitic TPP installed capacity and "design" LHV (compared with 2011).

SES	Installed capacity (2011) (MW)	Construction year	Lignite **design** LHV (kcal/kg)	Lignite LHV **2011** (kcal/kg)
Agios Dimitrios	1595	1984/1997	1300	1239
Kardia	1250	1975/1981	1320	1280
Megalopoli	600	1970/1991	1000	1150
Ptolemais	545	1959/1973	1340	1318
Amyntaio	600	1987/1987	1250	1477
Meliti	330	2003	1900	1846
LIPTOL	43	1959/1965	1340	1375

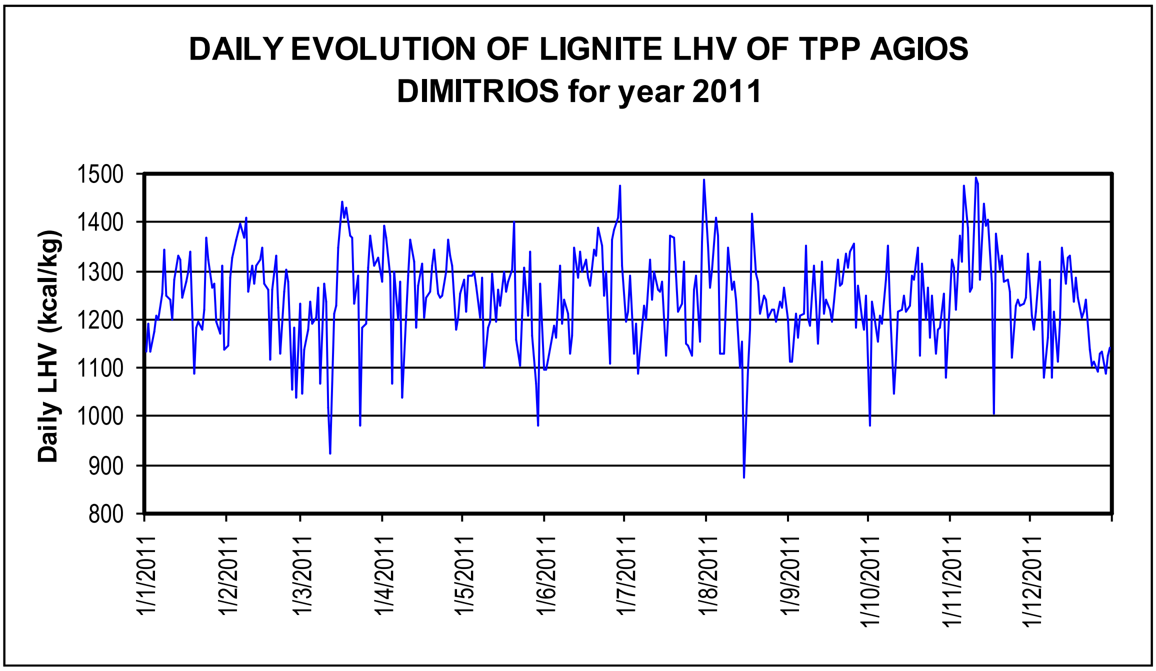
Table 2. Lignite's origin at the Western Macedonian region power plants.

MINES	**SES**				
	PTOLEMAIS	**KARDIA**	**AGIOS DIMITRIOS**	**AMYNTAIO**	**MELITI**
	3 Units	**4 Units**	**5 Units**	**2 Units**	**1 Units**
MAVROPIGI	✓	✓	✓		
KARDIA-WEST REGION	✓	✓(2 qualities)		✓	
KOMANOS - EASTERN EXPANSION			✓		
KARDIA-SOUTHWEST REGION	✓	✓(3 qualities)			
KOMANOS		✓(2 qualities)			
KARDIA - SUBMERGED REGION		✓			
SOUTH REGION		✓	✓		
AMYNTAIO	✓			✓	✓
ACHLADA (Private)					✓
OTHER PRIVATE MINES					✓(4 qualities)

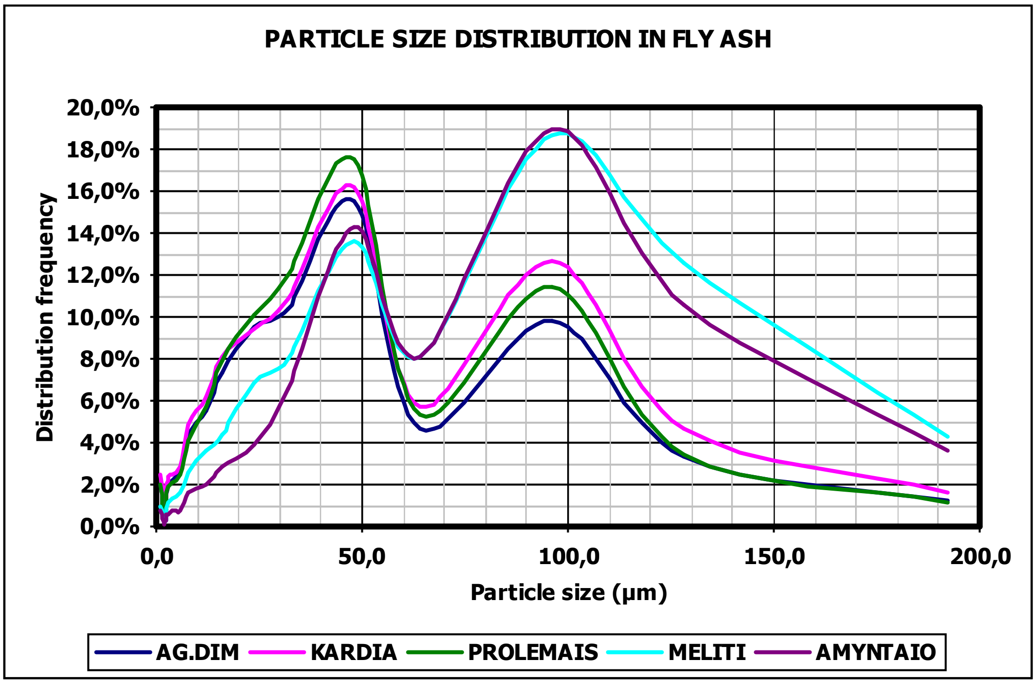
Graph 1. Annual LHV of TPP AGIOS DIMITRIOS



Graph 2. Daily lignite LHV of TPP AGIOS DIMITRIOS for year 2011

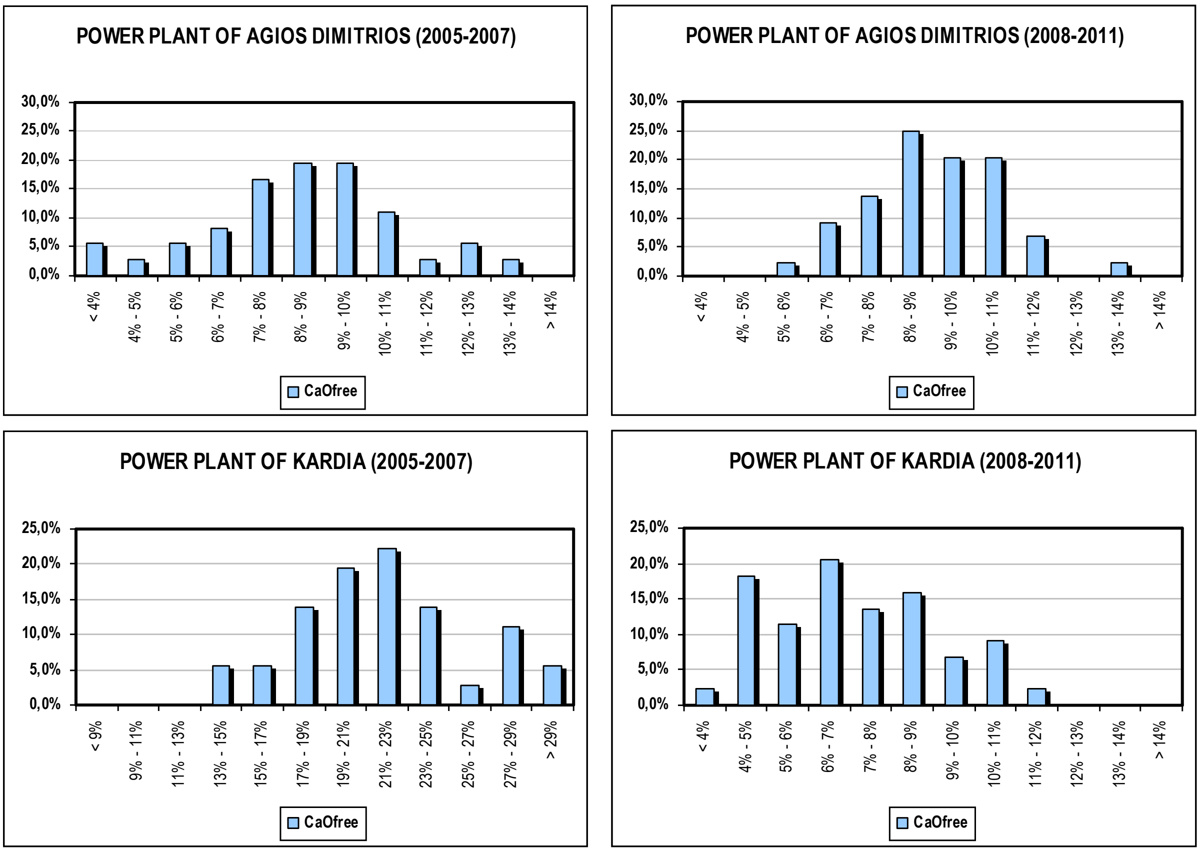


Graph 3. Particle size distribution of ashes of Western Macedonian TPPs

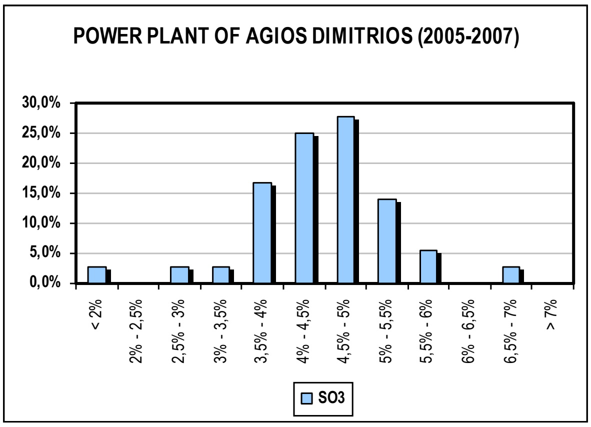


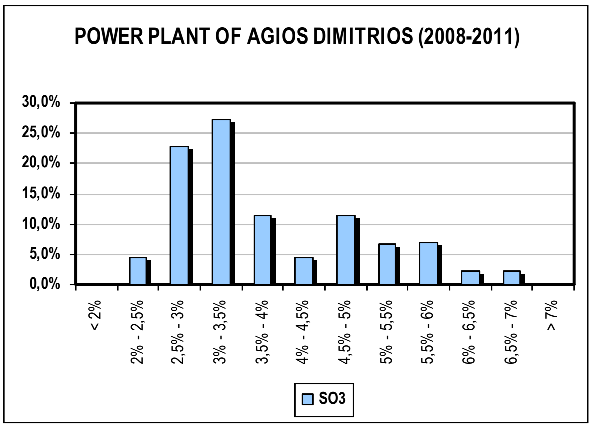
* The distributions refers to ashes delivered to TITAN cement industry

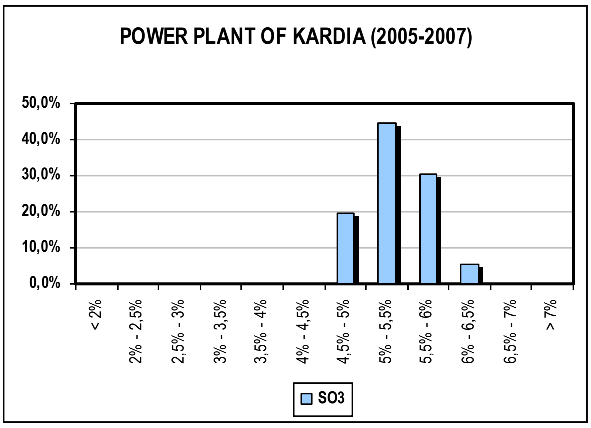
Graph 4. Distributions of free CaO of TPP AGIOS DIMITRIOS and KARDIA ashes

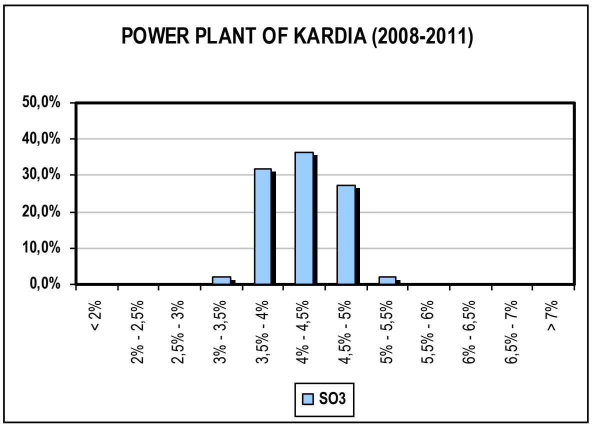


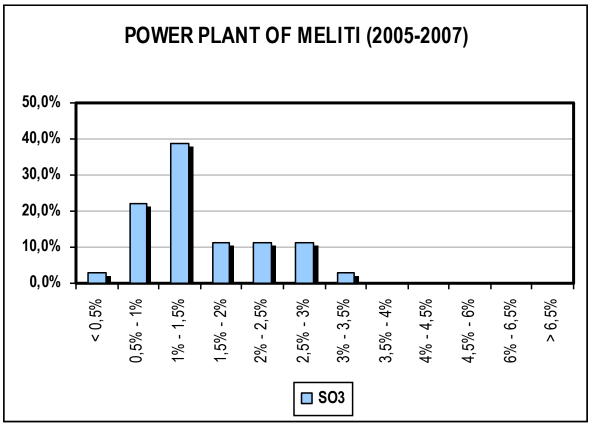
Graph 5. Distributions of Sulphates (as SO_3) of TPP AGIOS DIMITRIOS, KARDIA and MELITI ashes

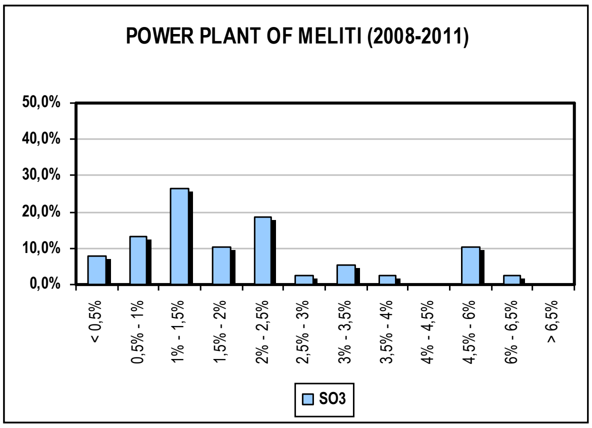




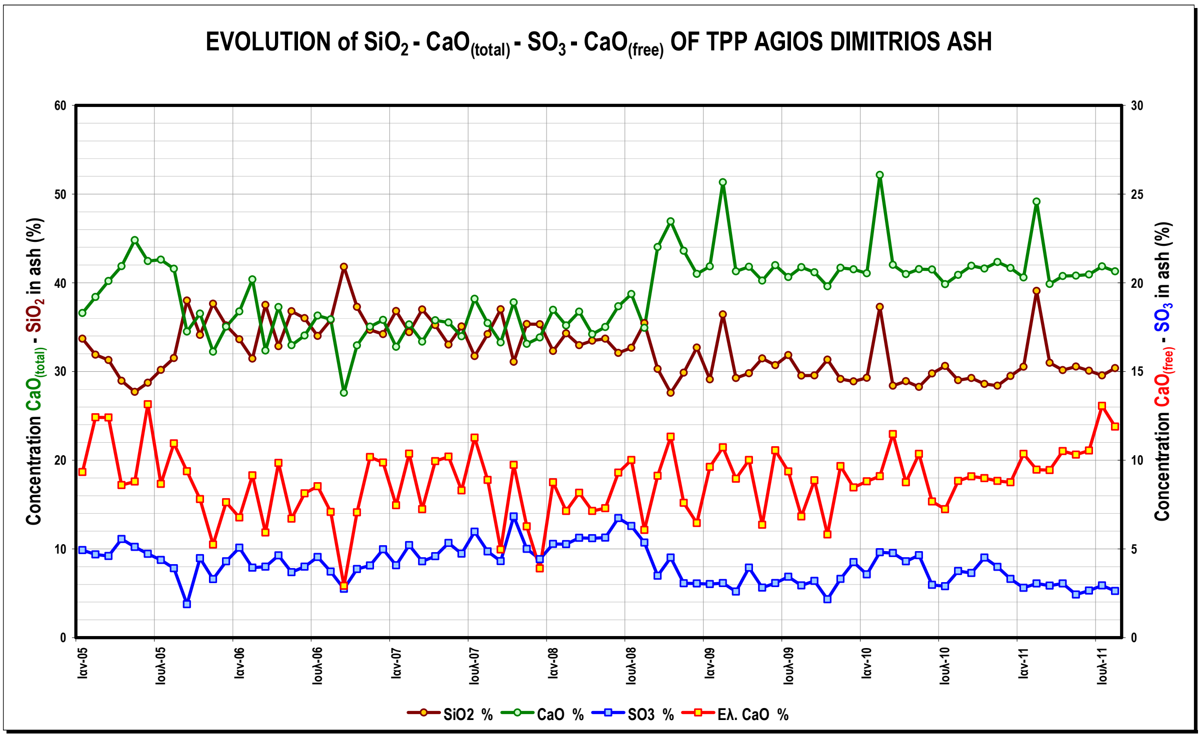




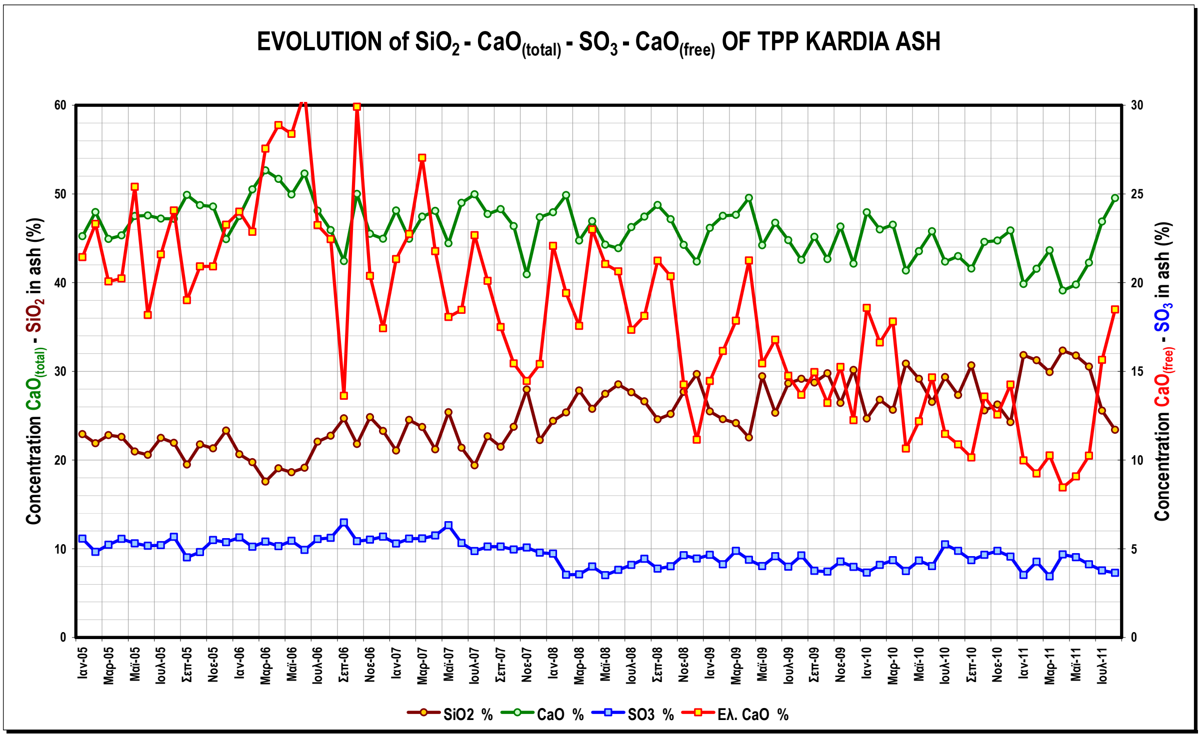




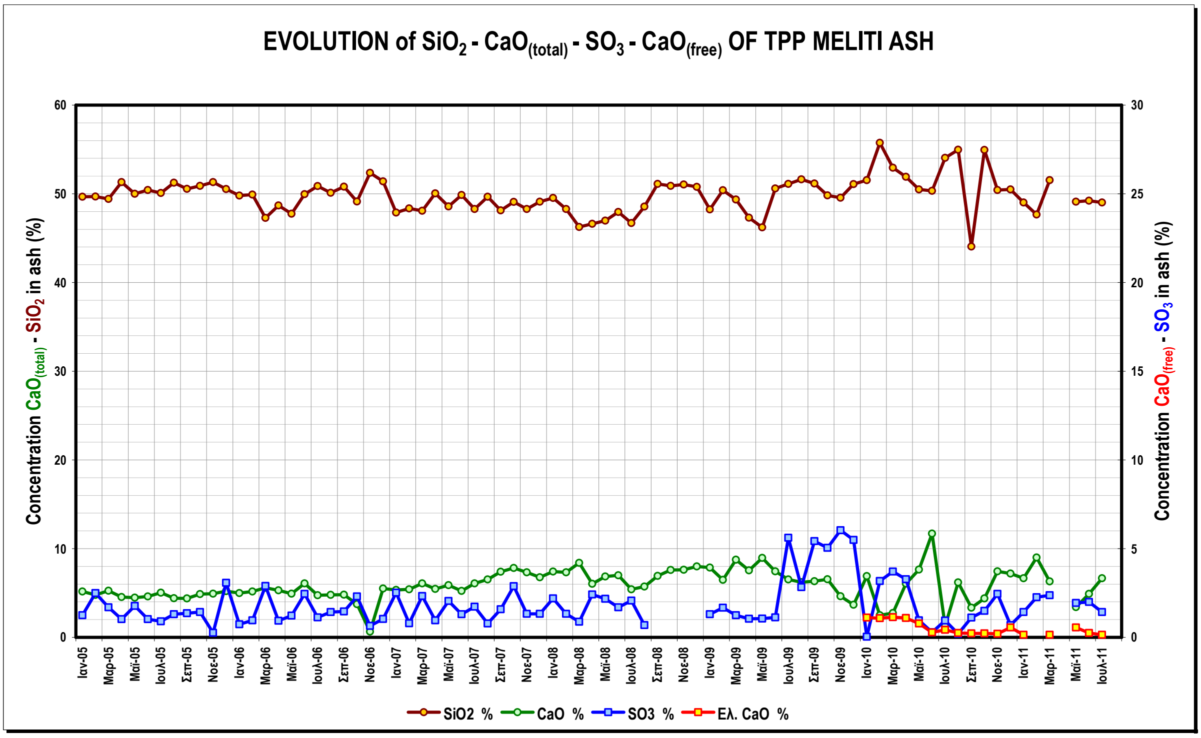
Graph 6. Evolution of Silicates, Calcium and Sulphates (as oxides) of TPP AGIOS DIMITRIOS's ash (2005-2011)



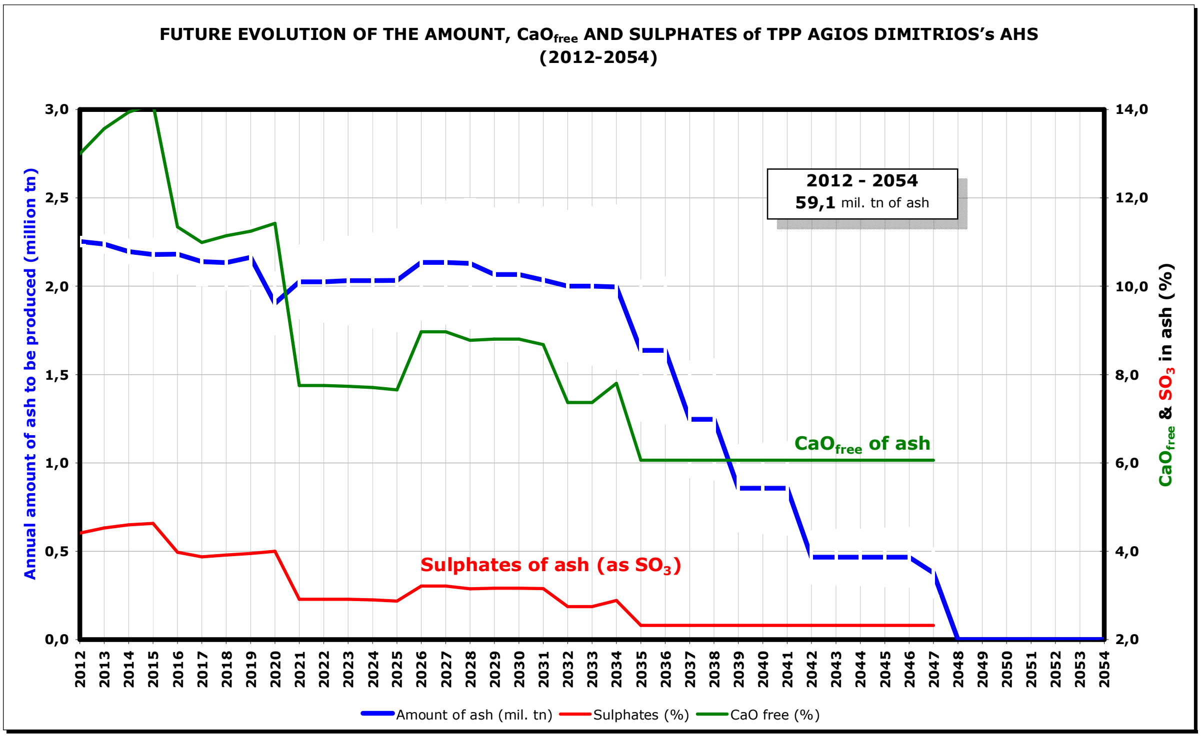
Graph 7. Evolution of Silicates, Calcium and Sulphates (as oxides) of TPP KARDIA's ash (2005-2011)



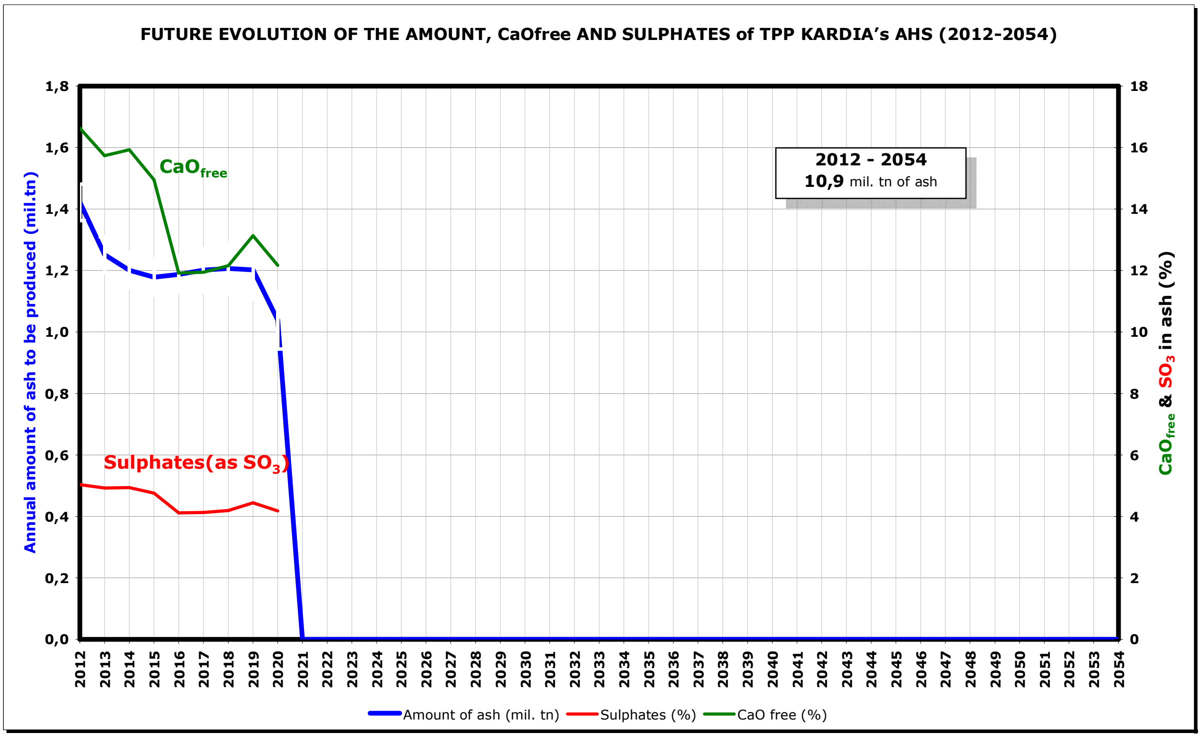
Graph 8. Evolution of Silicates, Calcium and Sulphates (as oxides) of TPP MELITI's ash (2005-2011)



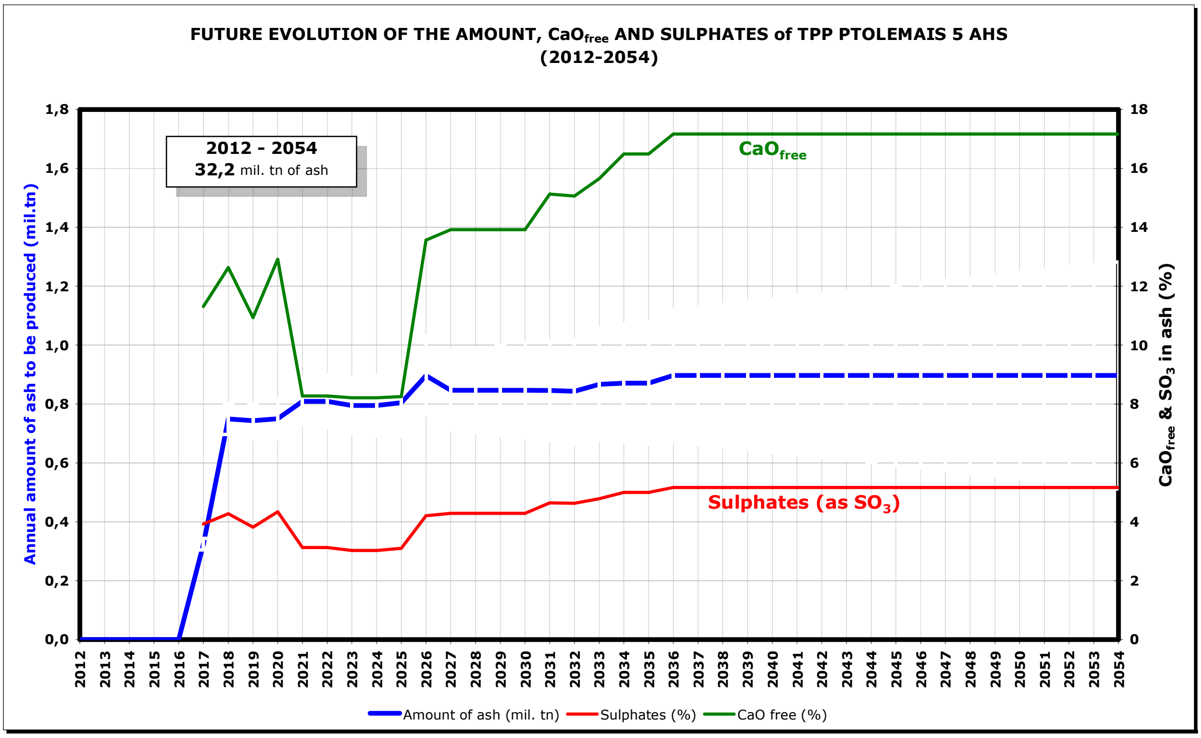
Graph 9. Future evolution of the Amount to be produced, free CaO and Sulphates of TPP AGIOS DIMITRIOS's ash (2012-2054)



Graph. 10 Future evolution of the Amount to be produced, free CaO and Sulphates of TPP KARDIA's ash (2012-2054)



Graph 11. Future evolution of the Amount to be produced, free CaO and Sulphates of TPP PTOLEMAIS 5 ash (2012-2054)



Graph 12. Distributions of free CaO and Sulphates of future ash of TPP AGIOS DIMITRIOS and PTOLEMAIS 5 (2012-2054)

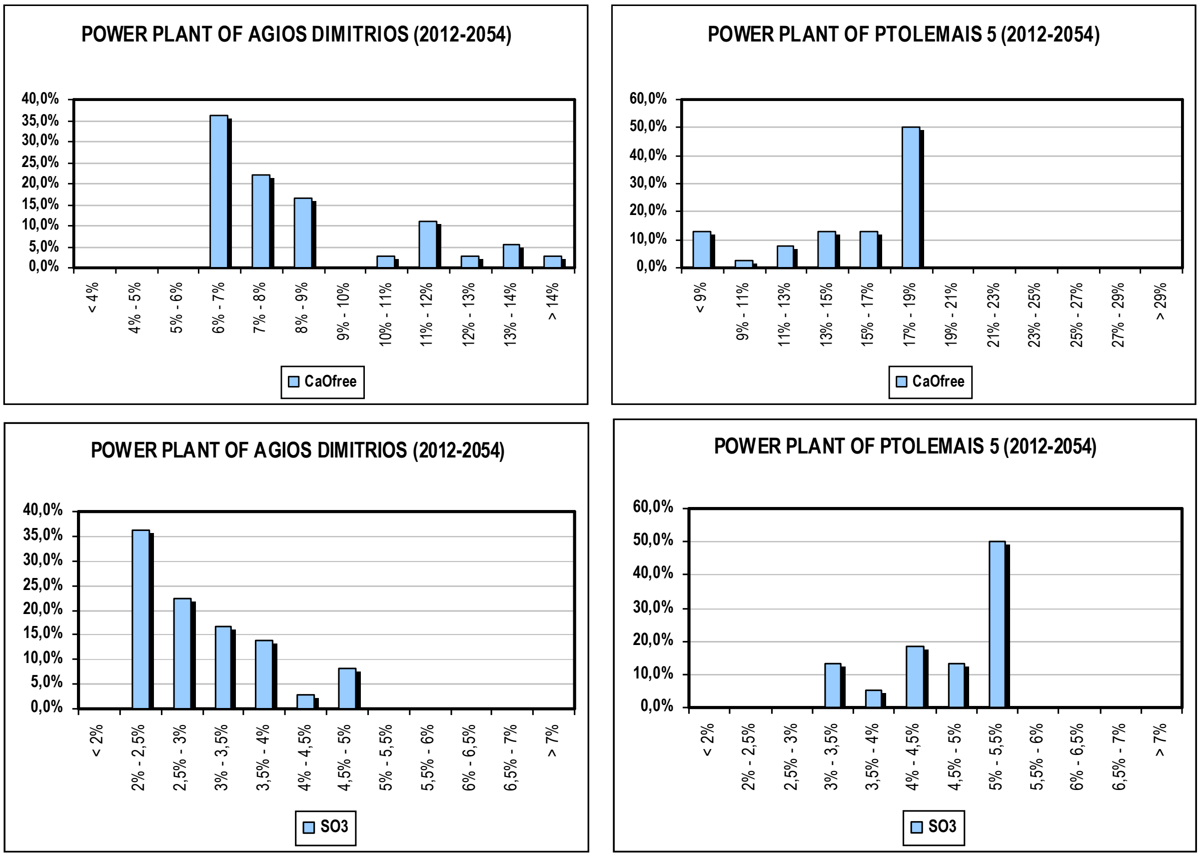


Figure 1. TPPs and their dedicated Mines in West Macedonia region (at design time)

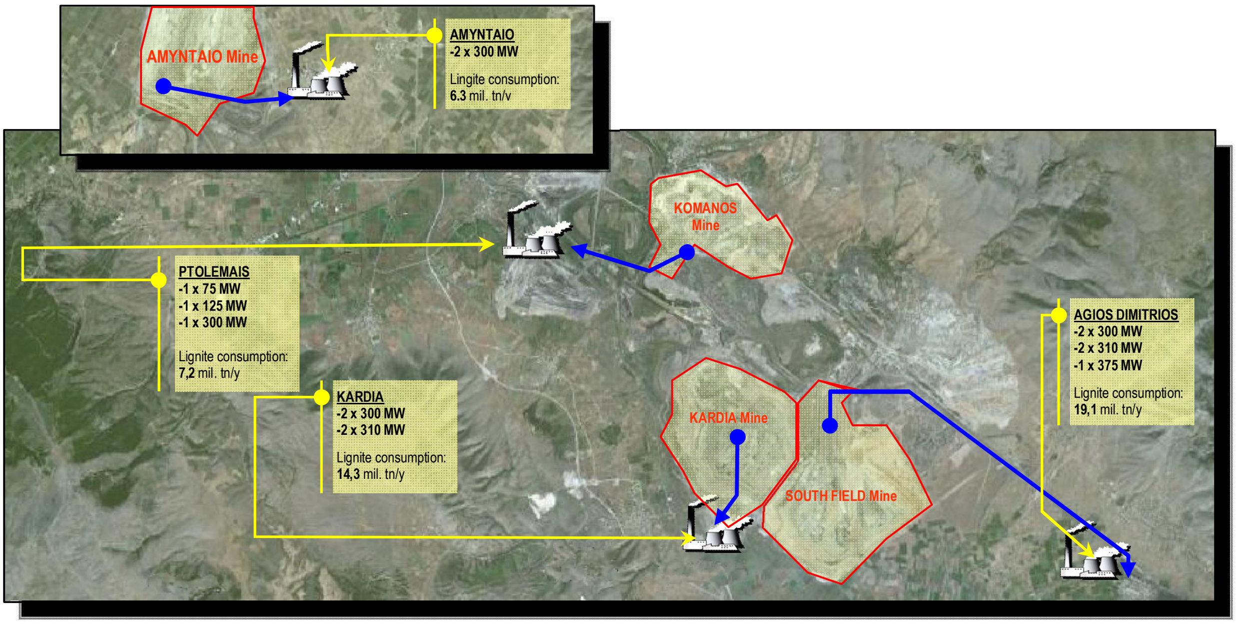


Figure 2. Indicative implementation of the new lignite management strategy in West Macedonia region