Prospects for coal and clean coal technologies in Greece

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Preface

This report has been produced by IEA Clean Coal Centre and is based on a survey and analysis of published literature, and on information gathered in discussions with interested organisations and individuals. Their assistance is gratefully acknowledged. It should be understood that the views expressed in this report are our own, and are not necessarily shared by those who supplied the information, nor by our member countries.

IEA Clean Coal Centre is an organisation set up under the auspices of the International Energy Agency (IEA) which was itself founded in 1974 by member countries of the Organisation for Economic Co-operation and Development (OECD). The purpose of the IEA is to explore means by which countries interested in minimising their dependence on imported oil can co-operate. In the field of Research, Development and Demonstration over fifty individual projects have been established in partnership between member countries of the IEA.

IEA Clean Coal Centre began in 1975 and has contracting parties and sponsors from: Australia, Austria, China, the European Commission, Germany, India, Italy, Japan, New Zealand, Poland, Russia, South Africa, Thailand, the UK and the USA. The Service provides information and assessments on all aspects of coal from supply and transport, through markets and end-use technologies, to environmental issues and waste utilisation.

Abstract

Greece's financial crisis continues to have a major impact on all facets of the country's economy – recent years have seen this contract by nearly a quarter. The period has seen the deepest and most protracted peacetime recession in the country's history. Until recently, there were some signs that the recession could be bottoming out. However, in 2015, the financial crisis continued unabated – as yet, there is little to suggest that the Greek economy will enjoy serious recovery in the near future. When significant economic recovery does occur, the energy sector will have a major role to play.

The country has a high energy import dependency. Almost all of its oil and gas is sourced from abroad; this amounts to almost two thirds of its gross inland energy consumption. Importing energy is also expensive – reportedly, the current level is ~US$20 billion per year. Compared to other EU member states, the overall diversification of the energy mix is rather limited. Greece's main indigenous energy resource is lignite, used to generate a significant proportion of the country's electricity. However, its overall quality is poor. The state-owned energy company Public Power Corporation S.A. (PPC) is the largest lignite producer with the right to exploit almost two thirds of the country's known reserves. More than 93% of Greece's energy is provided by fossil fuels, compared to the European average of 75% (Montague, 2015).

In January 2015, a new government was elected. This heralded a change of direction in energy policy, with earlier plans to privatise parts of the energy sector curtailed. However, conditions demanded recently by EU and IMF creditors, prior to disbursement of the next tranche of Greece's financial bailout, means that once again, privatisation schemes may be back on the table. This is likely to encompass natural gas and electricity supply.

There was a renewed focus on the potential of the country's lignite resources. In order to minimise the cost of imported energy and improve security of energy supply, the present government previously announced its intention to increase their use, primarily for electricity generation. However, this stance may have since softened, with emphasis shifting towards the greater use of renewable technologies.

The report examines the situation prevailing in the Greek energy sector, and how this might change in the future. Existing and proposed clean coal-based activities are discussed. However, major uncertainties (in terms of scope and timescale) remain over many aspects of energy production – the nature of, and rate of economic recovery will undoubtedly have major impacts.

Acknowledgements

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Staff of the Public Power Corporation S.A.

Acronyms and abbreviations

ADMIE	The Independent Power Transmission Operator
BAT	best available technology
boe	barrel of oil equivalent (one barrel of oil has the same energy content as 169.9 m^3 of natural gas
BP	British Petroleum
CBM	coalbed methane
CCC	[IEA] Clean Coal Centre
CCGT	combined cycle gas turbine
CCT	clean coal technology
CCS	carbon capture and storage
CERTH	Centre for Research and Technology-Hellas
CFBC	circulating fluidised bed combustion
CFD	computational fluid dynamics
CHP	combined heat and power
CRES	Centre for Renewable Energy Sources
CSLF	Carbon Sequestration Leadership Forum
CSP	concentrated solar power
CV	calorific value
DEPA	Public Gas Corporation (Dimosia Epichirisi Paroxis Aeriou)
ECBM	enhanced coalbed methane recovery
EEA	European Economic Area
EOR	enhanced oil recovery
EMS	Environmental Management System
EPC	engineering, procurement and construction
ESP	electrostatic precipitator
ETS	[EU] Emissions Trading Scheme
EU	European Union
FBC	fluidised bed combustion
FBG	fluidised bed gasification
FEED	front end engineering design
FGD	flue gas desulphurisation
FIT	feed-in tariff
FYROM	Former Yugoslavian Republic of Macedonia
GDP	gross domestic product
GHG	Greenhouse gas
GSRT	General Secretariat for Research and Technology
GVA	growth value added
HELE	high efficiency, low emission
HFO	heavy fuel oil
IEA	International Energy Agency
IED	[EU] Industrial Emissions Directive
IGCC	integrated gasification combined cycle
IGME	Institute for Geology and Mineral Exploitation
IPP	independent power producer
ISFTA	The Institute for Solid Fuels Technology and Applications
JV	joint venture
LCPD	Large Combustion Plant Directive
LHV	lower heating value

LNB	low NOx burner
LNG	liquefied natural gas
LULUCF	land use, land-use change and forestry
Mboe	million barrels of oil equivalent
MEA	monoethanolamine
MEE	Ministry of Environment and Energy
MEECC	Ministry of Environment, Energy and Climate Change
MoU	Memorandum of Understanding
MPa	megapascals
MSW	municipal solid waste
Mtoe	million tonnes of oil equivalent
NCRT	National Council for Research and Technology
NERP	National Emission Reduction Plan
NGCC	natural gas combined cycle
NREAP	National Renewable Energy Action Plan
NSDP	National Strategic Development Plan
NTUA	National Technical University of Athens
O&M	operation and maintenance
OCGT	open cycle gas turbine
OECD	Organisation for Economic Cooperation and Development
OPEC	Organisation of Oil Exporting Countries
PCC	pulverised coal combustion
PCI	pulverised coal injection
PES	primary energy supply
PPC	Public Power Corporation S.A (Dimosia Epicheirisi Ilektrismou)
PV	photovoltaic
RDF	refuse-derived fuel
RE	renewable energy
REN	Renewable Energy Policy Network
RFCS	[EU] Research Fund for Coal and Steel
SC	supercritical
SCR	selective catalytic reduction
SNCR	selective non-catalytic reduction
SNG	synthetic natural gas
TAP	Trans Adriatic Pipeline
TPES	total primary energy supply
TUED	Trade Unions for Energy Democracy
UNFCCC	United Nations Framework Convention on Climate Convention
USC	ultrasupercritical
US DOE	United States Department of Energy
ZEP	Zero Emissions Platform

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1 Introduction

Greece is situated in south east Europe. It is bordered by Albania, the Former Yugoslavian Republic of Macedonia (FYROM), and Bulgaria to the north and Turkey to the east. The country has a population of around 11.3 million and has been a member of the European Union (EU) since 1981.

As a consequence of its on-going financial crisis, during the past six years, the Greek economy contracted by nearly 24%. Investment in the country collapsed by almost two thirds and imports of many goods halved. The period has seen the deepest and most protracted peacetime recession in the country's history. Until recently, there were some signs that the recession could be bottoming out, with government sources suggesting that the country could shortly emerge from its six-year long recession. In 2013, following a period of austerity and the biggest debt restructuring in history, Greece achieved a primary surplus. In the same year, exports of goods and services rose by 1.8%, although these were still 15% below pre-crisis levels. During the first quarter of 2014, Greek manufacturing expanded, a hopeful sign that the economy was beginning to stabilise. However, in 2015, the financial crisis continued unabated – as yet, there is little to suggest that the Greek economy will enjoy serious, sustained recovery in the immediate future.

Greece has a high energy import dependency as it sources almost all its oil and gas from abroad – in recent years, this has amounted to almost two thirds of its gross inland energy consumption. Overall, the diversification of the energy mix is rather limited compared to other EU member states. The country's high reliance on energy imports makes it one of the most vulnerable in the EU in terms of security of supply. Most oil and gas comes from outside the European Economic Area (EEA) (Europa, 2013). For some years, the level of imported energy has varied, reflecting the prevailing state of the economy. The highest level was >73% in 2008, although this has since fallen (62% in 2013) (Figure 1).

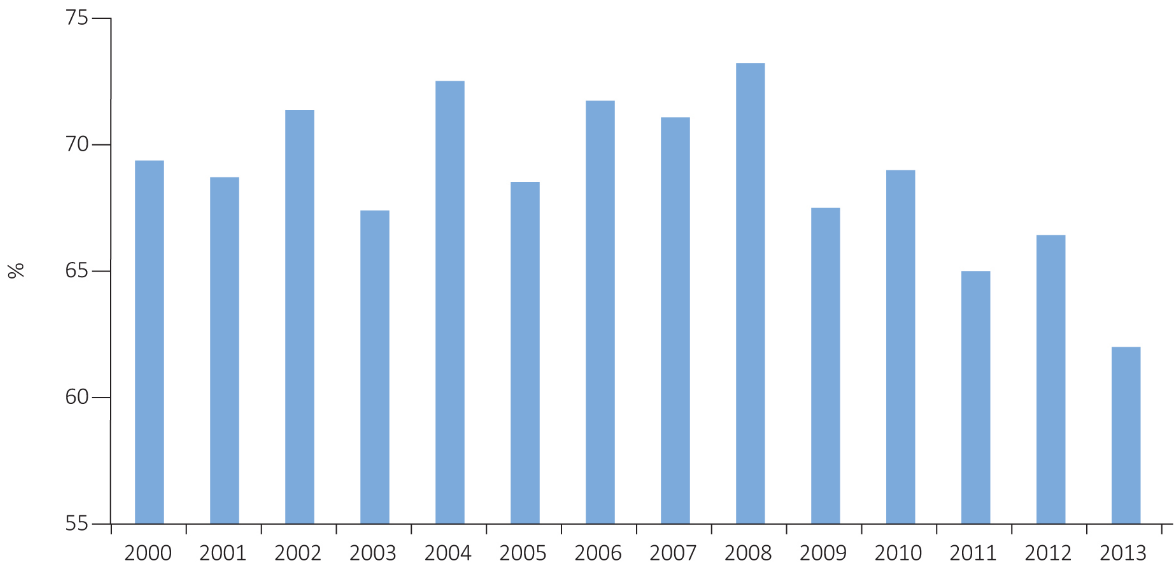

Figure 1 Greek energy import dependency 2000-13 (Eurostat, 2015)

In 2013, Greece was the 10th largest energy importer in the EU 28 (behind Malta, Luxembourg, Cyprus, Ireland, Italy, Lithuania, Portugal, Belgium and Spain) (Eurostat, 2015). Reports suggested that levels would begin to increase further, although the on-going financial crisis will undoubtedly have an impact on this (Michaletos, 2014). Importing energy is expensive, a situation that the Greek government would clearly like to address. For example, Greece imports nearly all of its oil and gas. In 2011, the associated fuel import bill was approximately US$16.5 billion. Reportedly, the current level is around US$20 billion (Stefanini and Oroschakoff, 2015).

As the country has abundant (largely unexploited) wind and solar power potential, there are ambitious plans to make much greater use of renewable energies. Over the next 5–10 years, development of the renewables sector is forecast to draw in significant investment. However, partly as a result of the country's economic problems, subsidies/incentives paid for some renewables-based generation are being reduced – this could deter some private sector investment.

There has been a renewed focus on the potential of the country's indigenous lignite resources. The present government had previously stated that, in order to minimise the cost of imported energy, it intended to increase the use of indigenous resources, primarily through the greater exploitation of the country's lignite for electricity generation. However, this view may have softened. Following the most recent election (of September 2015), in October 2015, the Minister of Energy stated that the energy policy of the newly-elected government will aim at reducing gradually the reliance of the Greek energy system on fossil fuels, plus the further promotion of renewable energies.

Alongside oil and gas, solid fuels (primarily lignite) are also a major energy source in Greece. These account for around a quarter of gross inland consumption. As a result, Greece is one of the EU member states that relies most heavily on solid fuels. However, there is no import dependence as all lignite is sourced from domestic mines. This reliance on indigenous lignite goes some way to counterbalancing the import dependency of oil and gas. Almost all lignite produced is used for electricity generation/cogeneration. Although lignite production has been partly opened to private sector companies, the state-owned energy company Public Power Corporation (PPC) remains the largest producer. The company has a license corresponding to 63% of total exploitable lignite reserves. To date, ~5% of these have been leased to the private sector via long-term contracts. A further 23% have yet to be leased or conveyed.

2 Greek energy policy

For some years, as with many other countries, Greek energy-related priorities were focused on safeguarding and managing energy resources such that they provided a secure, uninterrupted supply, capable of meeting national requirements. They also centred on the viable and sustainable development of the energy sector (from production through to end-use) in an environmentally-acceptable manner. The aim was to meet the country's energy needs by accessing a variety of energy sources that included an increased reliance on domestic resources and the greater uptake of renewable energies. In addition, in order to increase competitiveness, the strategy envisaged that the energy sector would be increasingly liberalised. Monopolies in the electricity and natural gas sectors would be ended; this move was expected widely to increase significantly the participation of the private sector. However, whereas some goals remain under consideration, others have been affected by recent political and economic events.

Following the elections of January 2015 that ushered in the left-wing Syriza party (The Coalition of the Radical Left), a number of significant changes were proposed for parts of the Greek energy sector. Thus, although a strong commitment to renewables remained in place, the new government announced plans for the greater use of domestic lignite resources, primarily for electricity generation, as well as development of a new major gas pipeline (the east Mediterranean gas pipeline). Because of the country's chronic economic situation, and irrespective of environmental concerns, Syriza's previously stated position was that it would reduce the level of imported energy, primarily through greater exploitation of domestic lignite. However, as noted, this may not now happen as recent government announcements suggest a gradual reduction in the use of all fossil fuels, coupled with the greater use of renewables. Alongside these measures, there will also be sustained emphasis on improving energy efficiency in general, viewed as an effective cost-effective means for simultaneously cutting emissions and reducing fuel poverty. Some observers suggest that in the medium term, the new government may need look again at issues around sustainable growth, as well as possibly reducing 'green' expectations.

A further important move has been the reversal of an earlier decision to privatise the Public Power Corporation (PPC) – the Greek government currently owns 51% of the company. PPC is responsible for generating ~72% of Greece's electricity from its 98 power plants; these are fuelled predominately by lignite, oil and natural gas. It also owns and operates major lignite mines at Ptolemais and Megalopolis. In 2014, despite strong protests from the workforce, the previous government approved legislation paving the way for the sale of 30% of the company. There were particularly strong protests over the proposed sale of the Florina power plant to foreign investors (Power Engineering International, 2012).

Some elements of the proposed PPC sell-off were based loosely on the model adopted in Italy in 1999 for the partial privatisation of the state-run generator ENEL. Until that year, ENEL had enjoyed a state monopoly on electricity generation, but was forced by law to sell 30% of its production capacity. This laid the groundwork for the opening up of the market and, with the cash flow it secured, allowed the company to expand into foreign markets and transform itself into one of the dominant players in the single European market. However, there were significant differences between the ENEL and proposed PPC models. Whereas the former was forced to sell 30% of its generation capacity, in the case of PPC, a new vertically integrated company ‘small PPC’ was to be created, comprising 30% of PPC's mines, generation and supply activities. This approach was proposed for the partial PPC sell-off to the private sector. Discussions focused on the possible sale of between four and six lignite-fired units.

An Implementation Law (4273/2014 (GG A’ 146/11.07.2014) detailed the units for sale. This contemplated the transfer of various assets to the new vertically integrated power company. These included the Amynteon I and II lignite-fired plants (total capacity of 600 MW), the existing Meliti I lignite-fired plant (330 MW), the generation license for the proposed Meliti II lignite-fired plant (450 MW), plus 903 MW of hydropower capacity, the Komotini gas-fired plant (485 MW), and PPC’s rights to extract lignite from the Amynteon (including the Lakkia mine), Kleidi, Lofoi Melitis, Komninon I & II, and the Vevi mines (in which PPC has concessions for 40% of the reserves).

The privatisation plan formed part of the effort to liberalise the energy market, one of the conditions demanded by EU and IMF creditors, prior to disbursement of the next tranche of Greece's €240 billion bailout. But in January 2015, the Syriza-led government announced that it would freeze privatisation plans and suitably restructure PPC. Halting privatisation was viewed as a crucial first step in the process of redeveloping the Greek energy sector (Anderson, 2015). However, such goals could take many years to achieve, and will require careful planning. A recent TUED working paper (Sweeney, 2015) identified four broad goals for reshaping the country’s energy and climate policy. These comprise:

- establish control over the country’s energy future (energy self-determination);
- secure a broad-based and inclusive process for developing and implementing a national energy transition plan;
- scale up publicly-owned renewable energy; and
- reduce fossil fuel dependency.

At the time, the last of these appeared to be at odds with Syriza’s stated aim of increasing the use of domestic lignite.

In March 2015, the government confirmed that Greece was unwilling to follow the EU’s energy strategy as it currently stood, and that any privatisation schemes for the country’s energy sector had been suspended. The previous coalition, centre-right New Democracy and the Socialist Pasok, had committed themselves to privatising the energy sector. However, the new government stated firmly that it intended to keep it under state control. Proposals for the privatisation of natural gas importer and distributor (DEPA) and PPC were abandoned (Euractiv, 2015a). However, under the terms of Greece’s most recent bailout, once again, the situation looks likely to change. Furthermore, there have been suggestions that Greece may look increasingly for cooperation with other non-EU countries. It appears that ties with Russia, a major gas supplier to Greece, are being strengthened – Russia currently supplies ~65% of the country’s gas.

Despite the government’s stated intention to stop all energy sector privatisations, under the terms of the last-minute financial bailout agreed with its creditors in July 2015, it appears that this may not be attainable. As part of the deal, Greece will have to sell-off/privatise its electricity transfer network (ADMIE – worth an estimated US$ 1.5 billion), operated by a wholly-owned PPC subsidiary. This marks a U-turn for the government who had strongly opposed earlier efforts to privatise the power grid, DEPA, and Greece's main utility PPC. The government considered the energy sector a strategic national asset that should remain under state control. This is not the first time that ADMIE has been earmarked for privatisation. In 2013, Greek officials began developing a plan to sell off 66% of the company's shares, with the Greek government retaining a minority share. Four companies were shortlisted to bid for the majority stake. When the current government came to power, privatisation plans were swiftly curtailed.

However, the current financing agreement with the institutions also provides a possible alternative way forward. This notes that by an agreed date, the Greek authorities must take irreversible steps (including announcement of a date for submission of binding offers) to privatise ADMIE, unless an alternative scheme is provided, with equivalent results in terms of competition and prospects for investment, in line with the best European practices and agreed with the institutions to provide full ownership unbundling from PPC.

Greece continues to attempt to improve its financial situation, in some cases, possibly at the expense of energy projects that the country is involved in. For example, Greece is a participant in the Trans Adriatic (natural gas) Pipeline (TAP), an important project that will provide EU countries with alternative sources and a gas supply route. The Greek section of the pipeline is 545 km in length. Initially, gas will come from the further development of Azerbaijan's Shah Deniz gas and condensate field. Greece has signed a number of political and technical agreements within this project. Despite the country's financial condition, it is considered unlikely that it would withdraw. It appears more likely that Greece will try to initiate a review of these agreements. Turkey, also a participant in this and other regional pipeline schemes, has stated that it would be willing to render financial support to Greece. The current Greek government has commented that it would like to get more benefits from the gas transit through the country's territory (Energy Central, 2015).

2.1 Economic impacts on PPC

The financial crisis continues to have major impacts on PPC's day-to-day operations. During the first quarter of 2015, reports in the media suggested that the company was owed more than €2 billion in unpaid electricity bills. The biggest share of the debts (~€1.33 billion) was attributed to households and small businesses. Major clients in energy-intensive industries owed ~€406 million, while medium-sized industries and corporations owed nearly €260 million. About €170 million was owed by state-run companies. The associated shortfall in income means that PPC has been forced to rely on its cash reserves, increasing the risk of destabilising the company's investment plans and impacting on planned future operations. For example, there were reports that because of the company's cash squeeze, PPC could withhold a €200 million down payment on a new €1.5 billion lignite-fired power project being developed (Ptolemais V – *see* Section 9.9.1). However, this payment has since been made. Based on agreements between PPC and the project's developers, the company will need to provide a further €200 million six months after the project's launch. Despite PPC's financial problems, the company considers that a major disruption to the country's power supply is unlikely as ~70% of Greek power comes from locally-mined lignite and renewables such as hydro, wind, and solar (in 2014, lignite provided 22,709 GWh, hydro 3906 GWh, oil 4521 GWh, gas 7456 GWh, and renewables 8583 GWh).

The financial crisis is also impacting on the private sector development of new renewables-based power projects – the threat of exit from the Euro has meant that some investors have delayed planned initiatives. Reports suggest that so far, at least four major solar and wind projects have stalled.

Recent years have seen a dramatic increase in the level of domestic fuel poverty. In the last few years, as the price of heating oil and electricity increased significantly, many households were affected. In 2012 alone, PPC's average tariff for low voltage customers increased by 9.2% (compared to 2011) and tariffs for medium voltage customers increased by 16%. Furthermore, Greek consumers currently pay 35% more for natural gas than the remainder of the EU. By 2013, a third of Greek residents were behind with their electricity bills. As a result of unpaid bills, thousands of households had their electricity supply cut off. A popular alternative (in, for instance, Athens and Thessaloniki) was to burn wood. However, although cheaper, this generated a lot of smoke, and increased local air pollution. As part of its election commitments, Syriza promised to provide a limited amount of free electricity for 300,000 of the poorest households. For such a plan to be financially viable, attention has been increasingly focused on the greater use of Greek lignite for power generation.

At the moment, more than 93% of Greece's energy is provided by fossil fuels, compared to the European average of 75%. Domestic lignite currently produces ~48% of the country's electricity (not taking into account imports of 9857 GWh). In the light of the many immediate challenges facing the present government, there is a growing consensus within Greece that fossil fuel dependency is a problem that can only be addressed over the longer term.

Despite any associated environmental drawbacks, earlier government announcements suggested that the country's lignite resources would be further utilised, although more recent announcements have made their position less clear. Syriza had announced plans for the construction of new lignite-fired power plants, but at the moment, only one such plant is under development (Ptolemais V) and no other lignite-fired power plants are planned for the foreseeable future (a second project, Meliti II, was licensed in 2009 but has yet to make any real progress). Syriza expects any new lignite-fired generating capacity to generate power 'as cleanly as possible' through the use of suitable clean coal technologies (CCTs). However, as a consequence of the country's economic depression, it appears that environmental issues and climate change in general may have been pushed down the political agenda (Montague, 2015).

3 The Greek energy sector

Over the past decades, up to the time of the country's economic collapse, the Greek energy system had been characterised by a steady increase in energy demand. Much was based on a high consumption of fossil fuels, a situation that prevails. For strategic reasons, following the oil crises of the 1970s, lignite was adopted as the main fuel for power generation. The Greek energy sector remains heavily dependent on fossil fuels, most of which are imported. The country has only limited indigenous energy resources, lignite being the most significant – this is used to generate a significant proportion of the country's electricity. Oil and gas reserves and production are minimal and there is a heavy dependence on imports. In recent years, despite the country's current economic problems, imports of natural gas have increased substantially. It is estimated that around 65% of Greece's energy needs are currently being met by imports. The balance is covered by indigenous sources, mainly lignite and renewables (Katsivelis, 2013).

The energy sector in Greece has a higher contribution to growth value added (GVA) and employment than most other EU countries. Prior to the onset of the economic collapse, a number of plans were being developed with a view to changing the sector. These included a reduction in the level of some fossil fuels used and their replacement with renewables, an increased reliance on imported natural gas, the privatisation of major energy assets (such as DEPA, PPC, and Hellenic Petroleum – ELPE), the liberalisation of the electricity and natural gas markets, and general improvements in energy efficiency. However, recent changes in the country's political make-up and direction has curtailed some of these aspirations, as least for the near term.

Significant investment in the energy sector is needed. In the period up to 2020, various forecasts suggest a figure of between €22 and €30 billion. This will be needed for upgrading existing power plants, the construction of new generating capacity, improvements to the grid, and the installation of more renewable energy sources (Papastamatiou, 2013). It will include €1.4 billion for the lignite-fired Ptolemais V plant, currently under construction. However, in the foreseeable future, no other lignite- or gas-fired power plants are planned (either by PPC or the private sector). Thus, the scale of investment noted above may be overly optimistic.

3.1 Oil

For some time, oil has been the dominant energy source in Greece. In recent years, it has accounted for between 45 and 55% of the country's total primary energy supply (TPES). Oil demand peaked at 450 kb/d in 2007, but has since dropped sharply – in 2011, it was 347 kb/d, and in 2012, it was 318 kb/d (BP, 2014). Typically, transport consumes around half of Greece's total oil demand, followed by residential use (~18%) and transformation/energy (~16%) (OECD/IEA, 2014).

Recent estimates suggest that the country has proved oil reserves of ~10 million bbl (Theodora, 2015). Crude oil production is currently only around 6500 bbl/d, whereas consumption is 450,000 bbl/d. As a result, the bulk of the country's oil requirements are met via imports. Most crude oil is imported from OPEC countries and Former Soviet Union (FSU) countries. Previously, more than half came from Iran.

However, as a result of the sanctions imposed on Iran for continuing with its nuclear programme, the supply reduced dramatically. Currently, a significant proportion (~44% in 2012) is supplied by Russia (Onti, 2013). Greek oil production is limited to small amounts from the Prinos (Kavala) offshore oilfield (Michaletos, 2011). In 1990, 0.8 Mt/y of crude oil was produced, but by 2003, this had fallen to 0.1 Mt/y – it has since remained at this level (BP, 2014).

In recent years, oil consumption has fluctuated, reflecting Greece's economic troubles, although recently, the level of imports had begun to increase again (Figure 2). However, in the near term, because of uncertainties over the country's economic recovery, growth in oil consumption is expected to remain muted (BMI, 2013).

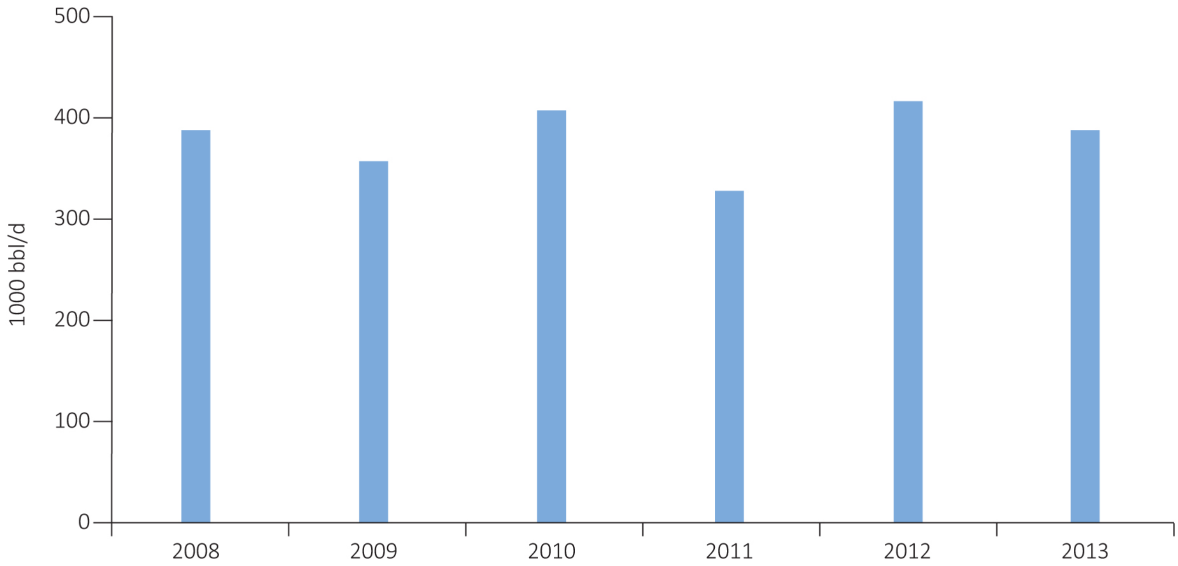

Figure 2 Crude oil import dependency 2000-13 (OPEC, 2014)

Oil imports currently cost Greece around €10 billion a year (reportedly ~5%/y of GDP). The country pays ~€1 billion (US$1.4 bn) a year alone for oil supplies for power generation on dozens of islands that are not connected to the national grid (Energypedia, 2014). By 2016, the cost of imported oil is expected to be US$ 10.8 billion, rising slightly to US$10.9 billion by 2021 (BMI, 2013).

Although proven oil reserves and production are limited, there are indications that there may be significant untapped reserves both on- and off-shore. With the aim of reducing energy imports, in 2013, the Greek government selected two consortia led by Energean Oil and Hellenic Petroleum (Greece's biggest refiner) to search for oil and natural gas in two blocks in the western part of the country. The Greek Ministry of Energy suggests that potentially, revenues from these two regions could reach about US$ 14 billion over the next 25 years (Reuters, 2013). Territorial disputes with neighbouring Turkey have prevented a search for oil in the east of the country.

Off-shore potential could be even greater – there may be at least US$600 billions worth of gas and oil reserves located under the seabed around Greece, particularly under the Aegean and Ionian Seas. The US Geological Society estimates there are around 22 billion barrels of oil under the Ionian Sea, off western

Greece, and another 4 billion barrels in the northern Aegean Sea. There is also an estimated 2 billion m^3 of natural gas off-shore of the Greek-held part of Cyprus (Aljazeera, 2013). Other regions of Greece in the Ionian Sea and in the south of Crete (a total 225,000 km^2) are being promoted for further seismic research. In early 2014, the results of offshore tests from these two areas (undertaken by Norwegian firm Petroleum Geo-Services) were said to be promising.

For some time, a policy aimed at the eventual privatisation of Greek oil and natural gas assets was underway. As part of this, in January 2014, an agreement was signed between Energean Oil (the Greek company exploiting the reserves) and BP Oil International, for the purchase (US$ 500 million) of the Prinos oil field reserves. The agreement was expected to result in the drilling of new wells, and the doubling of the present output (Menzel, 2014). However, because of the country's change in political makeup and plans to stop all energy-related privatisations, the current situation remains unclear.

There are currently twelve producing wells and two injector wells active in the Prinos field. Production peaked in 1985 but has since declined significantly. However, an extended drilling campaign is under way to increase production and recover remaining reserves. Although Prinos is a relatively mature oil field, there is still potential to increase recovery. Recent efforts have increased output from the field. To increase production further, enhanced oil recovery (EOR) using CO_2 is being considered.

In the future, Greek oil production is expected to be increasingly developed via joint ventures with major foreign investors and production companies. This includes the development of several major pipeline projects to supply Greece and elsewhere in the EU. Potentially, they could also make the country a transit centre, passing on oil to other countries in the region.

The biggest player in the Greek oil industry is Hellenic Petroleum (ELPE), one of the leading energy organisations in southeastern Europe, and one of Greece's biggest industrial companies. Main business activities comprise refining and marketing of petroleum products (ELPE owns and operates three of Greece's four refineries), petrochemicals and natural gas, and the exploration and development of hydrocarbon resources. The company also operates the country's first private combined cycle gas turbine (CCGT) power plant.

Some of Greece's oil-fired power generating capacity is on the mainland, although most plants are located on various Greek islands. Some examples of PPC-owned plants are given in Table 1.

Table 1 Examples of oil-fired PPC power plants on Greek islands

Plant	Location	Capacity (MW)	Fuel
Aliveri	Euboea	300	HFO
Linopermata	Crete	279	HFO, diesel
Soronis	Rhodes	232	HFO, diesel
Mytilene	Lesbos	92	HFO, diesel

In 2012, PPC's Generation Division reported that since 2011, fuel costs (both oil and natural gas) for its power plants had increased by €112.1 million. However, as a result of the current dip in demand resulting from the economic recession, the overall quantities of oil and gas consumed were less than in previous years. This mainly affected the company's gas-fired plants – compared to 2011, production from these fell by 27.9% (PPC Annual reports, 2012 and 2013).

3.2 Natural gas and liquefied natural gas (LNG)

The Public Gas Corporation (DEPA) was first established in 1988, although natural gas was not introduced in Greece until 1996 – the first gas consumer was connected to the DEPA grid in November of that year. With the main intention of reducing oil consumption, the use of gas was promoted strongly through tax rebates. However, as a consequence of the economic crisis, from 2010, gas consumption-related taxes have since been increased substantially.

Greek proven gas reserves are small – estimates suggest between 990 million m^3 and 1 billion m^3. Set against the scale of demand, domestic production is negligible. This is limited to the nearly-depleted South Kavala gas field, in the Kavala Gulf of the Aegean Sea. Because of its strategic location, this is currently being considered for conversion into an underground gas storage facility, to be supplied with imported gas via pipeline.

Up to the point of the country's financial collapse, electricity demand had been increasing. To partly meet this, new gas-fired power stations were built and as a result, for some years, demand for natural gas increased steadily (OECD/IEA, 2014). In 2010, demand was 4.5 billion m^3; in 2011, this increased to nearly 4.7 billion m^3. The vast majority was imported (Theodora, 2015), a significant proportion coming from Russia (BP, 2014). By 2016, the amount is forecast to be 5.3 billion m^3, rising further to 6 billion m^3 by 2021 (BMI, 2013). However, future political and economic decisions could have a major effect on the scale and timing of these forecasts. Despite the high import dependency, the country has very limited gas storage capacity, hence the interest in the South Kavala facility.

Gas is supplied by pipeline mainly from Russia, Azerbaijan (via Bulgaria) and Turkey, with much of the remainder coming in the form of liquefied natural gas (LNG) from Algeria. Russia has been the main gas supplier since imports began, although its share has decreased from 85% in 2005 to 54% in 2010, supplanted by supplies from Algeria and Turkey (IEA Greece, 2011; OECD/IEA, 2014). There are plans for LNG imports from Qatar to begin. In 2011, Greece imported around 1.3 billion m^3 of LNG. Depending on how rapidly the country's economy revives, by 2021, potentially, this could increase to around 4 billion m^3 (BMI, 2013).

LNG is imported through a terminal at Revithoussa. This handles the bulk of the gas from Algeria and is in the process of updating and expansion (due for completion in 2015). As part of this, DEPA has invested €130 million in the terminal. A second terminal had been planned for Palei Galini, on Crete. However, plans for this were subsequently abandoned as it was determined that interconnection with the mainland would be more economical and would help promote the island's high renewable energy potential.

In recent years, the country's economic crisis had been reflected in the level of industrial activity taking place and the amount of gas imported (Figure 3). This fell in 2009-10, but has since increased again.

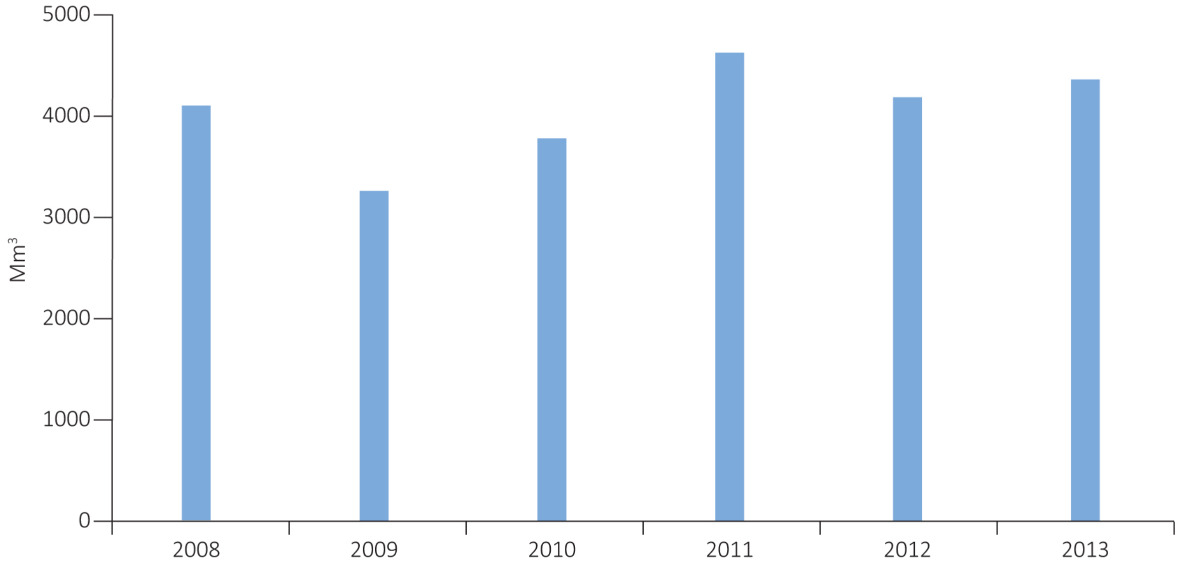

Figure 3 Greek natural gas imports (million m^3) (OPEC, 2014)

Gas imports are a significant component of the country's energy bill. In 2016, imported gas will cost an estimated US$2.39 billion, forecast to increase to US$2.7 billion by 2021 (BMI, 2013). However, in February 2014, it was revealed that Greece had negotiated a price reduction with Russia, its biggest supplier. The agreement between Greece's DEPA and Russia offered a 15% price cut and was applied retroactively (from July 2013). The current deal has since been extended by another 10 years to 2026. It will provide Greece with more flexibility on the amount of gas it is obliged to buy from Russia. Russia's Gazprom charges other European customers an average of US$393 per thousand m^3 of gas. The price charged to Greece was US$467, although this has now been reduced to US$395 (Stamouli, 2014).

Despite the cut in the price of Russian gas, Greek consumers continue to have some of the highest gas prices in Europe (Euractiv, 2015a). Industry observers have commented that DEPA's near-monopoly (90% of the wholesale and 51% of the retail market) has helped it dominate the market and make excessive profits. Despite a significant decline in gas demand, in the past few years DEPA has continued to make significant profits (€190.2 million in 2011, €106.3 million in 2012 and €146.7 million in 2013,).

DEPA is the largest natural gas corporation in Greece and owns and operates the domestic high and medium pressure natural gas pipeline grid. It is 65% owned by the state, with the remaining 35% controlled by the Hellenic Petroleum Group (Michaletos, 2011). Some of the Greek gas (and oil) industry has been privatised. The previous government intended that further assets to be sold would include ELPE, DEPA, and the state-controlled network distributer DESFA. In December 2013, Azerbaijan's state-owned oil and gas producer SOCAR was successful in its bid for a 66% stake in DESFA, for €400 million. The Greek state was to retain the remaining 34%. However, in November 2014, the European Commission opened an in-depth investigation to determine whether the acquisition was in line with EU merger regulations. As yet, no decision has been announced.

Although current proven Greek reserves of natural gas are small, it was announced early in 2014 that the country could have up to 4.7 trillion m^3 of untapped reserves (Natural Gas Europe, 2013). Most are thought to be in the Mediterranean basin south of Crete. These estimates have yet to be validated. However, if gas (and oil) reserves are confirmed and deemed to be viable, in the longer term, their exploitation would be of considerable economic benefit to Greece.

Natural gas is an important commodity. In 2010, it accounted for 12% of Greek TPES, up from 10% in 2009 (IEA Greece, 2011). Around 16% of Greece's electricity is generated by gas-fired power plants (Vamvuka and others, 2013). However, in 2014, the market model changed and some gas-fired plants lost the protection that had been in place for the last five years. This resulted in a steep decline in output and led to an increase in imports of electricity, mainly from Bulgaria and Italy (Euracoal Market Report, 2015).

In recent years, natural gas penetration in electricity production accelerated as the deregulation of electricity and natural gas markets progressed. The main gas-fired power plants are shown in Table 2; examples of plants are shown in Figures 4 and 5.

Table 2 Main gas-fired power plants (DEPA, 2014)

Existing plant	Plant owner	Installed capacity (MW)	Comments
Agios Georgios, Attica	PPC	160	Converted from oil to gas firing. Started up on gas in 1997 Main plant suppliers included BPL, TPE, Ansaldo
Komotini, Thraki	PPC	485	Started up 2001-02. DEPA supplies gas. Suppliers: Ansaldo, ABB, AEGEK
Lavrio V, Attica	PPC	385	CCGT. Started up in 2006. Suppliers: Alstom, GE, METKA, Empresarios Agrupados, Expo Power Systems SA
Lavrio Megalo, Attica	PPC	560	CCGT. Gas and oil fired. Started up 1997-99. Suppliers: Alstom, METKA
Energeiaki Thessalonikis (ENTHES)	ELPEDISON Power	395	Started up in 2006. First gas-fired IPP in Greece. Suppliers: CMI, GE, Tosi, Alstom, VA TECH, AEGEK, Foster Wheeler
Thisvi power plant, Viotia	ELPEDISON Power	422	Gas and oil fired. Suppliers: Nooter, Ansaldo, Aktor
Distomo I and II, Beotia	Aluminium S.A.	334 445	Started up in 2008 and 2011.Distomo I cogen plant produces steam and power for Aluminium of Greece. Suppliers: Alstom, GE, Siemens, METKA
Heron I plant, Viota	Heron S.A. (GDF SUEZ/ GEK TERNA)	148	Open cycle (peak) plant. DEPA supplies gas. Suppliers: GE, TERNA
Heron II plant, Viota	Heron S.A. (GDF SUEZ/ GEK TERNA)	432	CCGT. Started up in 2010. Claimed to be the most efficient plant in Greece (58%). Suppliers: Doosan, GE, TERNA
Korinthos Power, Attica	Motor Oil (Hellas) S.A/Mytilineos. S.A.	437	CCGT. Started up in 2011
Corinth Refinery	Motor Oil (Hellas) S.A.	45	Fired on refinery gas and propane
Aliveri, Euboea	PPC	427	Started up in 2013 Suppliers included Alstom, METKA, Israel Electric
Psittalia, Attica	EYDAP	12.9	Athens Water Supply & Sewage Company plant
Megalopolis V, Central Peloponnese	PPC	832	EIB provided ~€150 million to PPC towards project. TERNA awarded GE contract to supply equipment. Plant still commissioning in November 2015

Figure 4 The 132 MW gas-fired Chania power plant, Crete (photograph courtesy of PPC)

Figure 5 The oil- and gas-fired Energy Centre of Lavrio (photograph courtesy of PPC)

Apart from power generation, gas is also used for domestic and commercial heating, and for a range of industrial applications that include chemical manufacture, iron and steel production, and general engineering. In the future, once the Greek economy begins to recover, the consumption of natural gas is expected to grow more robustly than oil (BMI, 2013). Alongside aims to increase the use of gas for such applications, DEPA is also promoting it strongly for newer uses such as cogeneration, use in fuel cell technology, and greenhouse heating. Since 1990, PPC has converted a number of power stations for cogeneration, some supplying heat to district heating schemes; around 4% of Greece's electricity is generated by such plants.

For the foreseeable future, the bulk of gas supply will continue to be provided by imports. The construction of the natural gas transportation grid has been one of the largest energy infrastructure projects in recent years. There are three entry points, namely the Greece-Bulgaria border (where gas enters via a central pipeline from Russia), the Greece-Turkey border (where the grid links with the

Turkish system), and at the island of Revithoussa in the Gulf of Pachi near Megara, where there are facilities to receive, store, and gasify LNG from Algeria.

3.3 Nuclear energy

Although Greece has established the Greek Atomic Energy Commission, the country has no nuclear power plants and no intention to build any in the foreseeable future. This is based partially on the fact that that country is relatively small and earthquakes occur frequently in the region (Greek Atomic Energy Commission, 2010). Public opinion is firmly against the deployment of nuclear power in Greece.

3.4 Renewable energy sources

In recent years, the country has put in place key priorities and binding policies to encourage the generation of electricity from renewable sources. The reasons behind this are similar to those in other countries, and focus on sustainable development, improved security and diversification of energy supply, and environmental protection. In Greece, there are various policies aimed at promoting the development and deployment of renewables-based generating systems. Electricity produced by these sources is incentivised and supported by means of a combination of feed-in tariffs (FITs), subsidies, tax exemptions, and a net metering scheme. In addition, where electricity is supplied to the grid, it is given priority (Maroulis, 2013).

As elsewhere, renewables have been reliant on state subsidies – against the background of the country's economic problems, this has proved expensive. As noted, the use of renewables for electricity generation has been stimulated through, for instance, generous feed-in tariffs. By February 2013, these had created debts of €301.7 million for the Greek government. Largely as a consequence of the economic crisis, the government has since taken steps to weaken or remove FITs. In August 2012, FITs for solar power were reduced (for new contracts only) and Parliament (in November of the same year) voted to impose a temporary tax on all renewables revenues. Before these measures, Greek tariffs on solar power were amongst the highest in the EU. In June 2013, FIT cuts were enacted that were enforced retroactively, with an additional round of retroactive cuts proposed in early 2014 (REN 21, 2015). The cuts in state payments saw the closure of numerous small generators. Some others were bought by foreign energy multinationals (Montague, 2015). In 2014, further steps were taken to weaken or remove FIT policies. Further reductions in incentives may follow.

Part of the Syriza-led government's strategy is to reduce the country's dependence on imported sources of energy. Along with the use of indigenous lignite, the increased use of renewables is viewed as an important element of this (Anderson, 2015). Greece has large untapped renewable energy resources – for example, it has an average of 300 days of sunshine each year and also has considerable wind power and some geothermal potential. In 2012, Greek primary production of renewable energy amounted to 2.275 Mtoe. This comprised 14.5% from solar, 53.3% from biomass and wastes, 1% from geothermal, 16.6% from hydro, and 14.6% from wind (Eurostat, 2012).

So far, most renewables-based electricity has been generated by the private sector, although some is also produced by PPC Renewables – the company operates a combination of wind parks, small hydroelectric plants, and photovoltaic arrays. Some facilities are operated via joint venture arrangements with other generators or the private sector. Total PPC (including joint companies) combined capacity (operational and under construction) is ~200 MW (PPC Corporate Social Responsibility and Sustainability Report, 2012). Depending on their location, electricity is fed into the mainland interconnected system, or to the non-interconnected systems on the islands.

In general, Greek renewable energy policy is guided by EU requirements. There is a legally binding target for renewable sources to generate 40% of the country's electricity by 2020 (IEA Greece, 2011). In 2010, Greece endorsed its National Renewable Energy Action Plan (NREAP) covering the period 2010 to 2020. This ambitious plan aims to reform the country's energy sector such that by 2020, 20% of primary energy will be provided by renewables (40% electricity, 20% heat, and 10% transport) (IRENA, 2013). In the electricity sector, the biggest contributions are expected to come from existing hydro, plus new wind and PV capacity. In particular, both wind and PV have experienced significant growth during the past few years. By 2013, wind capacity amounted to more than 1.8 GW, with PV at 2.58 GW. Although the country's financial problems have undoubtedly hampered the process, there has been a steady increase in the amount of renewables-based capacity installed and investment made (Table 3). However, the various cuts in incentives, coupled with the current general difficulty of raising funds for new projects, is likely to have an impact of the viability of some projects.

Table 3 Greek renewables investment (2006-12) (Papastamatiou, 2013)

Year	Total capacity at year end (MW)	Amount added (MW)	Annual investment (million €)
2006	957	203	319
2007	1037	131	208
2008	1326	234	396
2009	1548	256	440
2010	1860	273	558
2011	2594	614	1154
2012	3638	1220	2360

In 2012, the share of renewables in gross electricity consumption reached 18.4%, compared to a NREAP intermediate target of 18.8%. Hydropower contributed 8.0%, wind energy 5.5%, solar PV 2.7%, and biomass 0.3% (Vamvuka and others, 2013). At the end of 2013, the Greek electricity sector included more than 3 GW of hydro-based generating capacity, plus a further 3.6 GW based on other renewables (renewables-based systems on the non-interconnected islands amount to ~450 MW). For 2013, the share of renewables reached ~27% of gross electricity consumption, compared to an NREAP intermediate target of 21.8%.

As noted, there is an ambition goal for the country to generate 40% of its electricity from renewable sources by 2020. The aim is to produce this using a combination of ~7.5 GW of wind power, together with

2.2 GW of PV, 250 MW of CSP plants, 120 MW of geothermal energy, 250 MW of bio-energy installations (biogas and solid biomass), 250 MW of small hydro plants, plus an additional 350 MW of larger hydro plants and 880 MW of pumped storage (MEECC, 2011). In the period 2010-20, forecasts estimate that €16.5 billion will need to be spent in order to increase renewables capacity to the levels suggested (Table 4).

There is also a national target of 10% renewable energy in the transport sector. The largest contribution is expected to be provided by biofuels. In 2012, renewables' share in the transport sector was only ~1%. However, national regulations oblige Greek refineries to blend at least 5% of biofuels in their production. Currently, only biodiesel is being commercialised in Greece. Around two thirds of the production is imported, the rest being produced locally, mainly from sun flowers and rapeseed. To date, bioethanol as well as second and third generation biofuels have not been introduced in the Greek market.

Table 4 Investment in renewables required (2010-20) (Papastamatiou, 2013)

Technology	Investment needed (€ million)
Large hydro	650
Small hydro	137
Pumped storage	1672
PV	5508
Solar thermal	1220
Wind	6710
Geothermal	264
Biomass/biogas	530
Total	16,591

In the future, renewables are expected to be of greater importance for both the mainland and the islands that lack connection to the mainland grid – a major priority for many is their eventual interconnection. This would result in the closure of some older island-based oil-fired plants, plus the development of local renewables-based generation facilities (using wind, solar and geothermal) and supply of the excess electricity to the mainland via new grid connections (MEECC, 2011). An estimated €5 billion will be required for grid reinforcement and new interconnections.

In the period up to 2020, electricity generation from most forms of renewable energy is forecast to increase (Table 5), although as noted, economic constraints could delay some projects.

Table 5 Electricity from renewable source (2010-20) (IEA Greece, 2011*)

	2010		2015		2020	
	MW	GWh	MW	GWh	MW	GWh
Hydro						
Up to 10 MW	197	754	230			
>10 MW	3018	6703	3171			
Geothermal						
	0	0	20	123	120	736
Solar						
PV	200	172	29250			
CSP	0	0	30	86	250	714
Wind						
Onshore	1297	2741	2150			
Offshore	0	0	0	0	300	672
Biomass						
Solid	20	73	20	73	40	364
Biogas	40	194	60	431	210	895

*citing data from NREAP, 2010. Table updated using data from PPC. S.A., October 2015)

- **Large hydropower**

Greece is a mountainous country with most of its mountains located in the north western region. This area is particularly suitable for hydroelectric applications. Hydroelectricity accounts for ~16% of Greek installed generating capacity and makes up ~40% of the country's total renewable energy capacity. All major Greek hydro facilities are owned by PPC; capacity of individual larger plants varies between 19 and 437 MW. The company also owns ~30% of all small hydro capacity.

At the end of 2013, the Greek electricity sector included more than 3 GW of hydro-based generating capacity. Total theoretical hydropower is 80 TWh/y and the economically exploitable level is around 12 TWh. To date, only ~40% has been developed. Average annual electricity production varies, typically between 3500 and 6700 GWh.

Depending on the availability of water, annually, hydro power is responsible for between 0.6 and 2.1% of TPES, and generates between 5% and 12% of the country's electricity (Vita and others, 2010; Eurostat, 2012). There has been little growth in the hydro sector over the past decade. According to the Greek NREAP, power generation from hydro should be increased through the addition of 250 MW of small hydro plants, 350 MW of new large hydro capacity, and 880 MW of pumped storage plants (IEA Greece, 2010). An example of a Greek hydro facility is shown in Figure 6.

Figure 6 The 116 MW Platanovrisi hydroelectric facility

- ### Small scale hydropower

As of August 2015, Greece had an installed capacity of 224 MW of small (<15 MW) run-of-river hydro power plants. Most only generate during the Greek Winter and Spring. There are around 100 such plants currently operating, located mainly in Epirus, Macedonia and the Peloponnese. The country's total economic potential is estimated at 1–2 GW.

- ### Solar energy

Within Europe, the leaders for solar PV per inhabitant are Germany, Italy, Belgium, Greece, and the Czech Republic. Greece has high levels of solar irradiation with an average global horizontal irradiation level greater than 1500 kWh/m^2. Solar energy is used directly for heating water – there are around 4 million m^2 (2.9 GWth) of solar thermal systems installed, the second largest total capacity in Europe after Germany. The use of solar for electricity generation is much smaller. However, encouraged by high feed-in tariffs, recent years have seen a significant increase in PV-based generating systems. At the end of 2011, PV capacity amounted to 610 MW. By the end of 2013, it had increased to ~2.6 GW, surpassing the national PV capacity target of 2.2 GW set for 2020 (REN 21, 2015).

The sector comprises around 14,500 small- and medium-sized plants, plus eight larger PV power plants of between 1 MW and ~4 MW, built mainly post-2009. The biggest is a 4.3 MW unit in Florina. Various projects have also been proposed that include a 50 MW facility at Megalopolis and a 200–300 MW plant in Kozani. Most existing PV capacity is linked to the main electricity grid, with only ~6% installed on the non-interconnected islands.

At the moment, there are no concentrated solar power (CSP) plants installed in Greece. However, there are some sites with direct irradiation levels in excess of 2000 kWh/m^2/y on some southern Greek islands – some may have potential for CSP systems. Several (with a combined total of 425 MW) are currently under consideration. There is a national CSP target of 250 MW for 2020. It is estimated that overall, at least 7% of Greece's electricity could be produced by solar energy sources. However, ample sunshine means that the available potential could push this figure higher. In the southern regions, there can be more than 3000 hours of year-round sunshine (Michaletos, 2011).

- **Wind power**

Greece has some of the most attractive sites in Europe for the exploitation of wind energy. In many parts of the country, wind resources are characterised by a profile of more than 8 m/s and/or 2500 wind hours a year. Average capacity factors are around 25% for the mainland and 30% for the islands. Estimates suggest that the economic wind energy potential of Greece is between 10 and 12 GW. At the end of 2013, 1.8 GW of wind power capacity had been installed. In recent years, average capacity addition has been around 70–80 MW a year (Figure 7).

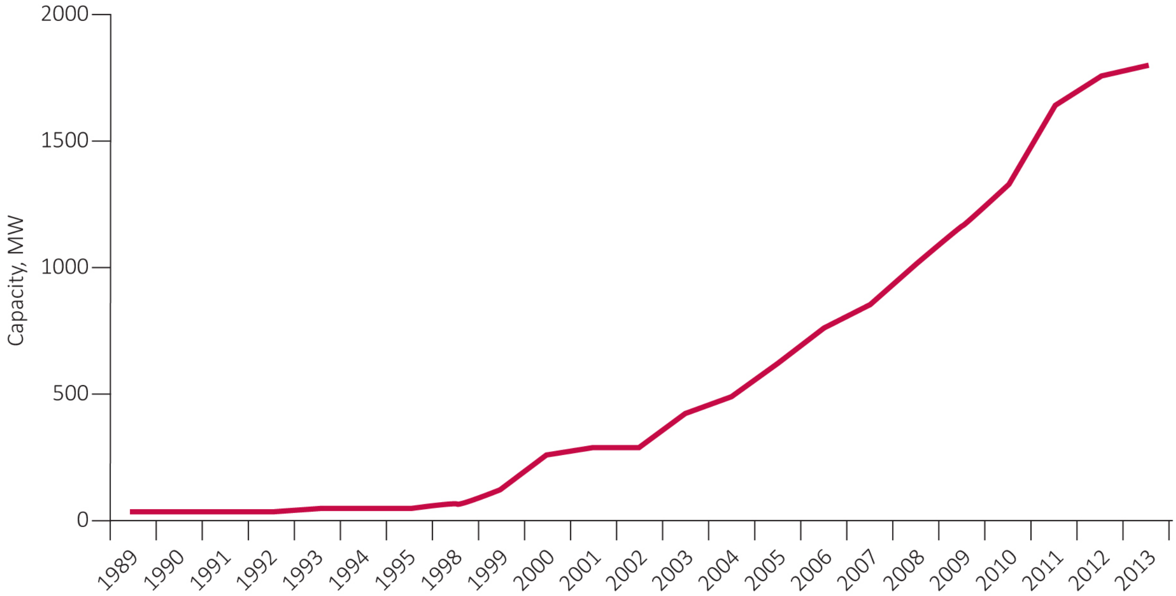

Figure 7 Total installed wind power generating capacity (MW) (Papastamatiou)

Nearly 300 MW of wind capacity has been installed on non-interconnected islands – ~70% of this total is on Crete (Figure 8). Various organisations are involved in the deployment of wind power systems; for example, at a cost of €16.2 million, PPC Renewables (PPCR) is building six new wind parks in the Aegean islands with a total capacity of 13.5 MW (PPC, 2013a).

There is a national capacity target to achieve 7.5 GW of wind capacity by 2020. Some 300 MW of this would be offshore. Wind parks continue to be constructed in various suitable locations and some forecasts suggest that wind power could eventually meet ~15% of the country's electricity requirements (Michaletos, 2014). At the moment, the biggest six players active in the Greek wind sector are EdF, PPC Renewables, ELLAKTOR, ENEL Green Power Hellas, TERNA Energy, and Iberdrola Rokas. In some cases, such companies are active in several areas of renewable technologies. For example, PPC Renewables operates 23 wind farms (81.1 MW), 15 small hydroelectric plants (63 MW), and 11 PV power plants (0.7 MW). This represents around 5% of the Greek renewables sector. There is additional capacity under construction, plus a further 308 MW of projects being developed (PPC Renewables, 2014). Similarly, ENEL Green Power Hellas operates a combination of wind (199 MW), solar (77 MW) and hydro (19 MW) facilities.

Figure 8 Wind park at Sitia, Crete (photograph courtesy of PPC)

- ### Geothermal energy

Some parts of Greece have potential for geothermal-based energy production, although at the moment, this remains limited – it is restricted mainly to direct uses such as heating greenhouses, fish farming, spas, and space heating. In 2007, the total thermal capacity was around 75 MWth. However, the technical potential for direct geothermal applications is estimated to be in excess of 1000 MWth (GEOFAR Project, nd). Two high enthalpy geothermal fields, on Milos Island and Nisyros Island have been identified; both areas are leased to PPC Renewables (PPCR). Milos and Nysiros have a combined potential of ~25 MWe (GEOFAR Project, nd). In 2011, a national target (upper limit) was set to achieve 120 MW of capacity by 2020 although this limit was later removed.

Four areas are currently leased to PPCR for exploration and development. PPCR is obliged to install capacity of at least 8 MW on Lesbos, 5 MW on Milos, 5 MW on Nisyros, and 5 MW on Methana). Four new areas (Akropotamos, Sperchios Basin, Sousaki and Ikaria island) are pending (awaiting the signing of contracts) leasing to PPCR (exploration rights for high enthalpy resources). However, due to the financial crisis all investment in the fields has been delayed.

Despite the large high-enthalpy resources in the active Aegean volcanic arc, no electricity is currently generated from geothermal resources, although some locations appear to have adequate resources to merit the installation of generation systems. Historically, exploration for suitable sites has been carried out in several parts of the country. Low, middle and high enthalpy fields have been identified; in particular, parts of Macedonia, Thrace and the Aegean Islands show promise.

In a number of locations, low enthalpy geothermal fluids (at 27–60°C) are currently used for a variety of applications. Low enthalpy fields (indicating deeper medium enthalpy resources) are located on the islands of Miocene, Chios, Lesbos and Samothraki (Mendrinos and others, 2006). High enthalpy resources have been identified in the islands of Milos and Nisyros in the Aegean volcanic arc. Several island-based projects are in the process of being developed, mainly by PPC.

- **Biomass**

Biomass has significant potential for energy production, especially through the use wastes and residues from the agricultural, industrial and residential sectors. To date, although a considerable proportion of Greek renewable energy supply is provided by biomass, most of this lies outside the electricity generation sector (Europa, 2013). Only a small number of biomass-based projects generate electricity in Greece, mostly using municipal waste to produce biogas. There are currently around 12 individual biomass-based projects with a total installed capacity of ~50 MW. The Greek NREAP has a modest target of 250 MW by 2020, but the expectation is that it could reach around 300 MW by this date. In terms of renewables-based electricity generating capacity, biomass is currently only fourth. However, for the provision of heat, it is expected to remain the largest contributor, albeit with a modest growth rate from just over 1000 ktoe in 2010 to ~1200 ktoe in 2020. Biomass is currently used for (mainly rural) household heating, heating of buildings in the public and commercial sector, and by small autogenerators (100 kWe–5 MWe). The Greek agricultural sector accounts for >5% of GDP, nearly three times the EU average of 1.8% – there could be opportunities for the sector to provide residues as well as grow suitable energy crops.

The use of biomass for larger scale electricity generation projects is currently limited as a cost-effective supply chain is lacking. If developed, this would be a major factor in encouraging wider application, particularly in more isolated parts of the country that lack access to heat and/or electricity. The weak supply chain is partially attributable to the limited interest so far shown by potential investors – an effective supply chain would require significant investment for infrastructure development.

There is currently little emphasis on the production of energy crops. There are no areas specifically dedicated to the cultivation of short rotation forestry or perennial grasses although this situation may change as the government has announced that such activities will be encouraged by the Programme for Rural Development. In addition, on-going EU Common Agricultural Policy reform is helping to encourage the growing of energy crops, avoid land degradation, and reinvigorate rural economies. Greece has ~60,000 ha of previously set-aside land that potentially, could be brought into use for the production of energy crops. There is the possibility that much greater volumes of biomass could be made available. An important factor could be the binding commitment to replace 10% of transport fuels with sustainable biofuels by 2020. However, in terms of future potential, electricity generation and/or cogeneration are expected to be the main focus of development. The government is supporting moves to develop projects of between 1 and 5 MWe within the next few years (using forestry and agricultural wastes). At this modest scale, cogeneration could be an attractive option (Castillo and Panoutsou, 2011). The development of a small number of larger scale (20–50 MWe) plants by 2020 is also possible. These would be located in close proximity to the large plains of central and northern Greece, and in the Peloponnese, where adequate supplies of multiple feedstocks would be available. Based on modelling underpinning the NREAP, the potential supply of different types of biomass in the period up to 2020 could be significant

(Table 6). Estimates suggest that more than 7.5 Mt of crop residues could be available for immediate use. A further 2.7 Mt of forest residues could also be available, most of which is currently unused.

Table 6 Potential Greek biomass supply (ktoe) (Castillo and Panoutsou, 2011)

Biomass source	2006	2015	2020
Wood directly from forestry	702	1361	
Wood as industrial by-products	27		
Dedicated energy crops		68,000	159,000
Agricultural by-products and residues	202	1200	1500
MSW (biodegradable fraction) + landfill gas	23.3		
Sewage sludge	9.6		

- **Hybrid renewables projects**

Hybrid power systems generally combine two or more clean energy-producing technologies. By integrating these, it can be possible to overcome inherent limitations of each system. A range of combinations is now offered commercially. Most are of low capacity and include combinations of geothermal/solar PV, biomass/solar CSP, solar PV/fuel cells, wind/solar PV, and coal/solar CSP.

In Greece, several projects are operational and others are proposed or being developed. Examples are shown in Table 7. Such systems are of particular interest to some Greek islands; most are not connected to the central mainland electricity grid and consequently, electricity is often generated using oil/diesel-powered facilities. Some are of low efficiency and can generate high local levels of emissions (such as particulates). Their replacement with hybrid systems (coupling renewables with energy storage) could offer the potential for cleaner, cheaper alternatives.

Table 7 Examples of Greek hybrid renewables-based energy systems (Fantidis and others, 2013; Kyriakidis and others, 2012; Mills, 2013)

Location/Project	Technologies
Plaka, Alexandoupolis	Wind + hydro
RES2H2 – Integration of renewable energy sources with the hydrogen vector	0.5 MW wind + hydrogen production
Kythnos	0.31 MW wind + 2.77 MW diesel
Lemnos	1.14 MW wind + 10.4 MW diesel
Agios Efstratios	Diesel + various systems + batteries/hydrogen storage
PPC Renewables, Ikaria	Two hydro plants (1.05 MW and 3.1 MW) + pumping station + wind (2.7 MW). Total capacity 6.88 MW. Project completed in 2014. Annual production of 9.81 GWh

4 Greek coal

Greek coal reserves are almost entirely lignite; there is no hard coal production. As elsewhere, there are a number of reasons for using indigenous lignite. Many are self-evident and focus on the provision of an affordable, secure source of energy for power generation and other industrial and commercial uses. Thus, lignite is of strategic importance to Greece as:

- extraction costs are low;
- it guarantees a stable and easily monitored price;
- it helps reduce dependence on energy imports;
- low cost electricity is generated by lignite-fired power plants;
- it offers stability and security in the availability of fuel supplies; and
- the mining sector provides many thousands of jobs, particularly in rural areas.

The use of domestic lignite reduces the level of imported energy and crucially, helps the national trade balance. For an annual lignite production of 50Mt, Greece avoids the import of ~36 million barrels of oil. Based on a price of US$ 53/barrel, the estimated saving is US$1.9 billion per year.

4.1 Lignite production

Following the oil crises of the 1970s, the systematic exploitation of lignite deposits in Northern Greece and the Peloponnese became a major priority of Greek energy policy. As Greece's most abundant indigenous energy resource, lignite is of major importance to the economy. It accounts for around a third of primary energy consumption and in recent years, has generated nearly half of the country's electricity. In the future, PPC expects this level to fall as some old lignite-fired generating capacity will be retired. Further environmental restrictions are also expected to have an impact.

The Institute of Geological and Mineral Exploration (IGME) has exclusive rights to explore for lignite and other minerals, while the State has similar rights over the development and exploitation of lignite deposits. Lignite is abundant in several regions of Greece. Depending on the criteria applied, proved lignite reserves lie between 3.9 and 5 bt, of which, 3.1–3.2 bt are considered economically recoverable. Most major deposits are at a depth of 150–200 metres, often interlaced with layers of soil and waste. The most important reserves are located in the north of the country (Table 8). Prospect test drilling suggests that a significant increase in proven reserves appears unlikely, at least in the immediate future.

Table 8 Greek lignite reserves (Vamvuka, 2013)

Region	Explitable reserves (Mt)	% of total
Western Macedonia (Ptolemaida, Amydeo, Florina)	1500	53.7
Drama	900	32.2
Megalopolis	225	8.1
Elassona	170	6.1

Firm data on production costs are difficult to obtain. However, depending on the individual circumstances, estimates suggest a figure of between 11 and 19 €/t (WWF, 2013). This is in line with lignite production costs elsewhere; for example, North Dakota in the USA produces lignite at 15–20 US$/t, and Thailand at ~17 US$/t. In comparison, although prices have fluctuated during the past few years, some globally traded hard coals have been selling at 65–74 US$/t (Reuters, 2014).

Greek lignite can be mined cheaply. A study undertaken in 2014 for PPC determined that the average excavation cost of Greek lignite was the second lowest of the eight European lignite-producing countries considered (Germany, Czech Republic, Poland, Romania, Serbia, Turkey, and Bulgaria). However, of these, most Greek lignites had the lowest CV – this clearly impacts on power generation costs. Simulations confirmed that Greek electricity generation costs would be significantly lower if indigenous lignite had the same CV as the other countries considered. Despite its low CV, the cost of power generation using indigenous lignite was found to be the most competitive of the fossil fuels. Greek lignite production is characterised by high productivity levels (Zervos, 2014).

To date, around a third of the country's reserves have been extracted. An estimated 2.1 bt has been mined, with up to 2 bt remaining (Vamvuka, 2013). Based on total deposits and the anticipated future rate of consumption, it is estimated that domestic lignite reserves will last more than 45 years (PPC, nd).

There are four main production centres. In 2012, combined production exceeded 62 Mt (Euracoal, 2013). However, in 2013, there was a fall in consumption to 53.8 Mt. This resulted from the decommissioning of old lignite-fired generating capacity, coupled with unexpectedly high input from renewable energy sources – these enjoyed favourable weather conditions during the period. Lower production in 2014 was also partly due to the reduced number of workers employed (due to the country's economic measures) – this had an impact on output (Euracoal Market Report, 2015). In 2013, in terms of EU production, Greek lignite production ranked third after Germany (182.7 Mt) and Poland (65.5 Mt) and 6th in the world (Euracoal Market Report, 2014).

4.2 Public Power Corporation S.A. (PPC) lignite production

The Public Power Corporation (Dimosia Epiheirisi Ilektrismou) is variously abbreviated to PPC, DEI, or DEH. It is Greece's largest power generator, electricity supplier and lignite producer. PPC's current power portfolio consists of conventional thermal, hydroelectric and other renewables-based power plants – combined, these make up approximately two thirds of Greek installed capacity. Seven major PPC lignite-fired power plants represent 24% of the country's total capacity and generate almost half of its electrical energy. The company also owns the national electric power transmission system and distribution networks.

PPC is a major lignite producer, with mining activities managed by its Mines Division. This is responsible for prospecting, extracting, managing and trading in solid fuels, and utilising the products generated in a cost-effective and environmentally-acceptable manner. Over the years, the policy pursued by PPC has led to a significant increase in lignite production – by 2010 it was nearly ten times higher than in 1970. Most

Greek lignite is produced by PPC, the third largest lignite producer in the EU. Output comes exclusively from opencast mines and is produced mainly using bucket-wheel excavators. On-site transport includes more than 300 km of conveyor systems (PPC, nd).

PPC has significant operations in Western Macedonia (Main Field, South Field, Kardia Field, Amynteon Field, and Florina) (Figure 9), as well as in the Peloponnese region (the Megalopolis Field). The latter supplies two power plants with an installed capacity of 600 MW. Up to 2012, annual lignite production from the Western Macedonia region had been a steady 50 Mt/y (Vamvuka, 2013). In 2013, it fell to ~45 Mt, and in 2014, it was ~42 Mt. In the case of the Florina field, two large mines have been developed (Vevi and Achlada) capable of supplying a 700 MW power plant for ~46 years (Kolovos, 2013). The five power plants supplied in West Macedonia and two in Megalopolis have a combined capacity of 4.76 GW.

Lignite mining remains crucial to PPC and the company continues to invest in new developments. In 2012, capital expenditure by PPC's mines business unit amounted to €140 million; in 2014, it was €102 million. This included significant amounts for extension of existing conveyer belt systems in Megalopolis and Western Macedonia, plus the installation of new conveyer systems. Other sums were expended on preparatory works for extending existing mining operations, plus the development of new ones (PPC Annual Report, 2012). Intensive excavation works were also carried out in the area of the new unit of the Ptolemais Power Plant (Unit V) in the West Macedonia Lignite Centre.

Figure 9 Western Macedonia Lignite Centre, South Field (photograph courtesy of PPC)

4.3 Private sector lignite production

PPC has priority in the development and exploitation of all lignite fields and is also responsible for most production. However, there are also a small number of privately operated mines in the West Macedonia/Florina area. These have estimated reserves of ~150 Mt. In 2014, they produced a total of 2.6 Mt of lignite. Some private sector output is supplied to PPC.

Most recently, a leasing agreement for the mining rights of a lignite deposit in Florina's Vevi region was concluded. This particular deposit was signed over to Aktor, a subsidiary of Athens-listed company Ellaktor S. A. It is linked directly to the lignite supply for the Meliti power plant. The contract covers the extraction of 90 Mt of lignite (exploitable reserves) and during the first 15 years of operation, is expected to produce >€150 million net profit for the Greek state.

4.4 The lignite levy

All lignite mined in Greece is subject to a special tax. This is an 'offset amount' used for financing infrastructure and environmental projects, plus other activities that support communities in specific areas affected by mining lignite and its combustion. It is paid by PPC in the prefectures of Florina, Kozani and Arcadia.

Law 2446/1996 originally set the levy at 0.4% of PPC's turnover. In 2011, PPC paid local communities €20.7 million (PPC Corporate Social Responsibility Report, 2011). In 2012, Law 4062/2012 increased the levy to 0.5% – in that year, PPC paid €29.4 million. On top of the levy of 0.5% on PPC's turnover, there is an additional 'special lignite levy' which is 2 €/MWh generated from lignite-fired units. The allocation of the funds produced is paid to each prefecture in proportion to the amount of electricity produced from the lignite-fired power plants operating within that region (PPC Annual report, 2012). Thus, in 2012, Florina received €5.26 million, Kozani €20.47 million, and Arcadia €3.71 million.

4.5 Lignite quality/characteristics

Greek deposits are characterised as low rank coals. In Greece, the term 'lignite' is used loosely to describe a variety of coal types that range from peat to subbituminous coals. They often comprise successive seams (ranging in thickness from a few centimetres to several metres) alternating with inorganic material (Anastassakis, 2004). Thus, in the Ptolemais-Amynteon Basin and elsewhere, deposits are sometimes referred to as 'zebra' seams. As with lignites in many other parts of the world, depending on the source, properties can vary widely, both within and between different geographical regions. Individual layers can vary widely both geometrically and morphologically. As a result, the quality of lignite burned can vary considerably in all timescales (hourly, daily, monthly and yearly) (Kastanaki and others, 2012). Quality can be affected by factors such as the nature of the individual deposit, the exploitation of multiple seams, mining conditions (such as the use of high capacity bucket wheel excavators with limited flexibility), and dilution from the co-excavation of inter-bedded waste layers.

Greek lignites vary in age between Eocene and Pleistocene. In general, more recently formed deposits are of lower quality than older ones. The majority were formed during the Miocene and Pliocene periods. Those of the Eocene period are of better quality and higher calorific value (CV). Most of these deposits are in the region around Thrace. However, as they are only present as thin seams, they are of little economic importance. The most important lignite deposits were formed during the Miocene and Pliocene periods, predominantly in Western Macedonia (Florina, Ptolemais, and Kozani) and in Thessaly. Here, seams are generally thicker (varying between several centimetres and up to 10 metres in the Ptolemais basin) and reserves are significant. However, overall quality is low. The last period of lignite formation was the Quaternary (Pleistocene). During this period, peat-lignite deposits were formed, the most significant of which are in Drama (Eastern Macedonia) and Megalopolis (Peloponnese).

As a consequence of these various factors, moisture content can vary between 30% and 66%, ash content between 3.5% and 40%, sulphur content between 0.3% and 6.4%, and CV between <4 and 9.6 MJ/kg (LHV). As a general rule, lignites mined in the northern part of the country have higher calorific values and lower sulphur contents than those from the south. Examples of mined lignites from different locations are shown in Table 9.

Table 9 Characteristics of different Greek lignites (Kavouridis, 2008; Papanicolaou and others, 2004; Vamvuka and others, 2013)

Region	Moisture (%)	Ash content (%, dry basis)	Heating value (MJ/kg)
Megalopolis	58–60	12.3–23.5	3.8–5.0
Drama	58	16–39	3.8–5.0
Ptolemais-Amynteon	51–61	15.1	5.2–6.3
Florina	37–40	17–39	7.5–9.6
Elassona	41	19–35	7.5–9.6

The variability of Greek lignites has the potential to create a number of problems during combustion in conventional power plants. These can include:

- low combustion efficiencies resulting from low CV;
- high feed rate may be required to meet nominal electric power output;
- may be difficulties in maintaining stable fuel quality;
- large quantities of fly ash produced;
- high maintenance and operating costs of plant mechanical equipment;
- deposition and scaling of combustion chambers resulting from the chemical composition of the residual ash; lignite ash often has relatively low softening and melting temperatures, resulting in deposition; and
- increased emissions of fine particulates, SO_2 and NOx. Electrostatic precipitator (ESP) performance (and hence, level of particulates emitted) can be influenced by the levels of sulphur in the lignite and amount of free calcium in the fly ash (Kastanaki and others, 2012). Under normal operation, emissions (mg/m^3) remain within the permissible limits. However, as a result of high flue gas flows, the overall amounts (t/h) emitted can be higher than better quality lignites and bituminous coals.

There are a number of techniques available that can reduce variability and improve the quality of mined lignite. These are examined in the following sections.

4.6 Lignite homogenisation/blending

Homogenisation is the process of mixing lignite in order to minimise the variability of the end-product. The process is usually carried out during stockpiling operations. The terms 'blending' and 'homogenisation' are often used interchangeably, although there are some differences. The most notable is that blending refers to stacking coal or lignite from different sources together in a single stockpile. Coal reclaimed from the pile will then have a weighted average output quality of the input sources. In contrast, homogenisation is used to reduce the variance of a single source. The process can be carried out at the mine or power plant. The usual procedure is to use a stacker to add a number of thin layers to the stockpile – this helps reduce variability. After the lignite is stacked in horizontal layers, it is reclaimed in vertical slices (Woodbine, 2010). Homogenisation can be carried out in linear or circular stockpiles – these can be of various configurations (chevron, windrow, or combined type).

In the case of Greek lignites, properties can vary significantly both within and between mining areas, and even within individual deposits. Variations can occur over short geographical distances. Even though individual power plants were intended to fire a 'design' lignite, in practice, this rarely proves possible. Different techniques are sometimes used to overcome (or at least, minimise) problems at power plants. In some cases, this begins at the point of production. For example, at the large mine in Megalopolis, PPC uses ten bucket wheel excavators for the continuous, selective mining of lignite. This helps to homogenise and smooth out variations in properties prior to its shipment to a nearby power plant (Raycap, 2013).

Serious efforts to minimise fluctuations in lignite properties began in 2008 when PPC introduced a new operating strategy aimed at improving overall quality and achieving optimum power plant performance. As part of this, in some situations, calcareous lignite (with low CV) is now sometimes mixed with low calcium lignite (with higher CV). This is done either at the mine or the power plant storage facility (Table 10). At the latter, lignites of various qualities from different mines are stockpiled prior to mixing in appropriate amounts. This process depends heavily on the expertise of plant personnel and quality is monitored continually. On occasions, PPC has purchased small amounts of high CV lignite from privately owned mines to be used in the homogenisation process. Although mixing in this way increases costs, the process has successfully reduced environmental issues (mainly particulate emissions) and allowed generating units to achieve their full design output. In some cases (for example, Kardia) improvements have been significant. Studies have shown that by controlling short- and long-term variations in lignite quality, CO_2 emissions from a power plant can be reduced by 2–5% (Vamvuka and others, 2013).

Table 10 Sources of lignite for major Greek power plants (Kastanaki and others, 2012)

Plant	Lignite supplies	Plant improvements achieved
Agios Dimitrios	3 different qualities from three different mines	Nominal load undertaking, reduction of SO_2 emissions
Kardia	10 different qualities from six different mines	Nominal load undertaking, significant reduction of particulate emissions
Ptolemais	4 different qualities from four different mines	Nominal load undertaking, reduction of particulate emissions
Amynteon	2 different qualities from two different mines	Nominal load undertaking, minor reduction of SO_2 emissions
Meiliti	6 different qualities from six different mines	Full design load achieved

To further address the issue of product variability, there is ongoing cooperation between PPC and a number of Greek organisations such as The Institute for Solid Fuels Technology and Applications (ISFTA). Part of ISFTA's remit is to develop techniques to improve fuel quality control. The two organisations are currently working on the evaluation of various on-belt systems for quality monitoring and control. Cooperation extends to the development of computer-aided techniques for lignite blending and homogenisation applicable under site-specific conditions in the opencast mines and power plants of the Ptolemais and Megalopolis Energy Centres (ISFTA, 2014).

Historically, not all online analysis techniques have proved to be successful when applied to Greek lignites. For example, a dual energy gamma ray transmission online ash analyser was installed at the Kardia mine of the Ptolemais-Amynteon Lignite Centre. Comparison of the results revealed that under some circumstances, ash levels indicated by the analyser failed to agree with those obtained using conventional laboratory techniques. The range of the measurements obtained by the analyser was narrower – the most likely reason was the frequent and wide ranging fluctuation of the chemical and mineralogical composition of the lignite (particularly its calcium content) (Kavourides and Pavloudakis, 2003).

4.7 Lignite beneficiation

All coals and lignites are heterogeneous mixtures of organic material and inorganic impurities. In some cases, they can require processing to improve the properties of the final product or reduce its variability. Various terms are used, often interchangeably, to describe this process: coal preparation, beneficiation, coal cleaning, and coal washing. The principal consideration is to suitably upgrade the material's quality, increasing its value and making it suitable for use in power plants. Thus, coals/lignites may be treated via a number of techniques such that their levels of moisture, ash and sulphur are reduced.

4.8 Lignite drying

Depending on the individual source, the moisture content of raw lignite can be very high. Thus, in a conventional lignite-fired power plant, a portion of the fuel's heat content will be consumed in the boiler during combustion and milling/drying in order to evaporate lignite-inherent water. This usually takes place at a high temperature and consequently, results in high exergy losses. Furthermore, as lignite-inherent water exits as steam in the plant's flue gas, this heat cannot be recovered as part of the plant process and is lost.

At least partially drying lignite prior to combustion can produce a number of benefits. However, the milling and drying process for lignite is fundamentally different to that for hard coals. With lignites, an important issue is to achieve adequate drying whilst avoiding mill fires and/or explosions. Thus, drying is usually carried out using hot flue gas in addition to air – this provides the heat required but reduces the oxygen concentration in the mills to a safe level. Hard coals can be milled safely without the addition of flue gas; air heaters alone provide adequate temperature for drying (~200°C). The types of mills are also different. Beater mills are normally used for lignite, and vertical spindle or tube ball mills used for hard coals (Reinartz, 2006). Particle size must be smaller for the latter as they are less reactive and take longer to achieve adequate burn-out.

Drying is applied to some sources of lignite supplied to Greek power plants. For example, at the Megalopolis plant, this is achieved using flue gas recirculation from the boiler. The dried fuel is separated from the gas stream (comprising flue gas and removed moisture) using specially designed ESPs before being fed to the boiler. The drying off-gas is mixed with the plant flue gas downstream of the main ESPs. Similarly, lignite (from the Meliti-Achlada mine) supplied to the Florina plant (moisture content of ~40%) is also dried in the plant's mills using recirculated flue gas from the upper part of the combustion chamber. A similar system is also used on the Agios Dimitrios II plant (Ballesteros and others, 2013) as well as a number of others.

Pre-drying will be important for the next generation of lignite-fired power plants. Studies have examined the suitability of drying processes based on newer more advanced techniques; for example, pre-drying using low pressure steam or other sources of low temperature heat as drying medium, as opposed to the more conventional hot recirculated flue gas. Waste heat from the drying process is then recovered. Potentially, application in this manner can increase overall plant efficiency by up to several percentage points.

Historically, PPC and the National Technical University of Athens (NTUA) were members of a multi-partner project known as DRYCOAL (2004-9), funded by the European Research Fund for Coal and Steel (RFCS). This focused on the integration of an innovative lignite pre-drying technique (WTA fluidised bed drying) into steam power plants. RWE Power of Germany was instrumental in the development of the system. With this, drying is made exergetically more efficient by undertaking it at a low temperature in a separate operating unit (upstream of the steam generator) and utilising the energy of evaporated coal-inherent water in the power plant process, either in the feed water preheaters or for evaporation in the WTA dryer. The development process culminated in the testing of a commercial-scale drying module with a dry lignite output of 110 t/h – this was cocombusted in a lignite-fired power plant. The project successfully determined all design data for a commercial-scale drier and its associated dry lignite-fired boiler. It also demonstrated the operational viability of the system, and determined the potential for the pre-drying concept in different types of power plant. As part of the DRYCOAL project, cocombustion tests were undertaken in a small lignite-fired Greek power plant (PPC's 75 MWth LIPTOL plant). The LIPTOL boiler was originally designed for cofiring raw and dried lignite. It was concluded that the cofiring of dried lignite with raw lignite in existing boilers could be achieved to the extent that the performance of the unit was unaffected (such as flue gas temperatures, steam temperatures, and plant emissions). In some circumstances, cofiring in existing systems can be limited as a result of the feeding arrangements in place (vom Bauer and others, 2013).

Subsequently, other studies were carried out (for instance, by Agraniotis and others, 2012). These focused on the possible integration of the WTA lignite pre-drying system in an existing Greek power plant; up to 30% of dried lignite would be utilised in the plant's fuel feed. The steam cycle of the Agios

Dimitrios Unit V in Kozani was used as the basis for modelling the project. The integration of a WTA dryer into the existing power plant was evaluated through thermodynamic cycle calculations. The moisture evaporated from the drying process was used as heating medium and partially replaced the steam bleed utilised for the first low pressure water preheater. In this case, calculations suggested that by increasing the share of dry lignite in the total thermal input, an increase in plant efficiency of up to 0.8% points could be achieved. More generally, in existing Greek boilers, the integration of a pre-drying system and the implementation of dry lignite cofiring could bring an efficiency increase of ~1.5% points, an important route for increasing plant efficiency and reducing CO_2 emissions. As the next step, start-up oil burners could be replaced with dedicated dual burners firing oil and dry pulverised lignite. The WTA technology is expected to play an important role for all future types of lignite-based power plants that could include IGCC and oxyfuel plant. However, the application in existing Greek lignite-fired power plants would need to be examined on a case-by-case basis using techno-economic criteria.

A recent study, involving NTUA and CERTH, examined the use of pre-dried lignite as a means for improving the flexibility of conventional thermal power plants when responding to the fluctuating input from renewables (such as wind and solar power) and variable electricity demand. Investigations focused on the application of pre-drying systems for enhancing flexibility at times of partial load/low demand (Atsonios and others, 2015). To assess the economic viability, various scenarios were examined – modelling was based on a 340 MW power plant. Thermodynamic analysis included mass and energy balance calculations at full and partial loads, using raw lignite and raw/dried lignite mixture respectively. It was determined that the use of the drying system was most effective when the plant was operating at partial load. Economic analysis indicated that under some conditions, potentially, plant income could be increased by more than 3.5–4.0%. By applying the proposed pre-drying technique, plant CO_2 emissions could be reduced by ~130 kt/y. The study concluded that (under varying power plant load) the adoption of pre-drying could simultaneously increase plant flexibility and efficiency, minimise CO_2 emissions, and reduce the cost of electricity generated.

4.9 Ash reduction

There are good reasons for reducing the level of ash in lignite – variations in lignite properties can be minimised and power plant performance improved. Many lignites tend to have low ash softening and melting temperatures, and Greek lignites are no exception. During combustion this can manifest itself as deposition in the boiler. Slagging and fouling are common in some Greek power units and can significantly impair their performance. This can manifest itself as reduced efficiency, steam leakage in the superheaters and water walls, and excessively high flue gas temperature leading to malfunctioning of ESPs. In addition, units may need to be frequently taken out of service so that such deposits can be removed. Thus, production is lost and maintenance costs increased.

With this in mind, various initiatives have been undertaken. These have included the investigation of slagging and fouling behaviour in the Kardia power plant, where a measurement campaign was carried out in a unit affected by excessive deposits. Modelling studies compared actual plant performance against plant design values (Panagiotidis and others, 2013). Several measures were suggested, aimed at reducing slagging/fouling issues, and prolonging the time between successive maintenance stoppages.

Internal cleaning of boiler deposits was also addressed as part of a 3-year RFCS-funded project (LIGPOWER) aimed at improving the availability and competitiveness of lignite as an energy source (Europa, 2014). A major aim was to develop novel ways to improve the internal cleaning of power plants, plus develop new easier-to-clean heating surfaces within the plant. PPC was involved in the project. As noted, the often-low ash softening and melting temperatures of Greek lignites can result in deposition in the boiler. Traditionally, conventional soot blowers have been used to remove such deposits but have not always been fully effective. LIGPOWER focused on developing and testing alternative improved techniques. However, as the cleaning regime developed was more intensive, the stress on superheater tubes was increased. Thus, superheater designs of increased resistance were produced and installed in several power plants. Overall, testing (between 17,000 and 21,000 hours) was carried out in commercial utility boilers in Germany. The end results of the project included improved plant cleaning processes, reduced deposition, and increased plant efficiency.

Clearly, issues such as deposition can be minimised by reducing the amount of ash present in the lignite feed. For several decades, through the evaluation of various techniques, a number of Greek organisations have addressed this issue (Anastassakis, 2004). For instance, heavy liquid separation was shown to be capable of reducing ash levels of Megalopolis lignite from 26% to 13% – this increased the CV such that it met PPC's specification for use in certain power plants (Stamboliadis and Nikolaou, 2002). Other studies have also examined the potential of heavy media separation combined with jigging; both proved suitable for relatively coarse particles, although the former was found to be more efficient. It was concluded that all Greek lignite deposits would be amenable to beneficiation by gravimetric methods. However, ash reduction techniques are not currently applied commercially within Greece. A major factor cited has been the requirement to keep the cost of electricity as low as possible, particularly during the country's recent economic crises.

5 Hard coal imports

Greece has no hard coal reserves and therefore none is produced. It relies entirely on imports to meet its hard coal requirement. However, only a modest amount is imported each year. This comes mainly from South Africa, Russia, Venezuela, and Colombia. Overall tonnage has fallen from a peak of 1.37 Mt in 2000. In 2010, the amount imported was 652 kt. This fell to 506 kt in 2011, and 240 kt in 2012 (US EIA, 2014).

Hard coal is brought into several Greek ports by a number of companies. One of the largest importers is ELINOIL (Hellenic Petroleum Company). The company imports metallurgical coal, anthracite, and bituminous coal, and operates two state-of-the-art solid fuel processing and grinding plants in Aspropyrgos and Volos. It also imports petcoke.

Imported hard coal is used mainly by the Greek **cement sector**. The amount used has fluctuated, reflecting the country's economic recession. Both coal and petcoke is used by the sector and all is imported – fuel costs account for a third of the cost of production (Global Cement Trader, 2013). The bulk of Greek cement production is centred on eight major plants operated by three companies (Heracles, Titan Cement, and Halyps Cement). Major production facilities are located near the major residential and commercial areas of Athens, Thessaloniki, Patra and Volos. National production capacity is between 15 and 16 Mt/y. Titan is one of the biggest producers, with a capacity of 6 Mt/y and a market share of ~40%.

As a result of the recession, demand for cement within Greece fell from 13 Mt/y to only ~2.5 Mt/y. However, there are signs that the market is beginning to pick up, with some suppliers (such as Titan) anticipating that in the near term, demand within Greece will increase. To compensate for the drop in domestic demand, some production has been directed to overseas markets (such as Libya and Algeria). Currently, considerable quantities are being exported. The Eurozone crisis led to a glut of spare capacity in Spain, Italy, Portugal and Greece – this region has now become an important hub for cement trading (Akram, 2013). Both Heracles and Titan operate fleets of ships used for exporting cement.

Limited hard coal is also used by the **iron and steel sector** in the Southern Balkan region. There are three major ports that facilitate the coal trade in this area, one of which is Thessaloniki, the largest in the region. Its proximity to major sea routes and road and rail connections with the hinterland make it an important option for shippers. Thessaloniki has several specialised coal unloading docks and the coal trade is an important component of the port's traffic (Vaggelas, 2014).

Most Greek steel is produced using electric arc furnaces. These use only scrap metal although anthracite is sometimes added as a carbon carrier and energy provider (injection coal) in the process. This creates a foam slag – controlled foaming improves the behaviour of the arc and prolongs the service life of the furnace lining (Carbones, nd). In 2011, Greece produced 2.0 Mt of crude steel, although this fell to 1.3 Mt in 2012 (Euracoal Market Report 2013). The Greek steel industry is currently in a difficult situation. Since the beginning of the country's financial crisis, there has been a drop of around 85% in demand from home markets. High energy costs have compounded the problem. As a result, a number of facilities have been closed or seen periods of inactivity. Major steelmakers (such as Viohalco and Halyvourgiki) have attempted to keep their operations running by operating at night when energy is cheaper and through exports sold below cost. However, by 2014, this had saddled them with >€600 million in losses (Neos Kosmos, 2014).

Historically, quantities of hard coal have been bought in for use in some PPC **power plants**. Small amounts are sometimes added as support fuel to the plant's lignite feed (for example, at Kardia) (Grammelis and Karampinis, 2011). In 2010, 158 kt were bought, although this fell to 34 kt in 2011 and 2 kt in 2012. In 2013, only 756 tonnes were purchased (PPC Sustainability Reports, 2012 and 2013). In 2013, Greece imported a total of 100 kt of steam coal (Euracoal Market Report, 2014).

6 The Greek power generation sector

Much of the Greek electricity system was developed post-1960, with the main aim of electrifying the country through the use of domestic sources of energy. On the grid-connected mainland, most demand came to be met by a combination of lignite-fired and hydroelectric power plants. Many of the Greek islands, lacking connection to the mainland grid, were supplied by stand-alone oil-fired plants.

PPC is responsible for generating much of the country's electricity. This includes the Ionian and some of the Aegean islands that are now connected to the mainland and form part of the interconnected system. Most of PPC's production capacity is concentrated in the north of the mainland, close to the large lignite mines that are the main source of fuel. The low cost of mining, the stability and security of supply, plus the fixed/controllable price, has made lignite a strategically important fuel for PPC and the country as a whole. Although there is now some private sector involvement in the power sector, the biggest player by far remains PPC. This is made up of four companies with separate legal and managerial identities: the parent company PPC S.A plus its three subsidiaries, ADMIE, DEDDIE and PPC Renewables. The group holds assets in lignite mines, power generation, transmission and distribution. With a market share in supply of ~98%, PPC is the biggest power producer and electricity supplier in Greece.

PPC currently holds assets in lignite mines, power generation, transmission and distribution. Its power portfolio consists of conventional thermal plants (lignite-, gas- and oil-fired), and hydroelectric power plants, as well as other renewable-based installations. Combined, these account for ~64% of Greek total installed capacity. In 2014, PPC's lignite-fired plants generated 22.7 TWh of electricity; a further 2.8 TWh was imported – combined, this covered around two thirds of total demand. Major lignite-fired plants are shown in Table 11. In 2014, these produced 48.1% of Greek electricity (total Greek generation of 53.5 TWh).

The Hellenic Electricity Transmission System (the 'Interconnected System') covers much of mainland Greece. Some islands (such as the Ionian Islands and some Aegean islands) that lie in close proximity to the mainland are included in the system as they are connected via sub-sea cables. In the Interconnected System, a significant proportion of generation capacity is located in north western Greece, close to lignite mines that are the primary fuel source. There is also gas-fired capacity and during the past two years, two new, state-of-the-art gas-fired plants have been built (Aliveri V and Megalopolis V – the latter is still in the commissioning phase) in the southern part of the Interconnected System. All remaining islands (the 'Non-Interconnected Islands') are served mainly by autonomous oil-fired power plants, although with some, demand is also covered by renewables. The largest power plants on the Non-Interconnected Islands are located on Crete and Rhodes (with total thermal capacity >1 GW).

Following the spin-off of the Transmission and the Distribution segments, two 100% subsidiaries of PPC were created, namely IPTO S.A. (Independent Power Transmission Operator S.A.) and HEDNO S.A. (Hellenic Electricity Distribution Network Operator S.A.). IPTO is responsible for the management, operation, maintenance and development of the Hellenic Electricity Transmission System and its interconnections, while HEDNO is responsible for the management, operation, development and maintenance of the Hellenic Electricity Distribution Network. PPC is active in the renewables sector through its subsidiary company (PPC Renewables S.A. – PPCR), with a portfolio of wind farms, hydroelectric plants and photovoltaic facilities.

Table 11 PPC lignite-fired power plants (Karampinis and others, 2011; Roques and others, 2014)

Plant	Capacity (MWe)	Fuel supply	Main suppliers	Comments
Agios Dimitrios, Kozani, Macedonia	1595: 2 x 300 2 x 310 1 x 375	(Units 1–4) 14.5 Mt/y from Lignite Centre of Western Macedonia. 5 Mt/y (Unit 5)	Siemens, AE & E, Stein, EVT, Biro, Alstom, LMZ, Eelctrosila, Ansaldo, Metka, Biokat	Largest Greek plant. Also supplies (67 + 70 MWth) for district heating. Limited to 32,000 hours running 2016-23
Amynteon-Filotas, Florina, Macedonia	600: 2 x 300	5.7 Mt/y from Ptolemais-Amynteon district	Stein, LMZ	Limited to 17,500 hours running 2016-23. Also supplies 25 MWth for district heating. Both units to decommission in 2020
Kardia, Kozani, Macedonia	1212: 2 x 300 2 x 306	14.3 Mt/y	Steon, Ganz-Rock, Alstom, LMZ, Teploenergo, Zarubezhenergoproekt, Metka	Limited to 17,500 hours running 2016-23. Units decommissioning 2019-20
Megalopolis, Arcadia, Pelloponesus	600: 2 x 300	Local lignite reserves but depleting	Vereinigte,Kesselwerke, AEG, Siemens, Alstom, Metka	Supplies 20 MWth for district heating. Also includes CCGT blocks. New CCGT 832 MW Unit V
Ptolemais, Kozani, Macedonia	425: 1 x 125 1 x 300	5.4–6.5 Mt/y	KSG, Stein, EVT, Alstom, BBC	Also supplies 50 MWth from Unit III for district heating. But unit out of commission following fire of November 2014
Florina (Meliti Achlada)	330	2.5 Mt/y	Alstom, Ganzrock, ABB, Metka	Decomissioning post-2040

The past few years have seen fluctuations and changes in the makeup of the energy market, reflecting the overall economic situation prevailing in the country, plus the seasonal impact of renewables (particularly hydro). Because of the economic collapse, electrical power consumption in 2012 was at the same level as in 2004. Heavy industry and other energy-intensive companies have voiced concerns that PPC's dominance in the marketplace makes them almost totally dependent on the company for electricity – there are few other options. They have urged PPC to enter negotiations on electricity pricing and tariffs. Greek industry claims that real negotiations have never actually taken place (Euractiv, 2015b). However, PPC points out that Greece does, in fact, have a number of alternative suppliers capable of supplying electricity to heavy industry and other energy-intensive companies. Some of these suppliers are wholly-owned subsidiaries of industrial companies. Importantly, they sometimes opt to supply high-margin customers and maximise profits. Thus, many industrial companies prefer to be supplied by PPC at tariffs that either have no profit margin or are below cost.

Since 2010, the contribution of lignite-fired power plants has decreased from 52.1% to 48.1%. The input from gas-fired stations has fluctuated more widely. In 2014, there was a steep decline in electricity production that affected gas-fired power plants more than lignite-fired. Much of the decline was due to new regulations that changed the Greek market model, as well as the impacts of the financial crisis. The decline in gas was replaced in the market not by other fuels, but mainly by electricity imports from Bulgaria: imports of electricity are normally ~4%, but in 2014 they rose dramatically to 16% (Euracoal Market Report, 2015; Atsonios and others, 2015). In 2012, the largest electricity markets were domestic (18.9 TWh), commercial (15 TWh), and industrial (12.20 TWh) (NSSG, 2014).

There has been a steady increase in the contribution from renewables, particularly during 2013, a trend that continued in 2014 (Figure 10 and Table 12).

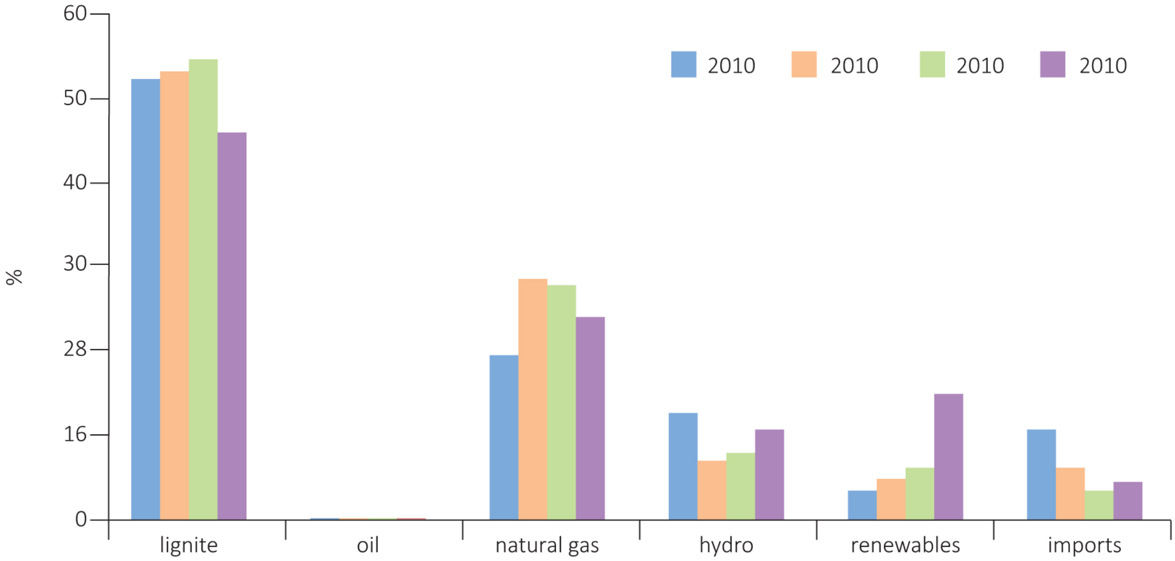

Figure 10 Greek electricity production by source (2010-13) (%)

Table 12 Electricity production by source (GWh) (2010-13) (Dalla, 2014)				
	2010	**2011**	**2012**	**2013**
Demand	59,126	58,848	58,717	56,174
Lignite	27,440	27,570	27,555	23,231
Oil	5073	4770	4790	4376
Natural gas	10,365	14,851	14,136	12,149
Hydro	6703	3676	3892	5640
Renewables	3932	4793	6560	8891
Net imports (imports minus exports)	5613	3188	1784	1887
* oil- and renewables-based generating capacity exists in both the Interconnected and Non-Interconnected Islands systems				

At the beginning of 2014, the Greek interconnected electricity system had a combined capacity of ~18 GW. This included ~5 GW of lignite-fired plants, 5 GW fired on natural gas, and 700 MW based on oil. Some 3 GW was based on large hydropower and 4.3 GW on other renewables. On the non-interconnected islands, the installed capacity comprised 1.78 GW of oil-fired generators plus 448 MW of renewables (Europa, 2014). Thus, the total national installed capacity was ~20.2 GW (61% thermal power plants, 15% large hydropower plants, and 24% other renewables).

Greece's economic crisis has had a major impact on the power sector. Recent years have seen reduced activity in most areas of industry and commerce and this has significantly reduced the amount of energy used. In 2012, electricity consumption decreased for the fourth consecutive year, falling to the 2004 level. Between 2008 and 2012, it fell by 9.67%. The biggest decrease was in the domestic sector – reportedly, this resulted largely from increased electricity prices and taxation (Kousta, 2014). However, in 2011, the amount of electricity generated by Greek power plants increased by 4%, due mainly to a fall in imported energy – Greece saw the second biggest decrease (12.3%) of energy imports among EU27 member states. However, in the following few years, levels again increased.

Although PPC remains the biggest power generator in Greece, since 2001, its monopoly on generation has been reduced and the market opened up to private generators. Since then, licences have been issued for around 2.8 GW of private thermal generating plants. However, even before the full onset of the economic crisis, many failed to find adequate funding. In the preceding decade, Greek electricity generation capacity grew by 50%. An additional 6 GW of generating capacity was forecast to be required by 2015 – much of this was expected to be in the form of gas-fired plants that failed to materialise.

During the past few years, the amount of electricity generated by PPC plants fell from 45.5 TWh in 2010, to 40.3 TWh in 2012, although the overall amount sold to customers increased slightly from 51.6 TWh to 52.8 TWh over the same period (PPC Annual Report 2012, 2013). The fall in PPC's production was attributable to a number of factors that included changing demand levels (mainly in the Interconnected System), the operation of the power market in general, increased generation by other companies (mainly gas-fired power plants – *see* below), and movement in the import-export balance. In addition, two electricity suppliers withdrew from the market, and ~200,000 customers returned to PPC.

Given the continuing economic crisis and the adoption of austerity measures, it is difficult to predict precisely what the longer term holds for the Greek energy sector. In 2012, the Greek Ministry of Environment, Energy and Climate Change (MEECC) published its *Energy Roadmap to 2050*. This examined the possible future of the Greek power system and reported on its long-term development. It covered the period between 2020 and 2050, using the National Renewable Energy Action Plan (NREAP) as its starting point. The NREAP presents the development plan for the national energy system, focused on achieving the obligatory targets set by EU Directive 2009/28/EC and by Greek Law 3851/2010. According to the NREAP, 2020 targets for renewables in the energy system include 20% of the gross end-use energy consumption for heating and cooling, 40% of electricity consumption, and 10% of the energy used in transport. The NREAP suggests that much of this increase will be at the expense of lignite-fired generators and that these will fall to a total of 3.25 GW. Gas-fired capacity will increase to 5.13 GW and total renewables-based generating capacity will increase to 13.27 GW (comprising mainly wind, hydro, and solar PV). Smaller contributions are also forecast for solar-thermal (250 MW) and geothermal (120 MW) (WWF, 2013). However, since the publication of the Roadmap and the NREAP, Greece's economic situation has worsened. Although the present government had previously stated its intention of increasing the use of indigenous lignite, recent statements suggest that this may no longer be the case, and emphasis on renewables will be maintained. However, recent cut-backs in subsidies for some renewables may also have an impact on the economic viability and timing of a number of projects.

6.1 Independent power producers (IPPs)

Electricity prices were fully liberalised in July 2013 although effective entry into the retail market has been limited and with a share of ~98% in supply, PPC remains the dominant supplier (Europa, 2014). Mainly as a result of earlier problems consumers experienced with several private sector suppliers (no longer trading), it has proved difficult to open up the retail market. In the wholesale market, PPC's share is ~60% (including imports).

During the past decade, the use of natural gas for power generation has increased significantly. Many such plants are operated by IPPs. Their appearance in the marketplace helped reduce PPC's market share from nearly 100% pre-2009, to the current level of ~72%. Gas-fired IPPs have achieved a share of ~20% (Europa, 2013) and there are now private power plants with a combined capacity of ~2.2 GW. The largest IPPs are represented by the Hellenic Association of Independent Power Producers. However, none operate lignite-fired plants. A summary of major IPP plants is given in Table 13.

Table 13 Major Greek IPP plants

Company	Generating capacity	Comments
Elpedison Energy	816 MW: CCGT plants in Thessaloniki (395 MW) and Thivsi, Viotoa (422 MW)	Elpedison is joint venture of Hellenic Petroleum Group, Edsison SpA, and Ellaktor Group
Korinthos Power	437 MW CCGT at Agio Theodoroi, Korinthia	Kornithos Power is 65% owned by Protergia and 35% by Motor Oil. Plant start-up in 2012
Heron S.A.	Heron I (148 MW OCGT) Heron II (432 MW CCGT)	Partly owned by GEK-SUEZ and Gas de France SUEZ
Aluminium S.A.	334 MW plant, Viotia	Major aluminium producer. Part of Mytilineos Group. 130 MW licensed to operate as cogen unit; remainder as CCGT
Motor Oils Hellas S.A.	Corinth refinery – 45 MW	Petroleum refiner. Plant fired on refinery gas and propane
TERNA	Lavrio 107 MW OCGT plant	Five GE gas turbines
Eydap S.A.	12.9 MW Psittalia WWTP, Attica	Athens Water Supply and Sewage Co plant

Activity in the private sector has continued. For example, in July 2013, it was announced that Qatar Petroleum International (QPI) had signed an agreement with Greek firm GEK-TERNA to acquire a 25% stake in the Heron II power plant. Other significant developments involving the private sector have included:

- US-based Third Point Gas has entered into the share capital of Energean Oil & Gas through an equity capital injection of US$ 60 million.
- Azeri state energy company Socar signed a deal for acquisition of Greece's natural gas transmission network operator DESFA (awaiting government decision).
- Canadian investment fund Fairfax Holdings became the third-biggest shareholder of Greek industrial energy group Mytilineos, acquiring a 5% stake worth about €30 million (US$ 41 million).
- US York Capital Management has announced €100 million investments in energy group GEK-TERNA, acquiring a 10% share of the firm (Invest in Greece, 2015).

In recent years, a number of new private sector gas-fired projects were proposed. However, mainly as a consequence of the country's economic condition, most did not proceed. Like PPC, there have also been impacts on private sector generators. The Hellenic Association of Independent Power Producers, the representative body, notes that the sector has been affected by late payments from consumers, a drop in electricity demand, on-going capital controls, and the general financial uncertainty. Association members are now making short-term plans (rather than longer term) but are hopeful that in the near future, electricity demand will again increase. However, they consider that unless underlying market problems are addressed, the prevailing market conditions could eventually lead to some independent generators withdrawing from the Greek market, increasing the risk of an energy shortage. They claim that the Greek power market remains too concentrated, where state-owned PPC still controls most of the retail market and enjoys a virtual monopoly on access to low variable cost generation sources, such as lignite and hydro. Consequently, this limits the ability of IPPs to develop equally diversified portfolios, and hence, compete effectively in supply with PPC (Williams, 2015). However, PPC refute this, noting that the company has a license for the exploitation of lignite mines corresponding to ~63% of the country's total exploitable lignite reserves. To date, ~5% of total exploitable lignite reserves have been leased to private investors through long-term contracts; some 23% of such reserves have not yet been leased or conveyed. Furthermore, in October 2014, the Vevi lignite mine was leased to private sector company Aktor S.A. Additionally, private investors have been granted generation licenses for lignite units that they have not yet developed, as well as for new hydro power plants (for example, for the 60 MW Avlaki facility); again, these have not yet moved forward towards implementation.

The Hellenic Association of Independent Power Producers has advocated increasing private sector access to lignite and hydro resources and is lobbying for a number of structural issues and reforms to be made to the electricity market. This includes issues of late payment from the transmission system operator (ADMIE), plus the high excise tax applied by the government to natural gas. They claim that as a result, gas as a resource (the only major one available to IPPs) is disadvantaged against lignite and/or imports.

6.2 Electricity imports and exports

Greece has electricity interconnections with Albania, Bulgaria, Italy, FYROM and Turkey. As a result of the current Greek oversupply situation resulting from the recession, between 2010 and 2012, electricity imports have fallen. However, in 2013, the reduced output from Greek gas-fired plants was replaced by increased electricity imports from Bulgaria. Imports normally make up ~4%, of the country's total, but rose to 16% in 2014 (Euracoal Market Report, 2015; Atsonios and others, 2015). The increase of imports resulted largely because all countries adjacent to Greece (apart from Italy) have no associated CO_2 costs for their power generation.

A significant proportion of the imported electricity comes from Bulgarian coal-fired and nuclear power plants (Europa, 2013). In October 2013, the AC 400 kV interconnection between Maritsa East 1 (in Bulgaria) and Nea Santa in Central Macedonia (in Greece) was labelled a 'Project of Common Interest' (PCI) by the European Commission. Turkey is the other major supplier (European Commission, 2014). There is some two-way trade – in 2013, Greece imported 5.6 TWh and exported 3.9 TWh. Recent years have seen increasing exports from Greece to Albania.

The European Commission has suggested the creation of an electricity-gas exchange Memorandum of Understanding (MoU) with Bulgaria. This would help expedite unhindered electricity supplies to Greece and, in return, reverse flow gas supplies to Bulgaria (should there be a serious disruption in gas supply). Key to the plan is a balance of interests: the amount of electricity sent to Greece would be roughly equivalent to the gas needed to produce that electricity in Greek gas-fired power plants, which would then in turn, be sent to Bulgaria (European Commission, 2015).

6.3 The future of the Greek power sector

The power generation sector seems set to undergo major changes although, as a consequence of the country's economic problems, there remain uncertainties on scale and timing. Many of these centre on the future of PPC, the country's main electricity generator and supplier. A decisive factor would be its privatisation or part privatisation – this would have a major impact on the structure and operation of the company, its generation assets, and the Greek electricity supply business as a whole. In 2014, with the aim of beginning the privatisation of the company in 2015, the then Greek government launched a period of public discussion for the splitting of PPC into several parts (Michailidis, 2014). The plan formed part of the government's commitment to accelerate the sale of state assets as part of an attempt to cut the country's debt. At the time, ministers expected the plan to raise revenue for the state through the privatisation of the company, whilst ensuring the creation of competition in the sector and the liberalisation of the Greek electricity market. The restructuring and privatisation plan consisted of three steps:

1. the sale of PPC's wholly-owned subsidiary IPTO, with 66% of IPTO's share capital to be sold to an investor, and the remaining 34% to be purchased by the Hellenic Republic;
2. the creation and sale of a new integrated electricity company in terms of assets, liabilities, human resources and customer base. The new company was to have comprised the following PPC plants and assets:
   - the Amynteon power station (Units I and II) with a generation capacity of 600 MW, the Meliti I power plant (330 MW), plus the license for the future 450 MW Meliti II plant. All units are lignite-fired;
   - all PPC's mining rights on the lignite concession rights of Amynteon (including the Lakkia mine), Kleidi, Lofoi Melitis, the Komnina I and II, and the Vevi mines;
   - the Platanovrisi (116 MW), Thesavros (384 MW), Agras (50 MW), Edesseos (19 MW), Pournari I and II (334MW) hydro plants; and
   - the 485 MW Komotini natural gas-fired plant.
3. the sale of an additional 17% of the Hellenic Republic's shares in PPC.

However, subsequent political events changed the situation, with the new left-wing coalition government halting the privatisation process (although following the country's most recent bailout of July 2015, the situation could again change – pressure on the government to instigate energy sector privatisation programmes has increased considerably).

At the outset of the original restructuring plan, PPC acknowledged that it would face major changes. It therefore adopted a series of strategic priorities focused on cost cutting and investment in new cleaner, more efficient power plants to replace older inefficient capacity. This included the development of the new 660 MW Ptolemais V lignite-fired unit. Increased promotion of renewable energy sources, plus expansion into foreign markets via partnerships was also planned (PPC Annual Reports 2012 and 2013).

With the election of Syriza, the situation for the immediate future has become less clear. The new government considers itself to be eco-friendly and pro-renewables and recent announcements appear to indicate this commitment remains in place. Previously announced plans for the increased use of indigenous lignite (largely to reduce energy imports) plus the construction of new lignite-fired generating capacity have become more muted. Syriza will therefore need to adopt a pragmatic approach and balance competing priorities – balancing environmental concerns against the country's urgent need for low cost energy. Deploying renewables at a scale capable of supplanting coal and other fossil fuels is not yet a realistic option (Dodson, 2015). Thus, investing in new clean coal-based generating capacity has been proposed as one of the most logical early energy policies to embark on. The party view has been that replacing outdated, highly polluting plants with new clean, efficient capacity is a sensible, viable option, one that would help minimise the level of energy imports. Thus, the government will need to resolve competing energy policies and align them with a major programme of reconstruction such that energy prices are restrained and emissions reduced. At the same time, it will need to ensure that a secure, reliable supply of electricity is available; Greek lignite and clean lignite-powered plants could play a vital role in this process, although, at the moment, only the new Ptolemais V is proceeding. However, the country's continuing financial crisis will undoubtedly have an impact on the scale and timing of any future developments within the energy sector in general.

6.4 Decommissioning of old lignite-fired power plants

The previous government announced that due to the current over-capacity in the system, apart from Ptolemais V, no further thermal power plants would be built in the foreseeable future. However, as noted, partly as a means of reducing energy imports, Syriza previously proposed the increased use of indigenous lignite for power generation. Part of the strategy was to focus on the replacement of outdated generating capacity with new cleaner, more efficient plants.

Some Greek lignite-fired capacity is getting old. The commissioning date for major power plants ranges from 1959 to 2003, with the bulk of the generating fleet coming on line during the 1970s and 1980s. Unsurprisingly, the efficiency of older units is relatively low – examples are shown in Table 14. Estimates suggest that around half of current generating capacity could be decommissioned by 2020. In recent years, three old lignite-fired units totalling 320 MW (Ptolemais I, Megalopolis I and II) have been decommissioned. Based on its energy planning, in the period up to the end of 2015, PPC expects that a further ~910 MW of lignite-fired generating capacity will be decommissioned (due to age and/or environmental reasons). The capacity in question comprises Megalopolis Units I and II (2 x 125 MW), Ptolemais I-IV (620 MW), and LIPTOL (43 MW) (total 913 MW). In addition, by the end of 2015, old oil and gas units of ~1.28 GW will be shut down. Overall, by this date, a total of ~2.2 GW will have been taken out of service.

Table 14 Dates and efficiencies of major lignite-fired power plants (Roques and others, 2014; PPC, 2013a)

Plant	Unit commissioning date	Net thermal efficiency (%, LHV)
Amyntaio 1, 2 (Florina)	1987	32.0, 32.5
Meliti	2003	30.2, 31.7
Megalopolis 3	1975	27.9
Ptolemais V (in development)	2019-20	41.5

The closure of further lignite-fired plants could happen post-2015, following the application of the EU Directive for Industrial Emissions (2010/75/EC) (IED). This will revise existing Directives, resulting in the imposition of stricter emission limits for power plants. This is expected to have repercussions for a number of older lignite-fired units. After 2015, the emission limits for new solid fuel units will be:

- SO_2 ≤150 mg/m^3
- NOx ≤200 mg/m^3
- particulates ≤10 mg/m^3

Some older lignite units may find it difficult to meet new requirements (although limits for older plants differ). Thus, for compliance reasons, a number could close by the end of the present decade. This will be in addition to the 913 MW of lignite capacity forecast to shut down by the end of 2015 (PPC S.A, 2014).

There is not yet a clear decision for the replacement of retired capacity. Replacement of capacity expected to be retired in the immediate future could require replacement thermal capacity of ~800 MW. However, when the Greek economy eventually recovers, electricity demand is expected to increase – potentially, as proposed by Syriza, this new demand could be met by the addition of further new (clean coal) lignite-fired generating capacity. However, at the moment, only the new Ptolemais V is currently being developed.

6.5 Development of new coal-fired generating capacity

A number of proposed developments have been adversely affected by the country's financial crisis. This has reversed the growth trend in electricity demand and rendered a surplus of capacity. It has severely challenged the financial viability of many new power plant projects – as a result, a number have been cancelled or deferred. This includes a number of hard coal-fired projects that were to rely on imported supplies. All were to use supercritical (SC) pulverised coal combustion (PCC) technology and fire imported bituminous coal. However, the Greek government of the time effectively blocked projects based on imported coal in favour of using natural gas and renewables for most new generating capacity (IEA Greece, 2011). All such proposals were abandoned.

Currently, there is only one major lignite-fired power project under active development, the 660 MW Ptolemais Unit V (*see* Section 5.1.1). This will be the first lignite-fired unit built in Greece since 2002 and is viewed as a critical strategic choice for PPC. It will replace some retired generating capacity and is expected to become operational in 2019-20. The plant will be built on a turnkey basis and commissioned by Mitsubishi Hitachi Power Systems Europe GmbH (MHPSE) and its client TERNA S.A. The design and award of the contract followed a lengthy period of planning and deliberation that took many issues into account. These included:

- the quality and quantity of the available, proven and exploitable lignite reserves in the West Macedonia region;
- the established technologies available for burning lignite in the suggested capacity range;
- the necessity of complying with new stricter emissions limits forming part of the EU IED (Industrial Emissions Directive) legislation; and

- the necessity of applying the Best Available Techniques (BAT) for the new power units, more specifically with regard to their environmental performance and efficiency.

The intention is that it will operate on base-load and also provide thermal input to the district heating system of the town of Ptolemais. The Ptolemais V project is viewed as being of considerable importance as it forms part of PPC's strategy for renewal of its existing power fleet. At the moment, >70% of PPC's units are more than 20 years old, while 46% are more than 30 years old. By adopting modern technology coupled with high efficiency supercritical steam conditions, the new unit will have the lowest variable generation cost, its lignite consumption will be lower than older units, CO_2 emissions per unit of output will be lower, as will emissions of classical pollutants.

As part of PPC's investment plan, a second supercritical lignite-fired plant (the 450 MW Meliti 2) has been proposed. A date of 2021 has been suggested for the start of operation (*see* Section 5.1). However, the project is currently on hold and seems unlikely to materialise before 2025. Progress after this date will depend on the conditions prevailing in the Greek electricity market.

6.6 Power plant modernisation and rehabilitation

All major Greek lignite-fired plants rely on conventional pulverised coal combustion technology, mostly with units of ~300 MW. Some are now more than 30 years old and are the focus of modernisation efforts. Thus, PPC is engaged in updating and/or enlarging a number of its lignite-fired power plants. The company aims to replace much outdated lignite-fired capacity by 2020. Average efficiency of older plants is low (<33%, LHV) although the country's only supercritical plant is somewhat higher.

An objective of the *2008-2012 Greek Energy Development Programme* was the modernisation of a number of lignite-fired stations. For some years, PPC's modernisation programme has been under way. As part of its strategic priorities, the company's Generation Division has an ongoing objective of replacing old inefficient generating capacity with new, cleaner systems. Thus, in some cases, a concentrated campaign has addressed a range of issues, whereas in others, specific plant problems have been tackled. An example of the former was the programme carried out at the Agios Dimitrios plant where a consortium comprising Power Machines and Siemens, modernised two 300 MW units. The total contract was worth €42 million. The scope of this major revamp included automation and installation of updated information and safety systems for Units III and IV. Power Machines modernised the medium and low pressure cylinders of two steam turbines, and supplied auxiliary power units (in conjunction with Energico Oy of Finland). Siemens was responsible for modernising generating equipment, regulating systems and turbine high pressure cylinders. The existing high pressure turbine (a Leningrad Metals Plant K-300-170 unit) dated from 1978 and had operated for more than 100,000 hours – as part of its upgrade, it was retrofitted with Siemens reactive blading (Wolf, 2014). In a separate exercise, new ESPs were also installed on Units I-IV and improvements made to cooling towers. In addition, waste heat recovery systems were installed on all four units – these were connected with the condensate preheating of Units III and IV.

Through major investment, PPC has achieved a significant number of goals of its modernisation programme. As with the update of the Agios Dimitrios station, many have centred on the upgrading of steam turbines, improvements to cooling systems, improving condensate preheating systems, plus modernisation of plant control and instrumentation systems. Examples of completed projects are given in Table 15 and Figure 11.

Table 15 Examples of completed upgrading/rehabilitation projects (ABB, 2014; MHPS, 2014)

Plant	Completed modifications/upgrades
Agios Dimitrios, Unit I	New ESPs and flue gas heat recovery units
Agios Dimitrios, Unit II	New ESPs and flue gas heat recovery units
Agios Dimitrios, Unit III	Upgrading of cooling tower, plus upgrading of steam turbine and condensate preheating system Supply and installation of online efficiency measurement system New ESPs
Agios Dimitrios, Unit IV	Upgrading of steam turbine, new ESPs and condensate preheating system
Megalopolis (Units III and IV)	Upgrading of cooling tower Improved lignite handling and classification systems and mills (ABB, MH Power Systems Europe GmbH)
Kardia Unit I	Upgrading of cooling tower Modification of flue gas-water heat exchangers
Kardia Unit II	Modification of flue gas-water heat exchangers
Kardia, Unit III	New ESP plus upgrading of older unit
Kardia, Unit IV	New ESP plus upgrading of older unit
Ptolemais	Improved lignite handling system (ABB)
Amynteon	Improved lignite handling system (ABB)
All PPC units	Upgraded lignite consumption measurement systems (belt-weighing devices). Installation of automatic solid fuel samplers and systems for determining lignite CV

Figure 11 The 1600 MW Agios Dimitrios power plant at Kozani (photograph courtesy of PPC)

The various plant upgrades have had a positive impact on overall emission levels. Alongside upgrading activities, older generating plants continue to be run down. In 2013, Units III and IV of the Aliveri power plant were reduced to system stabilisation or when natural gas supply was interrupted. Units I and II of the Lavrio plant, and the LIPTOL plant were also wound down. The latter has since been decommissioned. Closing down or reducing the operating hours of older plants has helped reduce overall CO_2 emissions and air pollutant levels (PPC Sustainability Report, 2014).

A number of Greek engineering companies are active in the area of plant rehabilitation/modernisation. For instance, Athens-based METKA has worked on and/or provided engineering, procurement and construction (EPC) services for a number of PPC's lignite-fired power plants that have included Agios Dimitrios, Florina, and Kardia.

- **Plant repowering**

Repowering an existing plant can increase its installed capacity and net electric efficiency, and decrease the emissions per unit of electricity generated. Several Greek generating units have recently been examined with a view to their possible repowering. The low efficiency of older units combined with the low quality/CV of Greek lignite increases the attractiveness of this option. Furthermore, suitable repowering can significantly reduce emission levels, making it easier for a plant to meet national and international environmental legislation.

There are a number of possible routes to repowering. Some configurations propose the addition of a gas turbine to the cycle – potentially, this can be achieved in several different ways. Studies by Karellas and others (2012b) examined the installation of natural gas-fired turbines in parallel operation with existing lignite power plants. The study focused on the simulation of gas turbine topping configurations from a thermodynamic point of view. Two lignite-fired units were considered, both of which had at least 15 years of operational time left before possible retirement. These were a 300 MW unit of the Megaloplis station, and the 330 MW unit at the Florina plant. Three configurations were examined:

- gas turbine exhaust gas was utilised for preheating boiler feedwater of the lignite plant;
- boiler feedwater was evaporated and superheated using gas turbine exhaust gas in a heat recovery steam generator for further power generation; and
- a combination of the first two scenarios.

The performance of each configuration was examined (energetically and exergetically). The main goal was the optimisation of overall performance in terms of electrical efficiency and power production of each cycle configuration.

Thermodynamic results demonstrated that the first option (feedwater preheating using waste heat from the gas turbine exhaust) could be effective. With the second, boiler feedwater was fed to a heat recovery steam generator (HRSG) to produce superheated steam that was mixed with the main steam flow upstream of the power plant's low pressure steam turbine. It was demonstrated that this produced the highest power output and also the lowest cost of electricity. Consequently, it was considered to be the best option for repowering under prevailing Greek conditions (Karellas and others, 2012a). However, the study did not evaluate the modifications necessary to existing systems, or consider space availability and other practical issues. Furthermore, associated financial issues were not studied.

6.7 District heating schemes

In order to provide district heating services to local communities, along with various community authorities, PPC has invested in the provision of a number of district heating schemes. These are located mainly in Western Macedonia and the Peloponnese, where heat generated by lignite-fired power plants is utilised for domestic and commercial heating in nearby towns (Koroneos and others, 2014). Energy is provided in the form of hot water. For example, three units (III, IV and V – two of them simultaneously) of the Agios Dimitrios plant supply medium pressure steam for district heating in the town of Kozani. A similar scheme was installed during the 1990s at the Ptolemais Power Plant Unit III – this provided heat to ~45% of the town. Heat is also provided in this manner to Amynteon and Ptolemais (Table 16). The largest system is in the region of Ptolemais-Kozani, where seven power plants provide heat to most of the local towns and cities. The first Greek installation was built here in 1960.

Assuming that a power plant's steam turbines are capable of operating safely and reliably in district heating mode, thermal energy can be provided via partial bleeding of their steam supply. Steam is then directed to heat exchangers where water for the district heating system is heated and pressurised. The cost to households of providing energy in this way is significantly lower than conventional alternatives such as heating oil. It is also much cleaner.

Table 16 PPC power plants supplying district heating schemes

Power plant/unit	Municipality	Installed capacity (MWth)
Agios Dimitrios 3	Kozani	67
Agios Dimitrios 4		67
Agios Dimitrios 5		70
Ptolemais	Ptolemais	50
Kardia 3	Ptolemais	50
Kardia 4	Ptolemais	50
Amynteon 1*	Amynteo-Filota	25
Amynteon 2*		25
Megalopolis 3	Megalopolis	20
LIPTOL†	Ptolemais	–
Total		424

* 17.500 hours operation from 2016 to 2023
† plant now decomissioned

Interest continues, and a number of new district heating schemes (involving for example, Kardia Units I and II; 2 x 50 MWth) have been proposed. The existing Meliti 1 plant is capable of providing 70 MWth for district heating in the city of Florina (to date, the initial agreement has been signed). In addition, the proposed Meliti 2 plant would also provide (70 MWth) for district heating.

Case study: The Kozani district heating system

The system started up in 1993 and covers most of the city of Kozani. It is fed from Units III and IV of the nearby Agios Dimitrios power plant. Kozani's district heating system serves >17,000 customers out of a total of 55,000 citizens. The total surface area heated is 1,625,000 m^2 – 5% of this covers the public sector. The total distribution network has a length of 285 km. The temperature of outgoing water/steam is 120°C and water is returned at ~65°C (Koroneos and others, 2014). Hot water is supplied to a range of houses, apartment complexes, commercial and official buildings. The total installed capacity of the Kozani system is 204 MWth – PPC plants provide up to 137 MWth of this.

The adoption of district heating has been instrumental in reducing local air pollution (by minimising the amount of oil and wood burned in households and other premises). In some cases, energy consumption has been more than halved and air pollutants reduced by similar amounts. The annual operating period for the Kozani system is between October and April – peak heating load exceeds 125 MWth, Between 2009 and 2014, annual demand (as supplied by PPC plants) was >300,000 MWh. Around 90% of the heat needed for the system comes from the Agios Dimitrios power plant, although for peak loads, the balance is met using an 80 MWth unit fired on oil or LPG.

Since the Kozani district heating scheme began operations in 1993, the following benefits have been reported:

- cost savings, both local and national (reduced oil imports); the system avoids the use of >20,000 toe/y. Replacing oil produces an annual saving of €70 per capita. This has increased the city of Kozani's disposable income by €2.9 million each year;
- a significant fall in the levels of gaseous and particulate emissions in the area. During winter months, pre-district heating, average particulate levels were 62 µg/m^3. These fell to 22 µg/m^3 once the scheme was operating. Similarly, SO_2 levels fell from 170 µg/m^3 to 15 µg/m^3. CO_2 levels also reduced by ~45%; and
- the system provides potential for further development of the area in the primary and secondary sectors of the economy (such as greenhouse heating).

7 Environmental issues

Greek environmental policy in general is based largely on EU environmental regulations and directives. Consequently, Greece has passed important environmental legislation and transposed a number of EU directives into national law. The central organisation for environmental affairs is the Ministry of Environment and Energy – MEE (formerly the Ministry of Environment, Energy and Climate Change – MEECC). This has responsibility for the definition and implementation of national energy and environmental policy, as well as coordination of the energy sector. MEE is responsible for the formulation of policies concerning environmental protection and for the coordination of implementation efforts. It is also responsible for the provision of information on the state of the country's environment, in compliance with the requirements defined in relevant international conventions, protocols and agreements.

With a view to Greece achieving clean and sustainable growth, MEE is pursuing a number of objectives. These include:

- combating climate change by moving to a competitive low-carbon economy. This encompasses a series of policies focused on improving energy efficiency;
- sustainable management and protection of natural resources;
- enhancement of the quality of life, with respect for the environment; and
- strengthening of environmental governance mechanisms and institutions.

A significant proportion of Greek emissions to air emanate from the energy sector – permitted levels are regulated by various domestic and international legislation. Emission standards for air pollutants from large combustion plants were first established in 1993. In 2005, these were supplanted by new standards (set in a Joint Ministerial Decision) on defining measures and conditions to limit emissions of certain pollutants from large combustion plants; this was in compliance with EU Directive 2001/80/EC which came into force the same year. Other legislation has since followed. For example, the Industrial Emissions Directive (IED – Directive 2010/75/EU) of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) is an EU directive that commits member states to control and reduce the impact of industrial emissions on the environment. It came into force in January 2011 with an implementation date in January 2013.

According to recent annual business plans, any new PPC power plants will comply fully with the IED's provisions for new installations. With only small scale interventions, the newest lignite-fired units (Meliti-Florina and Megalopolis III and IV) along with existing NGCC plants will meet IED provisions. Older lignite-fired units (expected to operate post-2016) such as Kardia, Amynteon and Agios Dimitrios will face greater problems and may require considerable expense for necessary upgrades. PPC continues to follow IED developments and assess all technical, environmental and economic elements, in order to reach to the best solution for their lignite-fired fleet.

7.1 Emissions from lignite-fired power plants

The extensive use of poor quality lignite in Greek thermal power plants is responsible for a significant proportion of the country's emissions of SO_2, NOx, particulates, and CO_2 (Kaldellis and Kapsali, 2014). During the 1980s and 1990s, PPC instigated a programme aimed at improving the efficiency of its major power plants and their associated pollutant control systems. A major goal was to reduce levels of particulates and SO_2 – significant investments have since been made in order to minimise these. In addition, Environmental Management Systems (EMS) status has been certified for lignite-fired power plants such as Meliti, Amynteon and Kardia. The West Macedonia and Megalopolis Lignite Centres have also been granted EMS certification (according to ISO 14001:2004) (European Social Charter, 2014).

In application of Article 32 of the EU Directive 2010/75/EC on industrial emissions, Greece produced a *Transitional National Emission Reduction Plan* – this was submitted for approval to the European Commission and covers the period from January 2016 to June 2020. The plan was approved by the Commission in December 2013. PPC then filed an application to MEECC to make limited changes to its scope. PPC also declared that under the terms of Article 33 of the Directive, it would make use of the limited scope derogation for specific units. The revised plan was resubmitted to the EC in March 2014 for approval. This was granted in July 2014 and now includes the Agios Dimitrios, Meliti, and Megalopolis A and B power plants. The Amynteon and Kardia plants are the subject of limited-scope derogation.

The Transitional Plan imposes gradual linear reductions (between 2016 and 2019) in the total annual emissions of SO_2 and particulates. It relates specifically to:

- Units I-IV of the Agios Dimitrios plant;
- Unit III of the Megalopolis A plant;
- Unit IV of the Megalopolis B plant; and
- Unit I of the Meliti plant.

As part of the plan, PPC has set out its policy, and defined how it intends to operate its fleet of lignite-fired plants during the prescribed period. It has also addressed activities and environmental actions needed, plus the timeframe for implementing these (PPC Sustainability Report, 2014).

As part of its contribution towards the country's *National Emission Reduction Plan* (NERP), and the EU environmental Directive 2001/80/EC on the limitation of atmospheric pollutant emissions, PPC is continuing to undertake actions aimed at reducing power plant emissions (primarily SO_2, NOx and particulates. In 2013, levels of SO_2 and NOx fell, although particulates increased slightly (Figure 12).

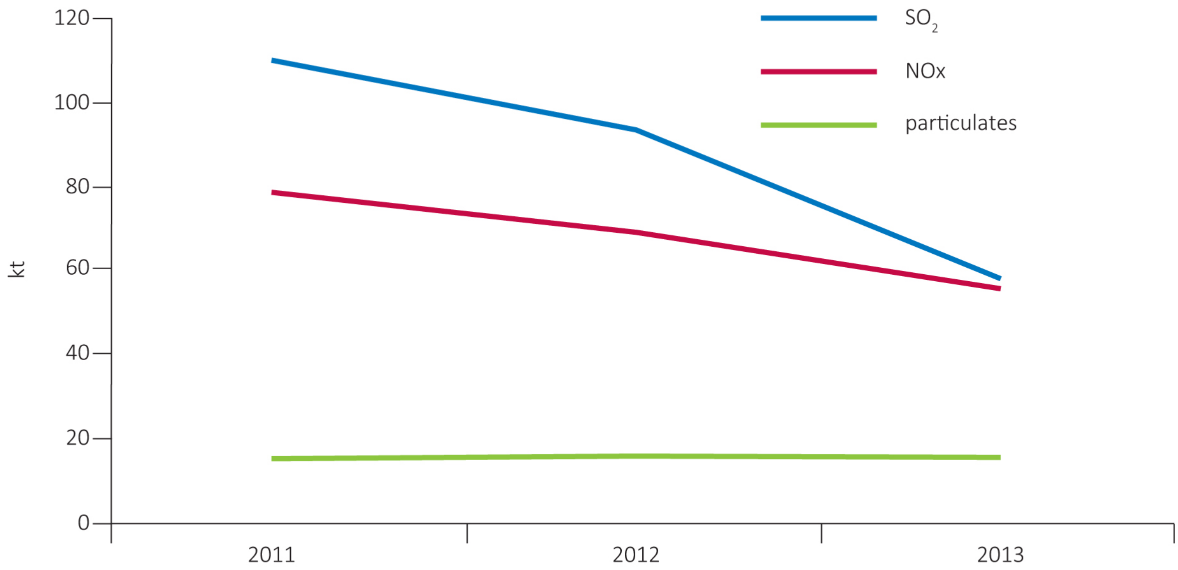

Figure 12 Main air emissions from PPC power plants (2011-13) (kt) (PPC Sustainability Report, 2014)

The falls in SO_2 and NOx emissions were attributable largely to reduced power generation in general, changes in the fuel mix adopted, plus longer hours of operation for FGD plants. As part of its monitoring programme, PPC operates a network of 35 stations that measure air quality and meteorological parameters in the areas around its power plants and mining sites.

7.2 Environmental controls on lignite-fired power plants

All major lignite-fired power plants are owned and operated by PPC. In recent years, the company's Generation Division has made increasing efforts to minimise the environmental impact of its generating fleet. An important remit has been to ensure the optimal running of individual plants, such that they comply with all environmental requirements. This strategy is being applied across all areas of the company's activities, spanning lignite mining, power generation, transmission, and the distribution of electricity.

To maintain its position in a deregulated energy market, PPC has taken a number of strategically important decisions that include the deployment of appropriate environmental management systems (EMS) (PPC Environmental Report, 2011). The latter have been put in place at individual power plants and PPC is in the process of obtaining certification for them. To date, ISO 14001:2004 has been obtained at the Western Macedonia Lignite Centre (responsible for ~84% of PPC's lignite-fired generation) and in major plants such as Agios Dimitrios, Amynteon-Filota, Kardia, Megalapolis I and II, and Meliti. In addition, the Megalopolis Centre now has EMS certification, and is also in the process of obtaining appropriate certification in line with the ISO 50001 standard (PPC Sustainability Report, 2014).

In some cases, older lignite units are now only operated for a limited number of hours. Such limited running has helped reduce overall SO_2 (and other) emissions. For example, as a consequence of the implementation of EU Directive 2001/80/EC, two 125 MW units at Megalopolis A were given a limit of 20,000 operating hours – this was reached in 2011 and both were then shut down.

- **SO_2 control**

The emission limit values for SO_2 from lignite-fired combustion plants depend on plant capacity, age, fuel characteristics, and hours of operation. For existing smaller plants, a sliding scale is applied. However, for larger plants (rated thermal input >300 MWth), at least 95% desulphurisation rate is required – the maximum permissible emission limit value is 400 mg/m^3. All future new plants will be expected to achieve 200 mg/m^3.

Some power plants can experience irregular peaks in SO_2 emissions that result from variations in the lignite feed – these can be minimised by appropriate mixing and homogenisation. However, this response may be inadequate and some plants deploy limestone-gypsum FGD scrubbers to control emissions of SO_2. There are also plans for several others to be similarly equipped although some projects have been delayed as a result of the prevailing economic conditions. Not all power plants currently deploy FGD. Under certain conditions, the dry scrubbing capability of some Greek lignite can be high (Konidaris, 2010), making it possible for a number of units to meet legislative limits without the need for FGD. For instance, the lignite supplied to the Agios Dimitrios plant contains high levels of calcium compounds that react with sulphur species present. This partially desulphurises the flue gases, enabling the plant to meet prevailing emissions limits (Ballesteros and others, 2013). However, increasingly stringent legislation means that further measures have since become necessary.

As part of the process for addressing this, PPC investigated means for reducing SO_2 emissions from Units I-IV of Agios Dimitrios, and Units I and II at Amynteon (PPC Sustainability Report, 2011). In 2011, a 12-month dry flue gas desulphurisation pilot scale test commenced at the former site, whereby absorbent materials were injected into the flue gas stream on the plant's Unit III. This project was completed successfully and the decision taken to fully equip Agios Dimitrios Units I-IV with dry desulphurisation facilities (although Unit V will use a wet desulphurisation plant). For future projects, where possible, PPC intends to opt for the use of dry desulphurisation (PPC Sustainability Report, 2013). The necessary environmental investments planned will be implemented within the time limits prescribed by law.

A recent study examined further the possibility of SO_2 abatement via 'natural' desulphurisation based on the use of calcium-rich lignite. Some lignites have a high calcium oxide content, partially in the form of limestone. The calcareous fly ash produced is rich in free lime and (as noted above) under the appropriate conditions, adequate flue gas desulphurisation has been achievable. The desulphurisation efficiency using this calcium-in-lignite technique averages ~80% – this only requires boosting to 96% in order to achieve SO_2 emission levels of less than 200 mg/m^3 (Efthimiadou and others, 2013).

Desulphurisation can be achieved via several commercially-available dry FGD techniques. Typically, these have a desulphurisation efficiency of ~80% (on the cool side of the combustion process, after the flue gas air preheater). Studies suggest that SO_2 concentrations of up to 1000 mg/m^3 could be treated using such low investment dry FGD systems. It is considered that if effective homogenisation of the lignite feed was also applied, some plants could possibly meet emissions legislation using cheaper dry FGD facilities, rather than their more expensive wet counterparts.

Currently, there are no FGD plants operating on Amynteon Units I and II, or Kardia I and II. The power plants so far equipped with FGD capabilities are:

- **Megalopolis** – Unit III has a wet limestone FGD plant, supplied in 2009 on a turnkey basis by Alstom. This was fully commissioned in May 2013. It also treats vapours produced by the drying of the plant's lignite feed; the mixed gas has a high moisture content and very high SO_2 concentration. Alstom incorporated all the latest design features into the unit (high gas velocity in the absorber tower, use of double orifice spray nozzles, wall rings, and roof-type demister). Megalopolis Unit IV was similarly equipped, this time by BK-Noell. Gypsum slurry is produced from unit operations (Ballesteros and others, 2013). SO_2 removal efficiency is >98 %.
    - **Meliti-Achlada power plant** – this uses a wet limestone scrubber (up to >96.5% capture efficiency) supplied by Alstom Power Environmental Control Systems. Alstom received the EPC contract in 1998 and both the power plant and FGD began operation in 2003 (Figure 13). SO_2 loadings to the FGD plant can vary widely (between 6000 and 11,000 mg/m^3). Even during the latter, the system has maintained the SO_2 emission concentrations below the required maximum of 400 mg/m^3. The system is similar to that of the Megalopolis plant. A number of Greek companies were involved in the project; for example, Atermon S.A. was responsible for mechanical construction.

The Ptolemais V power plant currently being developed will use an FGD unit supplied by Hitachi.

Figure 13 FGD unit at the 330 MW lignite-fired Meliti power plant (photograph courtesy of PPC)

In order to minimise transport costs, wherever possible, supplies of limestone used for FGD operations are sourced locally. For example, limestone for the Meliti power plant is supplied by Ergon S.A. from a nearby quarry. Annual cost to PPC is ~€540,000.

As numerous smaller islands lack connection to the mainland electricity grid, many rely on oil-fired power plants. Annually, considerable quantities of light fuel oil (LFO) are used; in 2013, 856,000 kilolitres were consumed (PPC Sustainability Report, 2014). Efforts to reduce SO_2 emissions have not been limited to lignite-fired plants and since October 2007, all PPC oil-fired plants have used low sulphur fuel oil (1% wt. sulphur).

- **NOx control**

The NOx emission limit values for existing and new large lignite-fired combustion plants with a rated thermal input of between 50 and 500 MWth is 600 mg/m^3. For plant of >500 MWth, the limit is 500 mg/m^3. From 1 January 2016, the general IED limit for existing plants will be 450 mg/m^3 for 50–100 MWth, and 200 mg/m^3 for 100–300 MWth. There are some exceptions to these – for instance, where specified plants operate for only a limited number of hours a year.

No Greek power plants currently deploy deNOx systems such as selective catalytic reduction (SCR) although some have adopted primary measures and/or fitted low NOx burners. For instance, Unit I of the Meliti plant uses low NOx burners supplied by EVT (Platts, 2014). Similar NOx reduction activities are underway at a number of other power plants. Unit V of the Agios Dimitrios plant has applied primary measures (burner modification and additional OFA installation, using Mitsubishi Hitachi Power Systems Europe technology).

Having completed a number of studies, PPC aims to further reduce NOx emissions from its fleet through a €28.6 million programme that will involve significant changes to Units I-IV of the Agios Dimitrios plant – this will include improving the fuel preparation system, replacing burners with low NOx variants, and changing the distribution of combustion gases within the boiler. In addition, a project involving lesser changes (primary measures, but no burner replacement) is in progress in Agios Dimitrios Unit V; the budget is €3 million. PPC notes that any necessary environmental investments will be implemented within the time limits prescribed by law.

Under the terms of the *Transitional National Emission Reduction Plan*, compliance on the level of NOx emissions is required by the beginning of 2016. However, in December 2013, PPC requested an amendment excepting Units III and IV of the Kardia plant – this needs approval from MEE, followed by that of the European Commission. PPC also requested limited derogation status (for the period 2016-23) from Article 33 – 2010/75/EC, for Units I and II of Amynteon, and Units I-IV of Kardia.

Historically, there has been Greek R&D involvement in efforts to develop improved NOx control measures. For example, between 2006 and 2009, a Research Fund for Coal and Steel (RFCS)-funded multi-partner project examined the development of an advanced large-scale low-NOx oxyfuel burner for pulverised lignite and/or subbituminous coal combustion. Greece was represented by the National Technical University of Athens (NTUA). The project combined experimental work, CFD modelling and cross validation through experimental data. Parameters investigated included design scale-up, oxygen injection method (pre-mixing or direct injection), and operational issues (such as switching from air to oxyfuel mode). A burner design applicable to lignite-fired systems was produced. However, this is not currently in commercial use.

- **Particulates**

Greek power plants are equipped with ESP units supplied by various technology vendors (Platts, 2014). Historically, some units have been upgraded via the installation of new, improved systems. As part of this, starting in 1987, PPC instigated a programme for reducing particulate emissions from its power plants. This focused mainly on replacing and upgrading existing ESPs, plus the addition of new state-of-the-art high performance units. This was carried out under the terms of the EU Directive 96/61/EC on Integrated Pollution Prevention and Control, and the Best Available Technologies Reference Documents on Large Combustion Plants. The implementation of the programme led to a significant improvement in ambient air quality, particularly in areas around power plants.

As part of the programme, ESPs were replaced on Units I-II of the Kardia plant (old ESPs on Units III and IV were also upgraded at a cost of €40 million), Units I-IV of Ptolemais, Units I and II of LIPTOL, and Unit III of Megalopolis A. Improvements were also made to ESPs on Units I and II of the Megalopolis plant. PPC installed new higher efficiency ESPs to Units I-IV of the Agios Dimitrios plant – the work (costing €130 million) was carried out by a consortium comprising Alstom and Greek company METKA. The scope of supply included new ESPs, fly ash handling system, and flue gas heat recovery system. This was the third contract awarded by PPC to the consortium for the supply of air pollution control equipment to Agios Dimitrios Units I-IV.

PPC maintains on-going efforts aimed at improving ESP performance further as suitable opportunities arise. To date, significant reductions have been achieved. In the Ptolemais/Kozani region, between 2007 and 2010, airborne particulate levels fell by 55%. The reduction at Agios Dimitrios was 90%, and at Kardia, 41%. As well as addressing particulate emissions from lignite-fired power plants, PCC also began a process to reduce those from its oil-fired units, mainly in island locations. Some are located in close proximity to areas of high population density (for example, the 92 MW Mytilene plant on Lesbos) (Figure 14). Work is focusing on the use of combustion improvement additives, as well as replacement of existing oil burners with more efficient (steam atomisation type) variants (PPC Environmental Report, 2015).

Figure 14 The oil-fired Mytilene power plant on the island of Lesbos

7.3 Power plant solid by-products

As Greek lignites usually have a high ash content and low CV, and are burned in large quantities in power plants, considerable quantities of combustion by-products are generated. The biggest amount comprises around 10–11 Mt/y of fly ash. Of this total, ~7.6 Mt originates from power plants in northern Greece, and ~2.5 Mt in the south (predominantly Megalopolis). In 2012, PPC plants generated nearly 10.9 Mt of fly ash. But only 300 kt of this was recycled, the remainder being deposited in specially designated areas. Thus, 8.6 Mt (combined with other waste materials) were disposed of in exhausted mine workings of the Western Macedonia Lignite Centre, 1 Mt (combined with gypsum) near the Meliti power plant, and 1.6 Mt in depleted mines of the Megalopolis Lignite Centre (PPC Sustainability report, 2013). In 2013, a total of 9.5 Mt of fly ash was produced. Deposition was to the same sites (8.1 Mt in Western Macedonia, 0.4 Mt near Meliti, and 1.6 Mt at Megalopolis (PPC Sustainability report, 2014). Fly ash sales were the same as in the previous year. Annually, a limited amount is bought by cement companies and used mainly in the manufacture of blended cements and specialised Portland cements. Residual carbon-in-ash levels are normally less than 5%, hence ash meets the necessary specifications (Tsimas, 2010). From 1980, lignite fly ash has been used in Greek blended cement production – since 2002, it has been accepted under European Standard EN 197-1. However, overall ash utilisation in Greece is much lower than the European average rate of 47% (Vardoulakis and Karamanis, 2011). Depending on the location, the bulk is used for the restoration and reclamation of exhausted opencast lignite mines and slope stabilisation of the overburden (Mavrikos and others, 2014).

Greek fly ash produced is usually classified as type C (according to ASTM C 618). It exhibits both pozzolanic and hydraulic behaviour. Ash from power plants in Western Macedonia is classified into two groups:

- calcareous ash (from Agios Dimitrios, Kardia and Ptolemais power plants) with a total calcium content of 25–50% and containing 20–35% silica; and

- siliceous ash (from Amynteon and Meliti plants) with a total calcium content of 5–25% and silica content of 35–50% (Kastanaki and others, 2012).

Potentially, there are a number of outlets for fly ash that include road construction, incorporation into mortars, waste treatment, embankment construction, and cement grouting. It has also been used in major construction projects. For example, in 1992, PPC began construction of the Platanovrisi hydroelectric dam, applying the roller compacted concrete (RCC) technique and utilising fly ash as the basic cementitious material. The level of fly ash in the concrete was 82%. The completed dam was 95 m high with a crest length of 270 m and a volume of 450,000 m^3 (Koukouzas and others, 2005).

In Greece, part of CERTH (The Institute for Solid Fuels Technology and Applications – ISFTA) carries out R&D into by-product utilisation. This is the main Greek organisation for the promotion of research and technological development aimed at the improved and integrated exploitation of solid fuels and their by-products. Activities are focused on increasing the amount of fly ash used by the cement industry. Various pilot scale investigations have been undertaken – for instance, the use of fly ash for road base and sub-base construction.

During operation, as well as fly ash, lignite-fired power plants also generate bottom ash. However, quantities involved are much smaller. PPC estimates that the amount of bottom ash varies between 0.5% and 2% (wt) of the total solid by-products produced. Greek bottom ash is usually a coarse, angular material with a porous surface texture; size can vary but most particles are sand-sized (Kantiranis and others, 2004). In 2012, PPC plants generated 0.7 Mt of bottom ash, and in 2013, it was 0.6 Mt (PPC sustainability Reports, 2013, 2014).

During power plant operation, following combustion, bottom ash usually falls into a water-filled hopper at the bottom of the boiler, where it is quenched and subsequently removed (a wet bottom ash system – WBAS). An alternative is the use of a dry bottom ash system. On the 300 MW Unit IV of PPC's Ptolemais power plant, in order to improve the removal of bottom ash, the existing wet system was replaced with a dry bottom variant manufactured by the Italian company Magaldi (the Magaldi dry bottom ash extraction system – MAC). This removes bottom ash without the use of water for cooling or conveying. Thus, during operation, ash falls onto a slow-speed, continuously moving steel belt that is cooled by a flow of air. The amount of cooling air is controlled with variable inlet dampers that utilise the furnace's negative pressure. Ash cooling occurs in the sloped section of the system's extractor, in the primary crusher, and in the post-cooler. Depending on the boiler's operating conditions, the bottom ash is discharged at a temperature between 40°C and 100°C. Ash is recycled into the boiler in order to burn any unburned carbon remaining.

At Ptolemais, the deployment of the dry system did not increase the amount of bottom or fly ash produced. In fact, the recycling of bottom ash to the boiler reduced the amount to effectively zero (US DOE, 2011). An important advantage of the MAC technology was its impact on boiler efficiency – plant output increased by 1.6%. This was due mainly to the use of air, rather than water, as ash cooling medium. Usefully, lignite consumption was also reduced, as was water consumption. Globally, more than 100 MAC systems are now in use.

A modified version of the MAC was later introduced in order to accommodate bottom ashes that needed longer times to achieve complete post-combustion burnout of residual carbon. This provides an alternative to recycling the dry ash to the boiler (as on Ptolemais Unit IV). The new configuration (the Magaldi Ash Postcombustor – MAP) is capable of achieving substantial reductions in unburned carbon levels in bottom ash. The first full-scale implementation of this new configuration was on the 300 MW Unit III of the Megalopolis plant. With the plant's original wet bottom extraction system, unburned carbon levels were typically ~20%. The MAP system reduced these to <10%. This efficient recovery made it possible to increase the unit's power output by ~5–6 MW (Bassetti and others, 2001).

The other by-product generated in considerable quantities is **gypsum** resulting from power plant FGD operations. In 2012, PPC plants consumed a total of 410 kt of limestone and produced 800 kt of gypsum. Of this, 100 kt was disposed of in a licensed landfill near Meliti, and 700 kt at Megalopolis (combined with fly ash). In 2013, 60 kt was disposed of at Meliti, and 700 kt at Megalopolis (PPC Sustainability Reports, 2013 and 2014). In the future, PPC is hoping to develop commercial outlets for some of the FGD gypsum currently landfilled.

Although there are some differences between individual Greek FGD installations, in general, gypsum is produced in a similar manner. For example, at the Meliti power plant, gypsum cake with a solids content of ~85% is produced using horizontal vacuum belt filters. This is then discharged via diverter chutes to transfer belt conveyors that transport it to a storage silo (prior to landfilling) or directly to a truck loading station. If stored, it is reclaimed using a discharge screw conveyor and transferred to a mixing station where it is mixed with fly ash from the power plant. This mix is then disposed of to landfill.

Around the world, FGD gypsum is produced by many coal/lignite-fired power plants. In many Northern European regions that lack deposits of natural gypsum, it is the main source for the gypsum products industry. Conversely, in regions where natural gypsum is abundant (such as Greece), the gypsum industry is located close to natural supplies, and FGD gypsum has little or no demand. The low cost of natural reserves and the transport costs for FGD gypsum are major factors. However, some work has examined the potential for commercial application of FGD gypsum from Greek power plants. For example, supplies from power plants in Megalopolis (10% moisture) and Florina (25% moisture) were shown to be suitable as cement setting modulators, as a possible partial substitute for natural gypsum (used almost entirely by the Greek cement industry). Usefully, partially replacing natural gypsum with FGD gypsum improved concrete setting times, compressive strength and sulphate resistance.

In Greece, the majority of FGD gypsum currently remains unutilised, and is disposed of to landfill. As noted, in some cases, it is mixed with fly ash and bottom ash prior to disposal in landfills of exhausted opencast lignite mines.

8 Greek power plant construction capabilities

TERNA is the construction and energy company of the GEK-TERNA Group and has been involved in the construction of wind parks, hydroelectric facilities, plus open cycle and combined cycle gas-fired power plants. An example of the latter was PPC's 811 MW Megalopolis NGCC plant, where the company provided EPC services. TERNA is also a major supplier to the new 660 MW lignite-fired Ptolemais Unit V, currently under development. The contract from PPC comprises the design, engineering, supply, manufacturing, construction, testing and commissioning of the new unit.

ASPROFOS S.A. is a Greek engineering firm, originally set up in 1983 as a joint venture between Hellenic Aspropyrgos Refinery and Foster Wheeler Italiana. It is now a wholly owned subsidiary of Hellenic Petroleum Group and is mainly active in the oil and gas sector – it also provides the power sector with basic and detailed engineering design, FEED, project management, plus construction supervision and consultancy services. Power projects have included a 390 MW gas-fired plant in Thessaloniki. The company also has experience in the design of cogeneration systems.

Athens-based **METKA** (Metal Constructions of Greece) provides EPC services and undertakes fully integrated turnkey projects for both state-owned and private power generators. A range of generating technologies is covered that includes thermal (lignite and natural gas) and hydro plants. METKA was part of the consortium that developed the 300 MW lignite-fired Agios Dimitrios Units I and II. Other Greek steam power plants worked on include Florina and Kardia. There is a background in upgrading/rehabilitation of large lignite-fired units. The company also manufactures a range of major plant components and equipment that includes complete turnkey systems for lignite handling and milling, balance of plant, and ash conveying and disposal systems. On the environmental front, METKA has been involved in various projects to upgrade existing equipment or install new state-of-the-art emission control technologies. For instance, as part of a consortium that also included Alstom, METKA completed a series of projects to reduce particulate emissions from existing lignite-fired units throughout Greece; for example, upgrading ESPs on Agios Dimitrios Units I-IV. Replacing and upgrading existing ESPs, plus installing new units, helped PPC to meet the requirements of national legislation and the European Directive 2008/01/EC on IPPC. The company is also active in the areas of gas-fired and hydroelectric power generation, both within Greece and on the international stage.

Athens-based **Aspate S.A.** has worked on numerous projects, mainly in the areas of electromechanical installations, and especially projects concerning lignite mining and PPC thermal power plants. Strategic partnerships are in place with a number of specialist engineering companies around the world; these include firms in Bulgaria, Germany, the UK, and Switzerland. These alliances have widened the range of services offered and helped improve the performance of end products.

In the area of opencast mining, Aspate has supplied and installed electromechanical equipment for belt conveyer systems for lignite fields in Ptolemais and Kardia, as well as conveyors at the Agios Dimitrios power plant. Other projects have focused on conveyor systems at mines at Amynteon and Megalopolis.

Electrical equipment has been installed for bucket wheel excavators at the Ptolemais mine. The company has also worked on many of PPC's lignite-fired power plants; examples include electrical equipment for ESPs and lignite handling equipment at Agios Dimitrios. Aspate has also designed and installed online performance monitoring systems in the Amynteon and Agios Dimitrios power plants. Online belt weighing systems have been installed at the Amynteon, Kardia, Ptolemais, Meliti, Agios Dimitrios and Megalopolis power plants. The company also undertakes gas-fired projects; for example, they were responsible for the mechanical equipment installation of steam turbine plant at Chania.

There are also a number of Greek companies that have acted as subcontractors on various power sector projects. For example, Ptolemais-based **Mekasol** manufactures fabricated metal structures, industrial piping systems, vessels and storage tanks. The company worked as subcontractor on Agios Dimitrios Unit V.

ATERMON S.A. was established 40 years ago and provides integrated solutions for various types of turn-key projects in Greece and elsewhere, particularly in the area of EPC services. Numerous power-related projects have been undertaken. These include electricity transmission networks, wind parks, and natural gas-based facilities. Other projects have included diesel-fired power plants for several of the Greek islands, plus the erection balance-of-plant, belt conveyor systems, and FGD and ESP units at the lignite-fired Florina station. Some projects have been carried out as part of a consortium.

ATHENA S.A. is a Greek construction and EPC company active within Greece and internationally. Company projects encompass a range of industrial and environmental facilities, energy production-related work (steam, diesel, water and fossil fuels), renewable energy projects, and electromechanical installations. In the case of fossil fuel-fired power plants, the company supplies and installs all major systems that include electromechanical fire-protection, heating and ventilating systems, cooling towers, ESPs, fuel and ash handling systems, chimneys and all auxiliary systems. Greek lignite-fired power projects have included Ptolemais Unit IV and Kardia Units I and II (fly ash handling system and auxiliary systems), Megalopolis Unit IV (cooling tower, chimney, machine house), Agios Dimitrios Units III and IV (design and construction of cooling towers and chimney), Megalopolis Units I, II and III (cooling tower upgrade, ESPs), and Amynteon Units I and II (cooling towers, chimney).

Unsurprisingly, some major international power plant technology suppliers maintain a presence in Greece. Some have been present for longer and are more active in the country than others. For example, **Alstom** has long operated in Greece. It's Thermal Power Division has been active in the Greek power sector for more than 50 years and is currently the country's largest service provider, covering more than 30% of the installed fleet. In 2001 a dedicated Local Service Centre was established in Athens to serve the Alstom-installed base fleet (gas turbines, steam turbines, generators, boilers, and air quality control systems). Alstom clients have included PPC, Elpedison Power, Protergia, METKA, and Motor Oil Hellas. The three main areas of activity centre on gas turbine long term service agreements, servicing the installed OEM fleet (Alstom) and other-OEM fleets, and retrofits and upgrades. Examples of the latter include boiler restoration of Ptolemais Unit IV, and ESP control upgrade of Kardia Unit I. In other instances, international technology suppliers have worked with Greek firms in the development of power projects. For example, METKA has cooperated with Siemens on projects in Greece and elsewhere.

9 Clean coal technologies

Several forms of CCTs are in operation in Greece. These are examined in the following sections.

9.1 Supercritical (SC) pulverised coal combustion (PCC) power plants

Most of PPC's existing lignite-fired power plants comprise conventional subcritical PCC-based units, although there is also one SC plant currently in operation, namely the **Meliti power plant,** Florina. This 330 MW lignite-fired SC unit started up at PPC's Florina site in 2004 (Figure 15). The once-through, single pass, supercritical, tangentially-fired, pulverised coal boiler was supplied by Ganzrock of Hungary. The plant uses steam conditions of 24.2 MPa/543°C/542°C. The steam turbine/generator was supplied by

LMZ and Energosila. Engineering, procurement and construction activities were undertaken by ABB and METKA. INITEC Energía of Spain was involved in the basic and detailed engineering. The flue gas cleaning system comprises a wet FGD scrubber and a five-field electrostatic precipitator, both supplied by Alstom Power Environmental Control Systems. Fuel is in the form of low calorific, high xylitic/high ash lignite, sourced from the adjacent Florina opencast lignite mine. Reportedly, plant efficiency is ~34% (LHV).

Figure 15 PPC's 330 MW Meliti power plant (photograph courtesy of PPC)

9.1.1 Proposed SC plants and projects in development

Prior to the onset of the country's financial crisis, PPC had been considering new plants in the Florina area, as well as further developments at Ptolemais, Larimna, Aliveri and Evia. These were expected to adopt supercritical steam conditions. However, the economic problems made it increasingly difficult to start new major infrastructure projects. This situation was hampered further by the fact that electricity demand had fallen. This resulted in the deferment or cancellation of a number of power projects. However, some major projects are still being developed and are expected to proceed although it is not clear how the country's current economic situation will affect proposed timescales. The main projects comprise:

Ptolemais V power plant

In March 2013, a contract was signed by PPC for this new pulverised lignite-fired 660 MW plant. This will be the first lignite-fired unit built in Greece since 2002 and is viewed as a critical strategic choice for PPC. It will be constructed on a turnkey basis and commissioned by Mitsubishi Hitachi Power Systems Europe GmbH (MHPSE) and its client TERNA S.A. The site is on a depleted area of the Komanos lignite mine. As TERNA's sub-contractor, MHPE will provide the entire design engineering and will also supply the steam generator, balance of plant, and flue gas cleaning system. TERNA will construct the plant and put it into operation. Plant construction is now underway (Hitachi, 2013). MHPE subsidiaries Donges SteelTec (steel construction/main supports), Meeraner Dampfkesselbau (pressure parts), and Hamon Environmental GmbH will also be involved in the plant's construction. The new unit will operate on base load and replace older low efficiency generating capacity. Annual generation will amount to ~4300 GWh. It will also provide 140 MWth output for district heating for the town of Ptolemais.

The new unit will use steam parameters of 25 MPa/600°C/609°C and have a minimum guaranteed net efficiency of 41.5% (LHV). It will comply fully with Greek and EU environmental legislation. Thus, NOx emissions will be below 200 mg/m^3, SO_2 emissions will be less than 150 mg/m^3 (FGD capture efficiency of at least 97%), and particulates below 10 mg/m^3. Annual lignite consumption is expected to be ~6.5 Mt.

Reportedly, around 60% of funding for the plant will come from German investment bank KfW. Following approval from the German export credit agency Hermes, KfW will provide €700 million of the total estimated cost of €1.39 billion. The participation of German companies and the use of German equipment for the construction of the project is linked directly to its funding with German capital, plus insurance of that credit by the German state (Ekathimerini.com, 2013). A generation license for the project was issued in September 2010, and the Environmental Permit for operation of the relevant lignite mines issued in November 2011. The Environmental Permit for the power unit was issued in May 2012 (PPC, 2013b). The plant is expected to come fully on line in 2020.

Florina Power Plant, Vegora (Meliti 2)

In 2003, PPC's 330 MW Meliti unit in Florina (Western Macedonia) came into operation. PPC has since proposed a new lignite-fired unit for the site. In July 2008, an international tender was issued for a new unit of between 420 and 450 MW. It was also to be capable of providing 70 MWth for district heating. The budgeted cost for the new unit was €675 million. As no offer was submitted, the basic technical and commercial parameters of the project were reconsidered, and a new tender subsequently announced (PPC annual report 2012, 2013). However, prospects for the proposed unit depend on the future status of PPC.

9.1.2 Supercritical PCC R&D

The possibility of using poor quality Greek lignites in 700°C ultrasupercritical PCC-based power plants has been examined. Studies involved VGB of Germany and the National Technical University of Athens and focused mainly on associated technological aspects. The thermodynamic analysis carried out as part of the study suggested that the expected efficiency of a 700°C power plant burning Greek lignite could be up to 42% (compared to a 36% average for existing Greek plants) when using a conventional lignite drying system, and up to 50% when using a pre-drying system based on WTA technology. The calculated feasible increase of 6–14% points indicated the substantial potential of the 700°C concept and WTA pre-drying for such fuels (Karakas and others, 2006).

RWE Power International also examined the possibilities of using low grade Greek lignites in supercritical applications; this included technical and economic analyses. Lignite from Florina, Ptolemais and Drama were assessed and their potential for this type of application (as well as other clean coal technologies) compared with various hard coals. The Florina lignite had a relatively high CV, low moisture content, and high ash content. The Ptolemais lignite had a low CV, high moisture content, and high ash content. The Drama lignite had the lowest CV, plus high moisture and ash contents. The project noted that the ash composition and properties of Greek lignites were significantly different to, for instance, those in Germany. In particular, they had a higher propensity for deposition. The findings suggested that the combination of high moisture and high ash for the Drama and Ptolemais lignites could result in combustion problems, hence the need for quantification of such effects prior to commercial application (Reinartz, 2006).

9.2 Fluidised bed combustion (FBC)

Greece is a member of the IEA implementing agreement on Fluidised Bed Conversion. The country is represented by a contracting party, Aeval Group of Ptolemais.

Some Greek lignites have been evaluated and confirmed as suitable fuels for CFBC plants. Combustion tests have been carried out in several different CFBC facilities. This included testing in a 100 kWth facility at NTUA and in a semi-industrial scale 1.2 MWth unit at RWE's Niederaussem power plant in Germany. Cocombustion tests with lignite and waste wood were also carried out in a 1 MWth CFBC unit of AE & E in Austria. In order to investigate ash melting characteristics, further laboratory-scale cocombustion tests were also undertaken in a bubbling fluidised bed. Testing confirmed that Greek lignites would make suitable fuels for FBC applications, both alone and cocombusted with biomass (Kakaras and others, 2003).

Currently, there are no commercial scale lignite-fired FBC-based power plants operating in Greece. However, there has been a proposal by PPC to build a 450 MW lignite-fired power plant based on fluidised bed technology in Kozani-Ptolemais. However, the present status of the project is unclear (Michaletos, 2011) – given the country's present condition, it seems unlikely to proceed.

As well as NTUA, a number of other Greek organisations have been involved in projects examining FBC technology and its potential for application to the country's lignites. For example, the Centre for Research and Technology-Hellas (CERTH) was a partner in an EU project Advanced CFB for clean and efficient coal power – CLEFCO. This ran between 2003 and 2006 and focused on promoting the further development of once-through steam cycle CFB technology. It was followed in 2005-08 by a project that examined the use of utility-scale CFB for competitive coal power. Again, CERTH represented Greece. Technology up to 800 MWe with a net efficiency of at least 45% was considered. As part of the project, a viable CFB plant

(CFB800) design of 800 MWe was developed. Using steam conditions of 600°C/30 MPa, this had a calculated net efficiency of 45%.

Although not specifically focused on lignite, there are a number of EU-funded FBC-based projects that have involved CERTH/ISFTA and NTUA (Table 17). Other R&D activities are also underway.

Table 17 FBC-based activities involving Greek organisations (IEA-FBC, 2013)

Project acronym	Title	Aims and status
CFB800 (RFCS)	Utility scale CFB for competitive coal power	Development of a 600–800 MW CFB boiler. A once-through SC CFB boiler design was developed by Foster Wheeler/Siemens. CERTH/ISFTA addressed CFB ash management issues, wastewater decontamination, and development of 3D models for combustion and pollutant formation mechanisms (NOx, N_2O). NTUA was also involved
Euroe-Bioref (FP 7)	European multilevel integrated biorefinery design for sustainable biomass processing	Development of a highly integrated and diversified concept using multiple biomass-based feedstocks to produce a range of products (such as aviation fuels and chemicals). CERTH involved (via two of its institutes, ISFTA and CPERI). Testing in CERTH/ISFTA 150 kWth CFB gasifier
Polystabilat (FP 7)	POLYgeneration via gasification of STABILAT (secondary fuels derived from MSW)	Design of integrated system (based on gasification and existing MSW plant). NTUA's Laboratory of Steam Boilers and Thermal Plants addressing process modelling and basic design characteristics
Energy-Waste (Life+)	Energy exploitation of non-recyclable urban waste in a sustainable waste-to-energy market	CFB gasification of non-recyclable waste for electricity generation. CERTH/ISFTA characterising SRF, carrying out laboratory-scale bubbling FBC testing, and undertaking technical, economic and environmental aspects with a view to process scale up

9.3 Gasification

9.3.1 Synthetic natural gas (SNG) production

Over the past decade, largely in response to the country's high dependence on imported natural gas, the gasification of Greek lignites to produce SNG has been examined. Various Greek organisations have been involved in a number of projects. For example, between 2009 and 2012, NTUA was part of a consortium that examined the production of SNG from coal/lignite; the process (*CO2freeSNG*) featured the internal sequestration of CO_2. A steam gasification process was proposed that would be competitive for medium-scale (50–500 MW) coal/lignite-to-SNG plants. It was claimed that CO_2 production would be a third lower than conventional systems. The consortium scaled up gasification, methanation and carbon capture technologies, each of which had originally been developed for biomass conversion. Technical and economic studies were undertaken and methanation carried out at an existing gasification plant.

The project is being followed up by a second one (*CO2freeSNG2.0*, 2013-16) focused on demonstrating the full process chain. The project will feature a simplified gas clean-up stage based on the use of potassium carbonate (K_2CO_3) scrubbing. This will allow the simultaneous removal of CO_2, sulphur and tar components by means of a single pressurised water/carbonate scrubbing process that should significantly improve process efficiency. Again, Greece is represented by NTUA. Some of NTUA's work has focused on avoiding methanation catalyst poisoning during coal-to-SNG production using carbonate scrubbing for syngas cleaning – part of this focused on an optimised 50 MWth plant design. The carbonate scrubbing process was found to provide a number of advantages over alternative clean-up systems (for example, inexpensive solvent and low thermal requirement) (Koytsoumpa and others, 2015).

Other studies have compared the effectiveness of different gasification processes for producing SNG from lignite. As part of these, NTUA's Laboratory of Steam Boilers and Thermal Plants, and CERTH modelled (using *IPSEpro*) a number of technologies with the potential for producing SNG for a range of applications. Analysis focused on the use of allothermal steam gasification and autothermal oxygen gasification-based processes. SNG produced would be cooled, cleaned, methanated, and conditioned prior to use. Heat recovered from the overall process would be utilised in a power plant's steam cycle (Karellas and others, 2012b).

Earlier work involving CERTH, NTUA and PPC was carried out between 2003 and 2007 (*Upgrading of high moisture, low rank coals to hydrogen and methane* – C2H UPGRADE). The project developed a novel process that yielded a hydrogen-rich fuel gas suitable as a natural gas substitute, plus a pre-calcined feed (comprising CaO, $CaSO_4$ and coal ash) suitable as cement clinker. The process comprised a steam gasifer with *in situ* CO_2 capture using CaO, and a sorbent regenerator capable of producing a separate CO_2 stream. Pilot scale gasification testing was carried out using three different reactor types (ABFB, PBFB, and rotary kiln). A hydrogen-rich (>85 vol%) and CO_2-lean gas with low tar content (<2 g/m^3) was produced. Two pilot plants of different capacity were designed. Simulations suggested that a C2H-based IGCC plant would have an efficiency of 45% (Hawthorne and others, 2008) although with CO_2 capture, this fell to 37.5%. Utilisation of the pre-calcined feed in cement manufacture would effectively reduce fuel use and CO_2 emissions. Life-cycle analysis indicated that a C2H-based IGCC process would be economically competitive with existing IGCC systems.

The ISCC project (*Innovative in Situ CO_2 Capture Technology for Solid Fuel Gasification*) ran between 2004 and 2007 and examined the production of hydrogen from coal for electricity generation. Greek partners comprised NTUA and PPC. The project focused on the gasification of low-grade lignite for the simultaneous production of hydrogen-rich gas, coupled with carbon capture and storage. Work concentrated on the lime-enhanced gasification (LEGS) process. This used a gasifier to produce a hydrogen-rich gas via high-temperature CO_2 absorption using lime (CaO) as the sorbent material. The CO_2-laden sorbent was regenerated by passing it through a second reactor that reactivated the lime and produced a concentrated high-purity CO_2 stream suitable for storage. The advantage of LEGS was deemed to be the ability of direct coal/lignite conversion to a single product (hydrogen), with a separate concentrated CO_2 stream. It was considered that coals/lignites with high sulphur content and of low quality (even waste coal) could be gasified successfully using the process. Unlike classic IGCC techniques, such low quality fuels with high sulphur content could be processed.

It has been well established (particularly for lower rank coals) that inorganic minerals in coal ash can affect reactivity by catalysing gasification reactions. This catalytic activity depends on their concentration, dispersion and chemical form in the coal matrix. Knowledge of lignite reactivity is important for understanding reaction mechanisms and kinetics, as well as for sizing gasifiers. Studies (for instance, Skodras and Sakellaropoulos, 2002) confirmed that inorganic constituents present in Greek lignites can affect gasification reactivity. A reasonably good correlation was found between the alkali index and gasification rate.

Investigations of the effect of mineral matter on lignite gasification behaviour have been continued by other researchers. For example, the Aristotle University of Thessaloniki (2012) studied various factors that affected the reactivity of Greek lignites. As part of this, the catalytic activity of mineral matter content was addressed. Various lignites with different mineral contents were gasified in a fixed-bed reactor. It was determined that inorganic constituents played a controlling role in determining gasification reactivity. As in previous studies, a reasonably good correlation was found to exist between the alkali index and the gasification rate – this varied almost linearly with the alkali index (Aristotle University of Thessaloniki, 2012).

Between 1985 and 1991, a project examined the operation of a novel system based on an indirectly heated rotary kiln gasifier. The work was funded by PPC and the NATO-SFS Programme. The project progressed via two stages. Stage I involved the development by PPC of a pilot plant (100 kg/h raw lignite) capable of producing a medium heating value gas (12–13 MJ/m^3). Stage II was based on a second smaller pilot plant (10 kg/h raw lignite) installed at the School of Chemical Engineering (at NTUA) (Hatzilyberis and Androutspoulos, 2006). Subsequently, a programme of experimental and theoretical work was carried out with a view to scaling up to commercial-scale operation. This smaller gasification unit was subsequently deployed on several EU projects (for example, C2H Upgrade).

Other studies continued to address the rotary kiln concept at pilot scale using Megalopolis lignite. The idea of using a rotary kiln as part of an IGCC facility was explored. As part of this, extended test runs were carried out at near-atmospheric pressure and 900–950°C. High lignite conversions (90–95%) were achieved, and a medium heating value synthesis gas (11–13 MJ/m^3) generated. The composition of the gas was similar to that produced by some pressurised oxygen-fed gasifiers (such as Lurgi and Winkler) (Androutsopoulos and others, 2010).

The separation of hydrogen and CO_2 from SNG streams has been examined. Thin-film metal membranes were developed to separate hydrogen, along with high-capacity carbon-based adsorbents and polymer gas-liquid contact membranes for the cold removal of CO_2 and other acid gases. This work was carried out as part of the RFCS-funded HYDROSEP project (*Hydrogen Separation in Advanced Gasification Processes*) that ran between 2006 and 2009. Designs for integrating some of these technologies into an existing IGCC plant (at Puertollano, Spain) were developed. Greek organisations involved in the project were CERTH and the Aristotle University of Thessaloniki.

At least one Greek organisation has engaged in international R&D gasification development. Helector S.A, an energy and environmental applications company, has coordinated a multi-partner project aimed at developing a 500 kWe fluidised bed gasifier in Osnabrück, Germany. This had a gasification capacity of 750 kg/h and was fired on RDF. Future work may include the use of biomass. A larger unit (2 MWe) is planned for Imathia in Greece. Funding for the project was provided by the EU 7th Framework Programme.

Commercial gasification plants

Between 1964 and 1997, Nitrogenous Fertilizers Industry S.A (AEVAL) operated a nitrogenous fertiliser complex at Ptolemais. This produced ammonia from the gasification of Ptolemais (xylitic) lignite. The complex was built by a joint venture company comprising Uhde and CASALE. Koppers-Totzek gasification technology was used. As the plant aged, the feasibility of switching to fixed bed gasifiers was proposed. This would have required a beneficiation stage to reduce ash levels in the lignite and minimise variations in properties. However, the Ptolemais plant closed in 1997.

9.3.2 Integrated gasification combined cycles (IGCC)

A number of studies have examined the suitability of Greek lignites for gasification and in IGCC cycles combined with CO_2 capture. These have indicated that pre-drying of some form would be a pre-requisite for their use in such applications – this step would significantly increase overall process efficiency. Potentially, pre-dried lignites would be suitable for gasification using a number of different technologies (such as fluidised bed gasification). However, it is considered that their ash characteristics would make entrained flow gasification difficult (Reinartz, 2006).

There are currently no commercial IGCC facilities operating in Greece.

9.4 Cocombustion

A number of Greek biomass-derived materials have been assessed for possible cocombustion with lignite. Testing has encompassed olive prunings, cotton residue, olive and peach kernels, pine needles, cardoon, and sewage sludge. A number of studies (for example, Vamvuka and Sfakiotakis, 2011) assessed the behaviour and combustion performance of each (blended with lignite) at varying scale. Variables have included oxygen concentration, particle size and moisture content of the different materials. Studies have determined that the combustion process is controlled largely by the emission of volatile matter from the biomass. Combustion characteristics of the blends tend to follow those of parent fuels in both additive and non-additive manners. Thus, lignite combined with cardoon exhibits synergy, whereas lignite and pine needles show additive behaviour. Blending lignite with either fuel has been found to increase its thermochemical reactivity.

In recent years, the potential of biomass-derived materials for cofiring in Greek power plants has been increasingly recognised. Co-utilisation in this manner could provide a number of benefits such as extending the lifetime of lignite reserves, greater use of marginal land, reduced emissions of conventional pollutants, and lower CO_2 levels (Bellona, 2010). In the longer term, biomass cofiring coupled with carbon capture and storage (CCS) could produce negative CO_2 emissions. However, suitable quantities of biomass may not always be available within the locale. Thus, in Western Macedonia, estimates suggest that potentially, a total of ~43 MWe of agricultural residues could be available. But, at the moment, adequate supplies would be difficult to obtain as there is only limited mechanisation, supply chains are lacking, and there is competition from non-energy uses. There is also limited experience of developing such supply systems in Greece (Castillo and Panoutsou, 2011).

During the past decade, several Greek organisations have been involved in biomass cofiring projects. This included the DEBCO project (*Demonstration of Large-scale Biomass Cofiring and Supply Chain Integration*). This was part of the EU 7th Framework Programme and ran between 2008 and 2012 with the aim of developing and demonstrating innovative and advanced technologies for cofiring biomass/lignite for large-scale electricity production and/or cogeneration, at more competitive costs and/or increased energy efficiency. The ultimate aim was to increase current biomass utilisation levels (typically 3–10% for power generation purposes) to 50% or more, in the process, effectively reducing CO_2 emissions. Greek project partners included CERTH/ISFTHA and PPC. Potentially, cofiring lignite with biomass could play a significant strategic role in energy production. Greek cofiring activities have included the following:

Lignite + cardoon

There is interest from parts of the agriculture sector in the growing of energy crops. As the quality of Greek lignite can vary widely, biomass has the potential to act as support fuel when quality is poor or variable. Its addition can help smooth out some of the fluctuations. Such was the case at PPC's Kardia power plant which frequently utilises lignite from a number of different sources – as a result, there can be large variations in the properties of the lignite feed. As part of the EU DEBCO project, cocombustion trials using cardoon were undertaken in a (tangentially-fired) unit of the Kardia plant. Its addition to the plant's lignite supply was economically useful as it allowed access to generous feed-in tariffs. There was also some previous experience with cofiring (olive kernel). The lignite supplied to Kardia typically had a CV of 5–5.5 MJ/kg, whereas the cardoon was 14–15 MJ/kg.

As part of the programme at Kardia, pilot scale cofiring was undertaken using locally-grown cardoon. Around 1700 t were used in the trials (up to 10 wt%). An extensive measurement campaign was undertaken; this included fuel and ash sampling, particle sampling from the boiler, the use of fouling/slagging and corrosion probes, and assessment of the impact on gaseous emissions and ESP performance. Despite the high levels of chlorine and alkalis present in the cardoon and its low ash melting temperature, cofiring had no major impact on the operation or environmental performance of the plant. In fact, combustion was enhanced and NOx emissions lower. The high sulphur and calcium content of the lignite appeared to have a positive impact during cofiring due to the sulphation of alkalis and the possible capture of chlorine by lime (Karampinis and others, 2012). Alongside the DEBCO activities undertaken at Kardia, the Prefecture of Kozani initiated a programme for the cultivation of cardoon. Some 60 farmers were involved, cultivating and harvesting 400 ha. Yields usually varied between 10 and >20 t/ha (Karampinis and others, 2011). Cardoon with a particle size of 4–5 cm was delivered to the plant, at a gate price of €51 per tonne. To replace 5% of the lignite feed to the Kardia plant with cardoon would require ~70 kt/y – this would require 3000–3500 ha of land yielding at least 20 t/ha.

Generally positive results were obtained for 10% cardoon thermal share in both modelling and actual combustion tests. Cofiring cardoon helped smooth out fluctuations in fuel properties and reduce overall CO_2 emissions (Karampinis and others, 2011). The variations of lignite quality had a bigger impact on boiler performance and slagging/fouling than the addition of cardoon. It was concluded that cofiring would be a beneficial option for both fuels. Work is continuing via examination of the combustion behaviour of blends containing higher levels of cardoon. Combustion tests are being carried out in a 0.5 MWth pulverised fuel pilot-scale test facility. Deposits have so far been characterised in terms of morphological and ash fusion behaviour, and slagging/fouling tendencies (Fuller and others, 2013).

CERTH/ISFTA undertook CFD simulation and modelling of the process applied at Kardia. The numerical results provided useful data regarding the maximum achievable biomass particle size and substitution ratio for efficient boiler operation. CFD modelling considered two possible options for combining the cardoon (co-milling of pelletised cardoon with lignite, and the milling of balled and/or shredded material in dedicated biomass mills). The non-spherical form of the biomass particles and their effect on the drag coefficient, devolatilisation and combustion rates was taken into account. Results indicated that the partial substitution of lignite with biomass would have minimal impact on power plant operations and had the potential for NOx reduction. However, where biomass particle size was too large, increased levels of unburnt carbon in fly and bottom ash could be possible. It was concluded that the most promising feeding option would be the application of separate biomass milling, followed by its injection via the plant's burners. Economically, dedicated milling was the preferred option, as despite the higher investment cost, the cost of non-pelletised biomass would be lower (Nikolopoulos and others, 2013).

Lignite + wood

Tests with pre-dried Greek lignite and wastewood were carried out in a 1 MWth bubbling FBC unit in Austria – a major aim was to examine ash melting characteristics. The lignites came from Megalopolis and Ptolemais, and biomass comprised wastewood, olive kernel and straw. Testing confirmed that Greek lignites were suitable fuels for FBC applications, both alone or cocombusted with wood and other forms of biomass (Kakaras and others, 2003).

Similar conclusions were reached in other studies that also examined the cocombustion of wastewood with pre-dried lignite from Ptolemais (as part of EU Thermie Action A, Contract SF/0261//97). 'Wastewood' is defined as wooden products that have been used commercially at least once, and remain as waste for disposal or recycling/reuse. Significant quantities are available – in Greece, estimates suggest that more than a million m^3/y of material is available (Skodras and others, 2002). In this study, wastewood comprised blends of natural wood, demolition wood, railroad sleepers, medium-density fibreboard residues, and power poles. Cocombustion testing was carried out in a laboratory-scale FBC of NTUA's Steam Boilers and Thermal Plants Laboratory. The main aim was to examine the impact of differing levels of wood addition on combustion efficiency and the level of pollutants emitted. As the wastewood had a high concentration of combustibles and low ash levels, and consequently higher heating value, its addition to the lignite feed was found to improve combustion efficiency. Furthermore, because of wood's low sulphur and nitrogen contents, overall pollutant emissions were reduced.

Other testing confirmed that wastewood/lignite blends were acceptable as fuel sources. Testing was carried out in a laboratory-scale fluidised bed reactor, a 1 MWth semi-industrial circulating fluidised bed combustor, and an industrial moving stoker boiler (Grammelis and others, 2003). In the FBC tests, cocombustion proceeded smoothly and homogeneous temperature and pressure profiles were obtained. Most problems encountered were practical issues, associated mainly with wastewood preparation and handling.

Lignite + agricultural wastes

Olive and citrus prunings are produced in large quantities in some parts of Greece (such as Crete). Their potential as a source of energy, both alone or cofired with lignite, has been studied. The thermal behaviour of these materials was tested in a laboratory-scale fluidised bed combustion facility. The effect of the inorganic constituents of the fuels on slagging/fouling and agglomeration propensities, as well as emissions generated, was examined. Kinetic models were developed and reaction rates determined (Vamvuka and Bandelis, 2010). It was concluded that such agro residues would make viable energy sources.

The potential for agro-wastes for cofiring in conventional PCC power plants has also been examined. As part of the DEBCO project, milling tests using pelletised maize residues (and wood) were carried out at PPC's Meliti power plant. Up to 10% thermal share was evaluated for cofiring.

Other work examined the use of olive kernel for cofiring with Greek lignite in a 20 kWth Drop Tube pulverised fuel furnace at the University of Stuttgart in Germany. Low rank lignite with high ash and moisture contents (as used in the Megalopolis power plant) was used as the main fuel. The olive kernel was also sourced from Megalopolis. Thermal shares tested were 15% and 30%. Compared to 100% lignite firing, cofiring showed potential for lowering some types of emissions, and of improving combustion conditions in the furnace. Despite the higher alkali and chlorine content of olive kernel, deposits formed during cofiring were removed easily using conventional boiler cleaning equipment (Karampinis and others, 2013).

Lignite + Municipal Solid Waste (MSW) and Refused Derived Fuel (RDF)

As in many developed economies, the amount of MSW generated in Greece continues to rise. For some time, there have been year-on-year increases, even during the ongoing financial crisis. Forecasts suggest that for the foreseeable future, this trend will continue. The regions that produce the greatest volumes of MSW are Attica (39%) and Central Macedonia (16%), where Athens and Thessaloniki are located.

The Greek National Plan for Waste Management (published in June 2015) does not include any reference to cocombustion of RDF in lignite units as a method of waste management. With regards to energy recovery, the plan considers this a 'complementary' waste management method for municipal waste, after all efforts of recycling have been exhausted (reuse, mechanical and biological recycling); it focuses mainly on energy recovery from biogas without further detailing the energy recovery methods.

Historically, several programmes have examined the potential for RDF-type materials to be used as a cofiring feedstock. For example, RDF produced in the Athens Mechanical and Biological Treatment Plant was tested at laboratory-scale (at 15% and 30% thermal share) with Megalopolis lignite. CERTH/CPERI carried out a range of cofiring tests of the blends (in collaboration with the University of Stuttgart). This included measurements of flue gas pollutants, cofiring efficiency under different operating conditions, and ash characterisation. When cofiring, plant emissions were found to be lower than when using 100% lignite. Furthermore, combustion conditions in the furnace were improved and deposits formed were removed easily (Karampinis and others, 2013).

Work undertaken by, for instance, NTUA and ISFTA, and elsewhere in Europe has confirmed that partial replacement of lignite with waste-derived materials can have minimal impact on power plant operations or emission levels. Furthermore, capital investment can be low. NTUA and ISFTA evaluated the concept from a unit performance point of view and determined that such materials have the potential to be used in the Kardia power plant (2–3% addition), and probably also in the Megalopolis III plant. However, depending on the makeup and quantity used, cocombusting RDF or SRF (Solid Recovered Fuel) could increase the possibility of plant corrosion. The quality of the RDF/SDF can vary – where of low quality/high chlorine content, the recommended substitution should not exceed 10%; where of better quality, up to 15–20% could be achievable. Relatively small additions (2–3%, as in the case of Kardia) appear unlikely to create corrosion issues (Psomopoulos, 2014).

Where very large amounts of MSW are created (as in the areas around Athens and Thessaloniki) dedicated mass-burn facilities may present a better option. However, where viable, cocombustion in lignite-fired power plants has the potential to reduce lignite use and landfill volumes, as well as minimise plant CO_2 emissions (per unit of electricity).

Lignite + glycerol

Potentially, existing lignite-fired power plants could be adapted to cofire crude glycerol. This is available as a by-product of biodiesel production. However, the presence of various impurities precludes its use for pharmaceutical and cosmetic chemical applications; thus, it is considered a low value material. By cofiring, it would be possible to take advantage of the power plant's existing services and facilities, thus improving process economics. Furthermore, existing plants (such as Ptolemais) would only need minimal changes. The costs involved would be limited largely to the transport and storage of the glycerol. Cofiring glycerol would incorporate a green fuel source, reducing lignite consumption and lowering plant emissions of SO_2 and NOx; glycerol has low levels of nitrogen-, sulphur- and chlorine-containing compounds (Manara and Zabaniotou, 2014). In other work, the co-pyrolysis of lignite with crude glycerol (15 and 20 wt%) resulted in high hydrogen yield (>65 vol%). Potentially, this could form a useful means of hydrogen production (Manara and Zabaniotou, 2013).

9.5 Cogasification

The possibility of cogasifying Greek lignite with other solid materials such as RDF or MSW has been investigated. This included a feasibility study for a lignite/RDF co-fuelled IGCC plant to be located near Kozani in Western Macedonia. IGCC was considered to offer benefits that included flexibility of fuel supply, clean operation, and commercial application for by-products such as gasification slag and sulphur from the desulphurisation unit. The location was proposed on the basis that lignite was easily available and an integrated MSW treatment system already existed. The gasifier selected was a steam/oxygen-blown British Gas Lurgi (BGL) unit. This generates a syngas rich in CO, H_2 and CH_4. Syngas produced would be fed to an existing power plant. However, constraints on MSW supply limited the unit's capacity to ~30 MWe and at this scale of operation the process was deemed to be uneconomic (Karakas and others, 2005; Koukouzas and others, 2008).

Recent experimental work has included studies carried out by CERTH/ISFTA on the fixed bed cogasification of blends of lignite and biomass. These were evaluated in a 100 kWth air-blown, updraught fixed bed gasifier producing 75 m^3/h of fuel gas. Parameters measured included fuel gas flow and composition, calorific values, and exit gas temperature. The influence of the level of biomass on fuel gas quality was also examined.

9.6 Underground coal gasification (UCG) activities

CERTH/CPERI was a member of a RFCS-funded multi-partner project that ran between 2010 and 2012 (30 months duration). The project was coordinated by the Bulgarian company Overgas Inc. in collaboration with nine European partners. It comprised a study of deep underground coal gasification coupled with the permanent storage of CO_2. The main objective was to evaluate the potential of deep coal/lignite seams (depth >1200 m) for the development of UCG, and to confirm that the UCG boreholes could, with technical modifications, be used for the injection and permanent storage of CO_2. It was estimated that at 1600 metres depth, all CO_2 generated during gasification could be reinjected and stored in liquid form. Work was undertaken via eight work packages. The main goals included:

- evaluation of the potential of deeply lying coal seams for UCG + CO_2 storage through investigation of factors that impacted on technical and economic viability;
- use of computer modelling (geological, geo-mechanical, hydrogeological and UCG cavity growth) for evaluating deep coal/lignite formation as potential sites; and
- assessment of environmental benefits of UCG + CO_2 storage as a means of achieving near-zero CO_2 emissions.

A main focus of the project was on coal deposits in the Bulgarian Dobrudza coal field. However, it was assumed that the data obtained would also be applicable to, for example, appropriate lignite reserves in Greece. The Environmental Sustainability Index (ESI) methodology was applied to Bulgarian coal deposits and the Florina lignite deposit (Hristov and others, 2014). It was confirmed that the ESI concept was a practical option for application to such deposits, and could be used to assess the environmental feasibility of UCG + CO_2 storage. Other studies have examined the possibilities for UCG in the Kozani lignite deposits (Koukouzas and Katsimpardi, 2013).

Interest in UCG is continuing via a project entitled *Enhanced Coal Exploitation through Underground Coal Gasification in European Lignite Mines* (COAL2GAS). This is being co-financed by the RFCS. The EU is providing €1.32 million of the project's total budget of €2.21 million. The project began in July 2014 and will be completed by June 2017. The consortium is made up of members from Romania, Poland, Germany, Belgium, The Netherlands, Slovenia, and Greece. CERTH is representing Greece. The overall objective is to evaluate the feasibility of UCG in shallow lignite seams (in terms of geology, technology and environmental impact) and to illustrate this for a selected mining site in Romania. Although the general feasibility of gasifying such resources has been proven, it has yet to be confirmed whether the technology could be implemented under EU standards (COAL2GAS, 2014). A positive outcome could be of considerable interest for possible application to Greek lignite deposits.

10 CCS activities

In 2002, Greece ratified the Kyoto Protocol. The country is an Annex I party to the UN Framework on Climate Change. The Greek Ministry of Environment and Energy (MEE) is responsible for the coordination of all ministries involved, as well as relevant public and private organisations.

Greece does not stand out in the EU as regards the energy and carbon intensity of its economy. However, the carbon intensity of energy production is one of the highest, due mainly to its heavy dependence on lignite. Although the country has met its Kyoto targets (partly as a result of its recession and economic problems), some projections have suggested that there could be a shortfall in the 2020 target for the non-ETS sector (Europa, 2013). However, as with other aspects of the Greek energy sector, this may be influenced by the country's current and future economic condition.

Although Greece has continued its efforts to address climate change, the economic crisis has pushed the issue down the political agenda. A major concern is the continued affordability of the country's climate policies. Partly as a consequence of the economic problems, both ongoing and future programmes or initiatives will need to be extremely cost-efficient, and ensure that associated costs are not passed on to the end-user (Maroulis, 2012). The main climate policy instruments currently in place are focused particularly on improving energy efficiency, encouraging the greater use of renewables, and expanding grid connections to the currently isolated islands and neighbouring states. As part of this, a process of creating sustainable financing structures for renewable energy development is also underway.

To date, Greek CCS-related activities have been limited largely to desk studies and small-scale research and development, although useful work has been undertaken both via national research projects and through the participation of Greek organisations in various EU Framework programmes. Greek technology providers, private energy companies and other industrial players have at times expressed an interest in CCS, but this has not yet culminated in a major project. PPC operates most of the country's main power plants and as such, some of the biggest CO_2 emitters. The company continues to follow all related technological developments, although no concrete plans have yet been proposed for the demonstration or application of CCS to any of its thermal units. Given the difficult trading conditions that PPC is currently operating under, there seems little chance of a major project being developed in the immediate future. Previous governments saw a strong need to further support energy and CCS-related R&D in order to address issues associated with Kyoto commitments and domestic energy legislation (Ioakimidis and others, 2011). However, given the changes in the government's makeup and direction, coupled with the pressing need to resolve the country's economic woes, it may be some considerable time before this translates into firm project proposals.

Irrespective of future political changes that may occur in Greece, it seems likely that, for many years, fossil fuels will continue to play a significant role in the country's energy supply. Forecasts from MEE suggest that lignite, gas, and oil will continue to provide a major part of the country's energy, particularly for electricity generation, at least up to 2030. In the coming years, some older lignite-fired generating capacity is set for retirement – forecasts suggest that capacity could fall from 4.8 GW to ~2.3 GW by 2030 (Bellona, 2010). If this happens, it will help reduce national CO_2 emissions. However, for obvious reasons, recent events suggest that Greek climate policies in general may have slipped down the agenda (Burck and others, 2014).

Since the onset of the country's financial crisis and the subsequent economic collapse, Greek greenhouse gas emissions have fallen (Figure 16) (UNFCCC, 2014). This has resulted largely from decreases (triggered by the economic crisis) in emissions from public electricity and heat production, road transport, manufacturing industries, industrial processes (such as cement manufacture), and households.

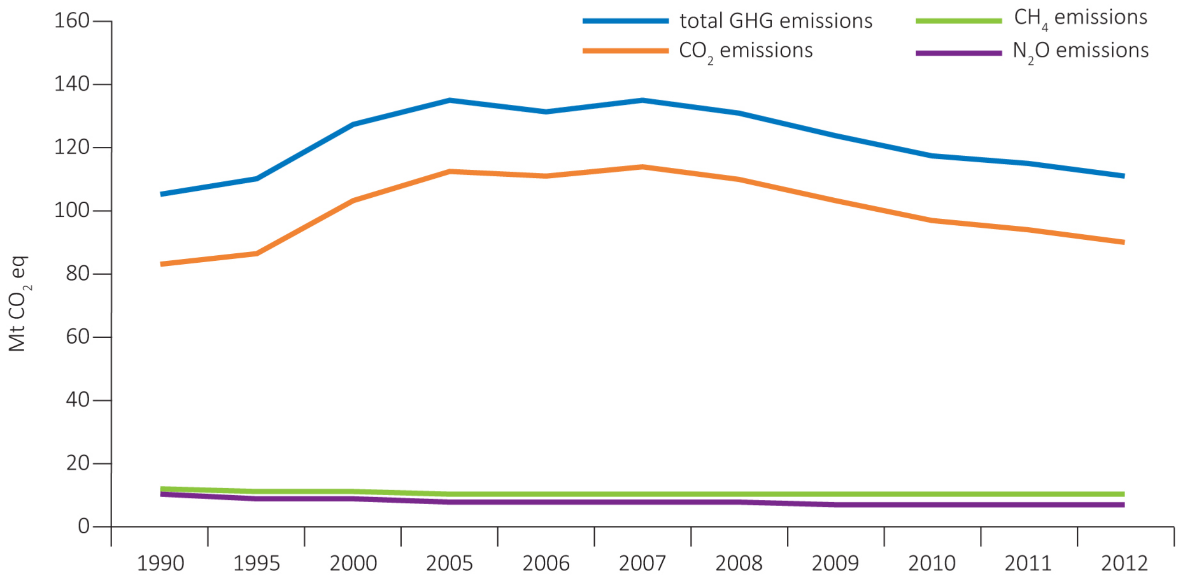

Figure 16 Greek greenhouse gas emissions (Mt CO_2eq) (UNFCCC, 2014) (excluding LULUCF)

Emissions emanating from the energy sector make up a significant proportion of the country's greenhouse gas (GHG) total. In 2012, this amounted to 54.7 Mt CO_{2eq} – CO_2 made up the bulk of this. In that year, the energy sector was responsible for nearly 50% of the country's GHG emissions. Of this total, ~46% was generated by public power and heat plants (UNFCCC, 2014). Between 1990 and 2010, GHG emissions from the electricity sector increased by 20%, reflecting the high share of oil and coal in the energy supply mix (Maroulis, 2012), although in the past few years, these have fallen.

Since the recent changes in the Greek government, it has become more difficult to predict future GHG emission trends. There are a range of factors that could influence this – the precise nature and scale of these will be influenced directly by the speed of the country's economic recovery, energy policies adopted, and decisions made by the government. Several earlier government reports suggested that in the foreseeable future, 'mild' reductions in GHG emissions would be achieved. The largest cuts would come from changes within the electricity sector – for example, increased reliance on renewables and an incremental move away from lignite to natural gas. A major tool in reducing Greek GHG emissions was (in the period up to 2020) to replace some lignite-fired generating capacity with more gas and renewables. However, as noted, for some time, lignite will maintain an important role in power generation.

Furthermore, recently, hours of operation of some gas-fired plants have fallen, and some incentives for renewables have been cut – this may impact on the economic viability of some proposed projects.

10.1 CO_2 reduction in the power sector

As a major contributor to national GHG emissions, the power generation sector (primarily PPC) has instigated a number of measures aimed at their reduction. This includes the adoption of a comprehensive energy strategy aimed at helping achieve EU energy policy objectives for 2020, as well as those of MEE.

To achieve its objective of reducing GHG emissions, the EU revised its Emission Trading Scheme (EU ETS) for electricity production companies. From 2013, power generators have been obliged to purchase all emissions through tenders conducted by the Member States. All PPC's thermal power plants with a thermal output of >20 MW are included in the scheme. Each is obliged to limit annual CO_2 emissions to the levels set in the *National Allocation Plan for Emission Allowances*. If that figure is exceeded, flexible mechanisms can be used to cover the shortfall by purchasing allowances. Thus, under the plan, existing PPC facilities covered by the scheme are granted appropriate allowances. For 2011 it was 44.8 Mt CO_2. For the period 2008-12, the total allowance was 219.3 Mt.

For some years, CO_2 emissions from the PPC generating fleet have declined. The Generation Division has had an investment programme in place, focused on reducing GHG emissions. This has been achieved mainly through improvements to existing lignite-fired units (sometimes coupled with restricted hours of operation) and the greater use of natural gas and renewables in the generation mix. With regard to lignite-fired operations, between 1990 and 2011, the programme contributed towards reducing PPC's CO_2 emissions (per unit of electricity generated) by nearly 30%. Measures adopted included:

- minimising the operation of several units at the Aliveri power plant, and replacing two oil-fired units at the Lavrio station with gas-fired units;
- limiting the operating hours of two lignite-fired units at the Megalopolis plant, and the LIPTOL plant;
- installing a lignite quality analysis system at the Amynteon power plant;
- improving the efficiency of the Ptolemais power plant;
- planting trees on abandoned lignite mines; and
- reducing energy requirements at lignite mines.

The thermal plants that are the largest individual CO_2 emitters are shown in Table 18.

Table 18 The largest individual CO_2 emitters in the Greek power sector (Bellona, 2010; updated with data provided by PPC, October 2015)		
	Fuel	**CO_2 emissions (Mt/y)**
Agios Dimitrios	Lignite	12.95
Agiou Georgiou	Natural gas	1.02
Aliveri	Natural gas	0.58
Aliveriou	Fuel oil	1.04
Amynteon	Lignite	3.93
Atherinolakkos	Lignite	0.39
Chanion	Diesel	0.80
Chiou	Fuel oil	0.13
Elpedison – Thisvi	Natural gas	0.78
Elpedison – Thessaloniki	Natural gas	0.70
Heron – Thiva	Natural gas	0.11
Kardia	Lignite	9.51
Keratias – Lavriou	Natural gas	4.19
Komotinis	Nat gas	1.13
Lasvou	Fuel oil	0.17
Linoperamaton	Fuel oil	0.82
Megalopolis 1, 2, 3*	Lignite	5.67
Megalopolis 4	Lignite	3.33
Megalopolis 6	Natural gas	na
Meliti	Lignite	2.03
Mytilieos – Agios Nikolaos	Natural gas	na
Parou	Fuel oil	0.12
Ptolemais	Lignite	4.33
Rodou	Fuel oil	0.55
* Units 1 and 2 decommissioned in 2011		

PPC maintains an interest in CCS technology and its potential to reduce CO_2 emissions. With this in mind, any new lignite-fired units, such as the 660 MW Ptolemaida V, will be built CCS-ready (PPC Sustainability Report, 2014).

Potentially, CO_2 reduction could be achieved at some existing power plants through improvements in the lignite feed. As noted earlier, the properties of Greek lignites can vary widely and despite efforts to homogenise these via selective mining and blending, can cause operational problems and reduce plant efficiency – this effectively increases the amount of CO_2 emitted per unit of electricity. There are a number of points in the lignite supply chain that have the potential to improve plant efficiency, hence help minimise CO_2 emissions. For example, studies undertaken by the University of Crete and PPC examined CO_2 reduction by the selective size reduction (SSR) and homogenisation/blending of lignite. It was determined that the use of effective homogenisation to control short and long-term variations in quality could reduce plant CO_2 emissions by 2–5%. Furthermore, the use of SSR for upgrading lignite is a simple method requiring no chemical additives. Upgraded lignite samples produced lower CO_2 emissions (of between 11% and 28%); this resulted from the reduction in carbonate minerals present, as well as lower ash content (Vamvuka and others, 2013).

10.2 Other major CO_2 point sources

The energy sector is the largest contributor to Greece's overall GHG emissions. The other main sources comprise transport, industrial processes, agriculture, and wastes (Vamvuka and others, 2013). The country lacks a large heavy industry sector. Hence, CO2 emissions from non-energy production undertakings remain comparatively low. Between 1990 and 2012, GHG emissions from the manufacturing sector fell by 40% (UNFCCC, 2014) – the financial crisis and the associated downturn in manufacturing and other industrial activities played a major part in this. Major individual heavy industry point sources are shown in Table 19. The biggest comprise cement production, oil refining, and aluminium and ferronickel production. Much of the country's industrial infrastructure is located in the regions around Athens and Thessaloniki.

Table 19 Major (non-power) Greek CO_2 point sources (Bellona, 2010)

Emission point source	Sector	CO_2 emissions (Mt/y)
Aluminium of Greece	Metals	0.52
ELPE Aspropyrgos	Refined petroleum	1.63
ELPE Elfesis	Refined petroleum	0.25
ELPE Thessaloniki	Refined petroleum	0.42
Halyps Aspropyrgos	Cement manufacture	0.54
Heracles Holkis	Cement manufacture	1.43
Heracles Milaki	Cement manufacture	1.25
Heracles Volos	Cement manufacture	2.85
LARCO S.A.	Ferronickel production	0.89
PFI-N, Karvali	Fertilisers	0.30
TITAN Elfesis	Cement manufacture	1.56
TITAN Kamari	Cement manufacture	1.96
TITAN Patra	Cement manufacture	1.10
TITAN Thessaloniki	Cement manufacture	1.14

10.3 CCS-related RD&D activities

The Greek Energy R&D Administration is managed centrally by the General Secretariat for Research and Technology (GSRT). This is the main authority responsible for the development and implementation of the overall framework for Greek R&D policy. Research for high-priority fields (such as energy) is conducted through different R&D consortia – this helps promote cooperation between partners and others.

For some time, Greek organisations have been engaged in various R&D projects focused on the development and application of CCS. CCS-related R&D activities were included as a high priority research topic in the *Greek National Energy Programme 2007-2013* (CSLF, 2013). MEE, as the main authority responsible for coordinating the transposition of the EU CCS Directive, established a Working Group that includes representatives of research organisations, universities and others. The major national programme supporting CCS-related work is the Operational Programme *Competitiveness*, coordinated by GSRT.

The national agency responsible for managing CO_2-related programmes is CERTH/CPERI. The institute has participated in a number of related EU Framework projects (such as ENCAP) as well as national CCS R&D projects funded by the Greek Competitiveness programme. In recent years, CERTH and other Greek organisations have continued to be involved in various international projects. Examples are shown in Table 20. CERTH also represents the Greek government in international organisations and European forums that include the United Nations, the International Energy Agency, CSLF, and the European Technology Platform for Zero Emissions Power Plants (ZEP).

Table 20 Greek involvement in major EU CCS-related projects (IEA GHG, 2015; Kakaras and Koukouzas, 2009; CSLF, 2013)

Project	Topic	Greek partner(s)	Duration	Comments
CASTOR	Post-combustion CO_2 capture, transport and storage	PPC, NTUA	2004-08	EU 7th FW Programme
ENCAP	Pre-combustion CO_2 capture	PPC	2011-16	EU 6th FW Programme
IOLICAP	Post-combustion solvent-based capture processes - novel ionic liquid and supported ionic liquid solvents for reversible capture of CO_2	PPC, Hellas National Center for Scientific Research 'Demokritos', N & K Konstantinos Goliopoulos ATE, Enditech Anonymos Eteria Meletes ke Efarmoges	2011-14	EU 7th FW Programme
CAPSOL	Design technologies for multi-scale innovation and integration in post-combustion CO_2 capture: from molecules to unit operations and integrated plants	PPC, CERTH, NTUA, Cao Hellas Makedoniki Asvestopoiia, Anonimi Etairia Paragogis Kai, EmporiasAsvestoy Kai Loipon, Domikoichimikon Ilon	2011-14	EU 7th FW Programme
CESAR	CO_2 enhanced separation and recovery	PPC	2008-11	EU 7th FW Programme
RISCS	Impacts and safety in CO_2 storage	PPC, CERTH	2010-14	EU 7th FW Programme
SARCO2	Requirements for safe and reliable CO_2 transportation pipeline	Corinth Pipeworks	2011-14	
ECO-Scrub	Enhanced capture with oxygen for scrubbing of CO_2 – oxygen enrichment, post-combustion solvent scrubbing, increased cycle efficiency	Aristotle University of Thessaloniki, CERTH, PPC	2007-10	RFCS-funded
CAL-MOD	Modelling and experimental validation of calcium looping CO_2-capture process for near-zero CO_2 emission power plants. Calcium looping post-combustion CO_2 capture	CERTH, Titan Cement Company	2010-13	RFCS-funded
EU GeoCapacity	Assessment of the European capacity for geological storage of CO_2	Institute for Geology and Mineral Exploitation (IGME)	2002-06	EU 6th FW Programme
NASCENT	Natural analogues for CO_2 storage in Europe	Institute for Geology and Mineral Exploitation (IGME)	2001-04	EU 5th FW Programme

Table 20 continued				
GESTCO	Assessing European potential for geological storage of $CO_2$from fossil fuel combustion	Institute for Geology and Mineral Exploitation (IGME	2000-03	EU 5th FW Programme
CACHET	CO_2 capture and hydrogen production from gaseous fuels	CERTH, NTUA	2006-09	
ISSC	Innovative in situ CO_2 capture technology for solid fuel gasification	CERTH, NTUA, PPC	2004-06	EU 6th FW Programme
GEOMECS	Investigation of long-term fate of stored CO_2 and the mechanisms of leakage through the cap rock and well	CERTH, Aristotle University of Thessaloniki, University of Patras, Technical University of Crete		43 months duration
UCG&CO2 Storage	Study of deep underground coal gasification and the permanent storage of CO_2 in the affected areas	CERTH	2010-13	RFCS-funded
ECCSEL	European Carbon Dioxide Capture and Storage - Laboratory Infrastructure Preparatory Phase Project	CERTH	2011-12	EU 7th FW Programme.
CO_2 sorbents when firing lignite in an FBC	Investigation of the mechanical and chemical stability of CO_2 absorbents during the thermal conversion of lignite	CERTH/ISFTA, PPC		Simultaneous carbonation and sulphation process. Effects on sorbent performance of FB operating conditions

Different capture systems and their potential for application within a Greek context have been examined. Most studies have focused on post-combustion capture using amines, or oxyfuel technology. Both greenfield and retrofit situations have been considered. For example, NTUA examined and modelled the possible retrofit of a Greek lignite-fired power plant. This encompassed thermodynamic cycle calculations, heat and mass balances, plus efficiency and exergetic and exergo-economic analyses. A 330 MW unit using supercritical steam conditions, with an ESP and FGD was adopted for the study. Post-combustion CO_2 capture using MEA was selected. As confirmed by many other studies, the deployment of capture technology would impose a significant energy penalty on the plant. In this particular case, the application of amine scrubbing technology decreased plant efficiency by 11.5% points (Doukelis and others, 2009). It was considered that under some conditions, lignite-fired systems equipped with CCS could still be competitive with gas-fired generation. However, this would be dependent on considerations such as the evolution of future gas and CO_2 prices.

Later studies also investigated the application of post-combustion capture using 30% MEA scrubbing on a 300–400 MW steam power plant fired with low quality Greek lignite (Kakaras and others, 2013). The reference power plant design represented a supercritical PCC unit (28 MPa/600°C/622°C) fired on pre-dried lignite (12% moisture content). Care was taken to optimise plant performance so as to minimise energy losses resulting from the capture process. As confirmed by other studies, plant performance was significantly reduced by the application of the scrubbing process. Gross power output for the non-optimised plant fell from 375 MW to 313 MW – this resulted from the LP steam extraction for amine regeneration. At 318 MW, the fall for the optimised power plant was not so pronounced. Net power output was 230 and 235 MW, for the non-optimised and optimised cases, respectively. Net efficiency of the non-optimised unit with CO_2 capture was 12.5% points lower than the reference power plant. With the integration of low-grade waste heat, the net efficiency of the optimised power plant was increased slightly to 30.4%, 11.8% points lower (Kakaras and others, 2013). The fluidised bed dryer used to reduce the moisture content of the raw lignite consumed 13.1 MW. However, drying had a positive impact on power plant efficiency as a considerable increase in the CV of the lignite was achieved at the expense of low-grade heat. In addition, as a result of the reduction in moisture, boiler flue gas heat losses were reduced, as well as the power consumption of the flue gas ID fan.

Several recent projects have focused on ways to reduce the energy penalty and operational losses associated with solvent-based post-combustion capture. For example, the EU 7th Framework Programme CAPSOL project (2011-14) examined, via a number of work packages, innovative ways for enhancing process efficiency and increasing sustainability, and reducing the cost of solvent-based post-combustion capture. The project was a continuation of the earlier CASTOR, CESAR and iCap projects and focused on optimising the performance of fossil-fired plants equipped with post-combustion capture systems though an examination of possible options for heat/process integration, cooling, and the utilisation of low-grade waste heat. As part of this, novel solvents and blends, plus innovative separation equipment were developed, aimed at reducing associated process costs. Furthermore, optimised process configurations were developed such that energy efficiency of the capture process was increased by means of careful heat integration with the power plant. A major achievement was the identification of integration options capable of overcoming the utility cost penalty. Thus, integrated plants could be more cost efficient than the initial benchmarks in terms of running cost. About a third of the power penalty introduced by the capture unit could be eliminated (Liew and others, 2014). Greek participants in the project were NTUA, CERTH, PPC, and CaO Hellas Macedonian Lime S. A.

Also funded under the EU 7th Framework Programme was the multi-partner *CESAR* project (*CO_2 Enhanced Separation and Recovery* – 2008-11). The Greek participant was PPC. Again, there was a strong focus on reducing the cost and energy penalty associated with CCS systems. The project aimed for a breakthrough in the development of low-cost post-combustion CO_2 capture technology suitable for both new build and retrofit applications. This goal was pursued through a combination of fundamental research on advanced separation processes, capture process modelling and integration, solvent process validation studies, and pilot scale testing. Part of the project modelled the integration of all elements of a power plant equipped with CO_2 capture. Several baseline cases were examined including lignite-fired 380 MW and 1000 MW PCC plant configurations. The project's achievements included the selection and pilot scale testing of the best available amine/amino-acid-based solvents.

As well as amine-based capture, other means for CO_2 reduction have also been considered. For example, Vorrias and others (2013) examined the use of calcium looping (CaL) for CO_2 capture from a lignite-fired power plant. In the process, two fluidised bed reactors are coupled. In the first reactor (the carbonator) CO_2 is absorbed by CaO, producing $CaCO_3$. In the second (the calciner), fuel is oxyfired, such that calcium particles, already having absorbed CO_2 in the carbonator in order to produce CO_2-rich flue gases, are regenerated. A number of studies have examined the process with respect to hard coal-fired power plants. However, limited attention has been paid to those fired on lignite. This particular study examined its potential for application on a 300 MW unit of the Meliti power plant. It was determined that the energy penalty for sorbent regeneration when the system was applied to a lignite-fired plant would be higher than in the hard coal-fired case. This results from lignite's higher moisture content and lower CV. The optimum configuration necessary to achieve the lowest energy penalty was the use of pre-dried lignite, the application of a solid heat exchanger, and the use of fresh limestone in the calciner instead of the carbonator.

10.4 Oxyfuel combustion activities

To date, only limited practical work has been carried out in Greece. However, a number of studies into the possibilities of applying oxyfuel technology to Greek power plants have been undertaken. Historically, some areas were addressed as part of the EU *ENCAP* project (2003-07); this included an examination of the concept for a 380 MW Greek PCC lignite-fired oxyfuel power plant using advanced supercritical steam conditions. Other studies considered CO_2 control on a 330 MW lignite-fired unit via the combination of partial oxyfuel firing coupled with post-combustion solvent scrubbing.

To demonstrate the potential for emissions reduction and evaluate the associated power output and efficiency penalties of various CO_2 mitigation strategies, NTUA and CERTH modelled a number of plant configurations – one was a Greek greenfield plant based on oxyfuel technology. The reference base case plant was a 360 MW (gross) output unit with reheat and water preheaters, using steam extraction from the steam turbine. As the raw lignite had high moisture content, a (WTA) fuel pre-drying system was integrated in both the reference power plant and the oxyfuel plant. Several process integration options were identified for the latter power plant, and an integrated configuration produced. It was determined that the application of oxyfuel technology reduced plant efficiency by 10.3% points. However, there was the potential for further process optimisation. As a result of the cost and complexity of the technology for retrofit applications, it was considered that under these particular conditions, oxyfuel technology would be more applicable to new power plants (rather than retrofitting to existing units) (Doukelis and others, 2009).

Later studies also examined the potential and performance of a small scale (demo) oxyfuel Greek power plant equipped with carbon capture. It was determined that even though an optimised oxyfuel plant would have a higher gross power output and efficiency, net power output and efficiency would be reduced significantly as a consequence of the increased auxiliary consumption. Thus, output from the reference plant was 326.7 MW, and that of an optimised oxyfuel variant, 269.7 MW. At 248.7 MW, the non-optimised plant was lower. The net efficiency of the optimised plant was 7.4% points lower than the reference plant, with the non-optimised plant at 10.1% points. The optimised plant had an efficiency of 34.8% compared to 42.2% for the reference case (Kakaras and others, 2013). It was estimated that the cost of electricity generated would be increased by between 60 and 80% as a result of the energy penalty combined with the associated increased capital and O&M costs.

The possibility of replacing part of the combustion air in PCC boilers with oxygen was also investigated as part of the multi-partner EU project *ECO-Scrub* (2007-10). Three Greek organisations were involved: the Aristotle University of Thessaloniki, CERTH/ISFTA, and PPC. The project concentrated on the retrofitting of carbon capture technology to existing boilers. The main focus was on the use of a novel combination of techniques that included oxygen enrichment and post-combustion solvent scrubbing, together with measures to increase efficiency, reduce steam consumption, and generate power without significantly reducing net plant capacity. The project encompassed process development, module integration, and optimisation for a range of plant types and fuels. As part of this, CERTH/ISFTA simulated the 330 MW PCC boiler of the Meliti power plant. Three operating principles were investigated and simulated, namely the existing (reference) case, partial oxyfuel, and full oxyfuel combustion modes. A pilot-scale combustion test facility with oxyfuel capability, simulated flue gas recycling and equipped with an amine solvent scrubber was used to evaluate solvent performance and the flexibility of the ECO-Scrub process. In addition, membrane separation systems were considered to be promising alternatives to conventional CO_2 capture methods for enriched CO_2 flue gas.

The project concluded that the ECO-Scrub system was technically and economically feasible for retrofitting to existing power plants for CCS. By optimising oxygen enrichment levels and flue gas recycle rate, it was possible to achieve satisfactory combustion, low NOx emissions, improved heat transfer characteristics, and to avoid issues of ash deposition. The cost and efficiency penalties for the process were comparable to those for post-combustion capture and oxyfuel combustion. However, ECO-Scrub was considered to be a more attractive for retrofit applications.

10.5 CO_2 storage

Greek organisations have been involved in several major projects that assessed the potential for underground CO_2 storage within the country. Several possible options were assessed as part of the EU multi-partner *GESTCO* project (2000-03). This had the main objective of determining whether geological storage of CO_2 could provide a viable method for wide scale application. It focused specifically on storage in saline aquifers and depleted hydrocarbon reservoirs, and via storage combined with ECBM production. Greece was represented by the Institute of Geology and Mineral Exploitation (IGME) and PPC.

As part of the project, an inventory of major Greek CO_2 emitters was compiled, along with geological structures potentially capable of storing large amounts of CO_2. Areas specifically addressed comprised the Mesohellenic Trough and the Thessaloniki Basin. The Messohellenic Trough is 40 km wide and 300 km long, and extends from Albania to Thessalia. This tertiary basin hosts thick sequences of conglomerates and sandstones that appear capable of providing suitable conditions for storing significant quantities of CO_2. The Thessaloniki Basin is located to the west of the city of Thessaloniki and covers an area of 4200 km^2 onshore and 4000 km^2 offshore (Koukouzasa, 2010). The potential storage sites in these two regions are in favourable locations, as distances to large point sources of CO_2 are not excessive. The sources considered included the Kozani–Ptolemais lignite-fired power stations, plus oil refineries, fertiliser and cement production plants near Thessaloniki. These were the largest individual emitters.

Potential storage capacity in Greece comprises mainly saline aquifers and hydrocarbon fields. An important example of the latter is the depleting offshore Prinos oil field in the North Aegean Sea. Estimates suggest that this could hold ~17 Mt of CO_2. Energean Oil/BP, the current operator of Prinos, has indicated that this reservoir has all necessary characteristics to accommodate the injection of CO_2 under a

CCS project (CSLF, 2013). The Prinos Miocene sedimentary basin covers an area of 800 km^2. The thickness of sediments within it exceeds 6 km. In addition, the offshore oil field in the Katakolon area and the onshore gas field in Epanomi area are proven deposits that have yet to be exploited. Thus, these fields could also be considered as prospective areas for storage in the long term.

It was calculated that the potential storage capacity in deep saline aquifers was ~2.3 Gt (ZEP, 2007), comprising one offshore and four onshore sites. The largest individual onshore sites were West Thessaloniki and in the Mesohellenic Basin (Kakaras and Koukouzas, 2009) (Table 21). However, Greece remains one of the most unexplored countries of the Mediterranean region. To date, exploration activities have been confined to relatively shallow depths (~2500–3000 m). There is little geological data available to allow a preliminary assessment of CO_2 storage at greater depths.

Table 21 CO_2 storage capacity of saline aquifers in Greece

Aquifer	Location	Storage capacity ($MtCO_2$)
Prinos	Offshore	1343
W Thessaloniki	Onshore	459
W Thessaloniki (sandstones)	Onshore	145
Alexandreia	Onshore	34
Mesohellenic basin	Onshore	360
Total		2345

CO_2 storage-related work was undertaken during the course of the EU *NASCENT* project (2001-04). This addressed key issues of geological CO_2 storage through the use of natural CO_2 occurrences as analogues for geological repositories of anthropogenic CO_2. Issues addressed included the long-term safety and stability of storage underground, and the potential environmental effects of leakage from underground reservoirs. Greece was represented by IGME.

Between 2006 and 2008, the EU *GeoCapacity* (Assessing European Capacity for Geological Storage of Carbon Dioxide) project was undertaken. The main objective was to assess the European capacity for geological storage of CO_2. Again, Greece was represented by IGME. It was determined that deep saline aquifers had the potential to store 184 Mt, and hydrocarbon fields, a further 70 Mt (EU GeoCapacity, 2006).

CERTH/CPERI and PPC were involved as part of the FP7 project *RISCS* (Research into Impacts and Safety in CO_2 Storage) (2010-14). This focused on improving the understanding of the safety and possible environmental impacts associated with the geological storage of CO_2. In practice, significant leakage from CO_2 storage is not expected. However, if this occurred, there could be adverse effects on the environment. Such issues are not well understood. Hence, RISCS undertook research on impacts arising from known CO_2 fluxes, in both marine and terrestrial environments. As part of the project, naturally leaking sites in southern Europe were examined – this included a natural CO_2 vent in Florina, Greece. The impact of leaking gas on vegetation, potable groundwater quality, and the possibility of using CO_2-impacted groundwater for crop irrigation were investigated.

10.6 CO_2 transport issues

Once captured from large point sources such as power plants, CO_2 would need transporting to a prescribed storage site. Greek studies have examined the associated cost implications of capture from a newly-built capture-ready 650 MW supercritical power plant, and its storage in deep saline aquifers. The proposed power plant would be located in the region of Western Macedonia.

Preliminary cost estimations were based on a pipeline transport infrastructure linking this CO_2 source with several different storage sites; these comprised onshore saline formations in West Thessaloniki and the Messohellenic Trough–Pentalophos, and the offshore Prinos saline aquifer. Geological reservoirs identified that occur within ~100–200 km of the majority of the major stationary CO_2 emission sources were considered; this is favourable in terms of infrastructure costs for the development of suitable CO_2 pipeline systems.

Cost analysis for the new 650 MW power plant suggested that CO_2 transport and storage costs would be less than 10 US$/t. For transport to suitable onshore saline aquifers, transport costs would be 1 €/t, and for offshore (Prinos), ~2 €/t. These preliminary cost estimates (0.7–1.13 €/tCO_2/100 km) are in line with those cited in other studies (that ranged between 0.3 and 2.4 €/tCO_2/100 km) (Koukouzasa and others, 2010). The choice of an offshore repository, plus the greater length of pipeline required, clearly impacts on overall transport costs. However, costs could be reduced by making use of existing infrastructure (within 30–40 km of the coast). This comprises mainly pipelines, wells and platforms for oil and gas production.

The cost estimates for the Greek situation noted above are considered to provide approximate transport and storage costs for much of the rest of the country. But, there are a range of site-specific factors that, for a particular scheme, would need considering. These would include specific geological analysis, stratigraphic mapping and correlation, petro-physical property characterisation, generation of quantitative and dynamic 3-D geological models, and geochemical simulations. For individual proposals, case-by-case cost evaluations would be required through the development of updated engineering and economic models of CO_2 transport via pipeline and its storage in geological formations.

CO_2 capture, transport and storage costs have been examined for PPC's proposed lignite-fired Meltiti 2 power plant. Estimates suggest that over its 45 year operational lifetime, this would produce 120–130 Mt (~2.7–2.9 Mt/y) of CO_2. The storage site suggested was the west Thessaloniki-Korifi aquifer that lies at a depth of 2000 metres. This has a total storage potential of 645 Mt. The cost per tonne of CO_2 avoided was estimated at 47 €/t. The largest component of this was CO_2 capture (~81% of the total unit cost), followed by compression – this would be required as the transport distance would be relatively long (Hatziyannis, 2009).

Other studies have considered CO_2 capture and transport from a natural gas-fired power plant, namely PPC's 480 MW CCGT Komotini station. To transport captured CO_2 to the Prinos oil field would require a 120 km pipeline, comprising both onshore and offshore sections. Because of the pipeline's relatively short length, no booster station would be required. An estimated 1 Mt/y of CO_2 would be transported in this manner. The cost (at 2005 prices) of the 100 km onshore section was estimated to be US$ 9.88 million. The 20 km offshore section would cost US$ 13.3 million. Operational costs for the system would amount to US$0.29 million per year. Although the data remains robust, these costs would need inflating to present levels. The transported CO_2 would be injected into the Prinos oil field and used for EOR (Koukouzos and others, 2005).The additional income thus generated would offset some of the Capex and Opex of the pipeline.

More recent studies have considered the transport of CO_2 captured from a series of lignite-fired power plants in northern Greece (Meliti, Amynteon, Kardia, Ptolemais and Agios Dimitrios). It was assumed that this would be transported to the Prinos oil field and used for EOR purposes. It was estimated that ~17 Mt of CO_2 could be stored in this way. Estimated probable recoverable reserves of oil using EOR were 32 Mboe (Kakaras and others, 2012).

The on-going *CO_2 Transportation Risk Assessment for Carbon Capture Storage* (CO2TRACCS) project is being coordinated by NTUA. It is examining a range of issues that relate to the safe pipeline transport of CO_2 in regions with high geological risk. These include the identification of potential pipeline sites, the determination of safe locations and appropriate installation techniques for pipelines crossing areas that have a high risk of landslides, and the determination of the basic principles for engineering, construction and operation of high-pressure CO_2 pipelines traversing such areas.

Although the technology associated with CO_2 transportation is considered to be known from similar activities (such as natural gas networks), there are additional specific design considerations and a number of potential hazards specific to CO_2 transportation. Thus, research is addressing the impact of impurities such as H_2S, N_2, and H_2O over a wide range of temperatures and pressures. Other considerations include risk analysis related to CO_2 pipeline transport, namely landslide, seismic, corrosion, design and construction error risk. Risk assessment guidelines will be developed based on the results obtained. The results of such projects are expected to have a significant impact on the development of the principles of engineering and construction for CO_2 transportation pipelines and of the technical prescriptions for their design, construction and operation.

11 Greek energy and environmental R&D capabilities

For many years, Greece has participated successfully in both national and international initiatives in a number of fields that include energy production and the environment. Partially as a consequence of the country's economic crisis, for some time, levels of R&D funding from both public bodies and the private sector has been low. Despite this, Greece has remained active in a number of major EU programmes and projects focused on energy, sustainable development, and environmental issues. However, recently, in order to further raise the country's scientific profile and increase its visibility on the wider stage, a *National Roadmap for Research Infrastructures* has been developed. This has the twin overarching aims of supporting the decision-making process in compliance with strategic priorities in research (aimed at enhancing the effectiveness of investment planning for research infrastructures), and supporting the development of a national strategy within the framework of international negotiations, linked to EU priorities. The process of drafting the Roadmap was coordinated by the General Secretariat for Research and Technology (GSRT) and began in 2013 (National R&D Roadmap, 2014). Initially, a bottom-up approach was adopted, followed by peer reviews plus further input from Greek academia and research providers. It is hoped that the Roadmap will aid national and regional economic recovery based on scientific excellence and innovation.

Despite the country's current economic problems, over the past two decades, Greece has made significant improvements in how it undertakes research and development. There are a number of research policy implementation programmes, and research providers are actively pursuing a range of energy and environmental-related objectives (*see below*). For some years, support for research, technology and innovation has been based on national plans and strategies. A recent example is the *National Strategic Development Plan 2007–2013* (NSDP). This encompassed eleven thematic priorities, one of which focused on energy. Energy R&D funding and the thematic priorities were analogous to those of the EU's 7th Framework Programme on Research, Technological Development and Demonstration (FP7) covering the same time period. The thematic priority on energy included the use of renewables for electricity generation; fuels, heating and cooling; hydrogen and fuel cells; clean coal technologies; smart energy networks; and energy efficiency and conservation. These continue to be the focus of on-going efforts.

GSRT is the main authority responsible for developing and implementing R&D in Greece. It supports R&D activities of public research centres and universities, as well as those of the private-sector covered by national programmes. GSRT is responsible for supervising 12 of the 18 public research centres in Greece and also manages regional R&D activities. Another advisory body on R&D policy is the National Council for Research and Technology (NCRT). This is supported by seven sectoral research councils, one of which focuses specifically on energy and the environment.

Two of Greece's most important public research centres tasked with identifying specific energy R&D policy priorities and implementing energy-related R&D are the Centre for Research and Technology Hellas (CERTH), and the Centre for Renewable Energy Sources (Setis, 2015).

11.1 Programmes, ministries, and research providers

The country's 22 universities are the main research providers – combined, they account for around half of all Greek R&D spending. Together, universities and public research centres are responsible for ~70% of total spending on all R&D (not only energy-related), while the private sector's share, at ~30%, is one of the lowest among IEA member countries. At least 20% of total public funding comes from the EU via the Community Support Framework (CSF). In the recent programming period 2007-13, 75% of the budget for the entire programme of R&D measures was financed by EU Structural Funds.

A major Greek programme is *Operational Programme for Competitiveness and Entrepreneurship*. This has the overarching goals of improving competitiveness and increasing the cross-border mobility of the Greek production system – there is an emphasis on innovation. In the energy sector, the main areas include low-carbon heat and power, and alternative fuels and energy sources for transport. In Greece, there are a number of government ministries and departments involved in energy and environmental-related research. The main ones comprise:

- the Ministry of Environment and Energy (MEE) (formerly the Ministry of Environment, Energy and Climate Change – MEECC). This was established partly to address existing environmental issues. It works to protect the natural environment and resources, mitigate and adjust to the implications of climate change, and improve mechanisms and institutions for environmental governance;
- the Ministry of Economy, Development and Tourism (formerly the Ministry of Development, Competitiveness, Infrastructures, Transport and Networks);
- the General Secretariat for Research and Technology (GSRT). This is responsible for the design and conduct of science and technology policy. It is the managing authority of the Operational Programme for Competitiveness and is responsible for relevant research activities;
- Centre for Renewable Energy Sources (CRES). This is the national coordination centre for renewables, the rational use of energy, and energy saving. It is supervised by MEE;
- the Centre for Research and Technology (CERTH). CERTH includes two institutions active in energy: the Chemical Process Engineering Research Institute (CPERI), which conducts R&D and innovation activities related to energy conversion, and the Institute for Solid Fuels Technology and Applications (ISFTA). The latter is the main Greek organisation promoting R&D in solid fuels and their by-products; and
- the Institute of Environmental Research and Sustainable Development (IERSD). This is one of the five institutes that make up the National Observatory of Athens. It aims to promote environmental science and engineering and is particularly active in solar and wind energy.

A significant proportion of Greek R&D directed towards solid fuel use (primarily lignite) is undertaken by the following organisations:

Founded in 2000, The Centre for Research and Technology-Hellas (CERTH) is the only research centre in Northern Greece and one of the largest in the country. It has non-profit status and is supervised by GSRT. The Centre covers a range of research areas such as energy, environment, and industry. Its main mission is to conduct basic, applied, and technological research leading to new products and services with industrial, economic and social impact. CERTH comprises a number of specialist institutes that include the Chemical Process & Energy Resources Institute (CPERI). Originally set up in Thessaloniki in 1985, in 2012, CPERI merged with the Institute for Solid Fuels Technology and Applications (ISFTA). CERTH/CPERI has participated in numerous EU multi-partner projects and programmes.

The Institute for Solid Fuels Technology and Applications (ISFTA) is the main Greek organisation for the promotion of research and technological development aimed at the improved and integrated exploitation of solid fuels and their by-products. It is actively involved in government planning for power production and industrial development, and acts as consultant to the Greek government and organisations such as PPC and the Institute of Geological and Mineral Exploration (IGME). ISFTA's activities are of major importance for national energy policy. ISFTA was established by Presidential Decree in 1987. It is supervised by GSRT and since 2002, has been one of the five CERTH institutes. For more than a decade, research efforts have been focused on:

- optimisation of the use of Greek lignite for power generation and industrial applications;
- improvement and further development of CCTs;
- CFD simulation of coal-fired boilers (PCC and CFBC variants);
- utilisation of fly ash for the production of cement and other building materials;
- improving soil quality using additives and organic fertilisers produced from low CV lignite and coal combustion by-products;
- developing innovative methods for environmental management in areas where lignite mining and power production occur; includes issues of surface and ground water, and land reclamation;
- biomass and/or waste co-utilisation with lignite in existing combustion/gasification systems; and
- technology transfer via international collaboration.

ISFTA is a member of several international organisations and collaborates with research institutions and organisations throughout Europe and Asia. It has established a long-term cooperation relationship with many organisations in more than 20 countries.

Several Greek universities are engaged in energy-related R&D, the most notable of which is The National Technical University of Athens (NTUA). In particular, for more than three decades, the university's Laboratory of Steam Boilers and Thermal Plants has been working in the following areas:

- the examination of phenomena that affect combustion processes in conventional and non-conventional steam boilers;
- pollutant formation and technologies for their reduction;
- examination of heat transfer phenomena on the exchange surfaces of steam boilers;
- the testing of heating systems for their efficiency and exhaust gas quality;
- energy saving measures for thermal power plants;
- the development of new technologies and combustion systems (such as FBC);

- the use of biomass for energy production (combustion, gasification);
- fuel cell technology;
- novel technologies for CO_2 capture in power production sector;
- hydrogen use in energy production; and
- process simulation and the development of advanced cycles for power generation.

In the area of lignite-based research, the laboratory has particular expertise on the use of advanced technologies for improving performance. Extensive theoretical and computational work has been undertaken examining novel pre-drying concepts and their application potential in Greek power plants firing high moisture lignite. On-going work is encompassing an integrated approach, combining lignite drying with gasification for high efficiency power generation, thus helping minimise CO_2 emission. Other areas of activity include cogeneration, hydrogen production and use, fuel cell applications, CO_2 capture technologies (pre- and post-combustion and oxyfuel), and steam boiler design.

Several Greek universities have been involved in various energy- and/or environmental-related projects, most notably, the Aristotle University of Thessaloniki where the Department of Mineralogy-Petrology-Economic Geology, and the Chemical Process Engineering Laboratory have undertaken projects that have included lignite analysis and recovery, ash deposition studies, ash disposal, cofiring waste and lignite, gasification, and emissions monitoring.

The Technical University of Crete has also engaged in various related projects. Most have been undertaken by the university's Department of Mineral Resources Engineering. Topics have included lignite production, trace element analysis of lignite, fly ash characterisation, ash leaching studies (from lignite and blends with agro-residues), the effect of power plant efficiency and lignite quality on CO_2 emissions, geotechnical investigations of lignite mines, and lignite cleaning.

The Geo-energy Resources Team of the University of Patras has carried out studies into the geological mapping, and the stratigraphic, qualitative and quantitative analysis of lignite deposits. It has also worked in the areas of lignite petrography, lignite combustion by-products and their utilisation, and the environmental impacts associated with the use of lignite for power generation.

As part of the Technological Research Centre (TRC) of Western Macedonia, the Lignite Technology Section is active in the mining and processing of lignite for power generation purposes. It is supported via a number of specialised labs of the Technological Educational Institute (TEI) of Western Macedonia (such as the Mining Information Technology, Mineral Resources–Mining, and Applied Geophysics Laboratories). The Section has undertaken projects and studies examining mine planning and associated equipment, carried out feasibility and environmental impact studies, and provided technical support. The Control and Protection of Environment Section focuses mainly on air quality/pollution – an on-going project is quantifying particulate emissions from lignite mining operations (the THEOFRASTOS project). TEI has been involved in various lignite-related projects such as the modelling of lignite drying using a fluidised bed dryer configured specifically for deposits in West Macedonia.

The Greek Institute of Geology and Mineral Exploration (IGME) was founded in 1976, and is the State's technical adviser on geo-scientific matters. It operates as a public research institute under the supervision of MEE. IGME's main aims centre on the geological study of Greece, and the exploration and evaluation of its mineral and groundwater resources. It carries out a range of specialised surveys, aimed at the further development of the country's energy potential, and the strengthening of its industrial base. More recently, there has been involvement in areas associated with climate change and the geological storage of CO_2. IGME has participated in three major EU projects focused on the latter – GESTCO, GeoCapacity and NASCENT. Through such involvement, the Institute now has considerable expertise in the various aspects of CO_2 storage and monitoring. It has also produced an estimate of the potential for geological storage in Greece. This has included a study of the available storage options around PPC's planned 660 MW Ptolemais V lignite-fired unit. As noted earlier, PPC has been a partner in a range of major EU-sponsored projects.

12 Summary

Background

The financial crisis continues to impact on all facets of the Greek economy – recent years have seen this contract by nearly a quarter. The period has seen the deepest and most protracted peacetime recession in the country's history. Until recently, there were some signs that the recession could be bottoming out. However, in 2015, the financial crisis continued unabated – as yet, there is little to suggest that the Greek economy will enjoy serious recovery in the near future.

Greece has a high energy import dependency. Almost all of its oil and gas is sourced from abroad; this amounts to almost two thirds of its gross inland energy consumption. Compared to other EU member states, the overall diversification of the energy mix is rather limited. In terms of security of energy supply, the high dependence on imported oil makes Greece one of the most vulnerable states in the EU. The country is the 10^{th} largest energy importer in the EU 28. Importing energy is also expensive – reportedly, the current level is ~US$20 billion per year.

Solid fuels (primarily lignite) are the country's major energy resource, accounting for around a quarter of gross inland consumption. Greece is one of the EU member states that relies most heavily on solid fuels. Almost all lignite produced is used for electricity generation/cogeneration. The state-owned energy company Public Power Corporation S.A. (PPC) remains the largest producer with the right to exploit almost two thirds of the country's known reserves.

Over the next decade or so, development of the renewables sector was forecast to draw in significant investment. However, partly as a result of the country's economic problems, subsidies/incentives paid for some renewables-based generation are being reduced – this could delay some proposed projects or deter private sector investors.

The present government had previously announced that alongside supporting the further uptake of renewables, in order to minimise energy imports, it intended to encourage the greater use of indigenous lignite for power generation. However, following the latest election, this position appears to have softened – emphasis appears to have switched towards the greater use of renewable sources. At the moment, only one new lignite-fired power project is under construction.

Greek energy policy

The energy-related priorities of previous Greek governments focused on the provision of a secure, uninterrupted supply of energy, capable of meeting national requirements. The strategy was to access a variety of energy resources, boost the use of domestic sources, and increase the uptake of renewable energies. Furthermore, to increase competitiveness, the energy sector was to be increasingly liberalised and monopolies in the electricity and natural gas sectors ended, a move that was widely expected to increase private sector participation. However, following the first 2015 election, the new government stopped all energy-related privatisations, and also announced plans for the greater use of domestic lignite for electricity generation. But the conditions demanded by EU and IMF creditors, prior to disbursement of the most recent tranche of Greece's €240 billion bailout, means that privatisation schemes may be back on the table once again.

The financial crisis continues to have major impacts on the day-to-day operations of PPC. As a result of unpaid electricity bills, the company is owed a significant amount of money. The knock-on effect has been that PPC has been forced to rely on its cash reserves. Potentially, this could destabilise the company's investment plans and impact on planned future operations. For example, there were concerns that PPC could withhold a €200 million down payment on the new lignite-fired power project being developed (Ptolemais V), although these fears proved unfounded and the payment was made. The financial crisis is also impacting on the private sector development, particularly on new renewables-based power projects.

The energy sector

More than 93% of Greece's energy is provided by fossil fuels, compared to the European average of 75%. Domestic lignite produces much of the country's electricity.

Up to the time of its economic collapse, the Greek energy system had been characterised by a steady increase in energy consumption. Much was based on a high consumption of fossil fuels, a situation that prevails. Significant investment in the energy sector is needed – in the period up to 2020, forecasts suggest a figure between €22 and €30 billion. This will be needed for upgrading existing power plants, the construction of new capacity, grid improvements, and the installation of more renewable energy sources. This total will include €1.4 billion for the lignite-fired Ptolemais V plant, currently under construction.

Apart from nuclear power, the energy sector encompasses all major sources (oil, natural gas, lignite, and renewables). As production is limited, most oil and gas is imported. Crude oil comes mainly from OPEC and Former Soviet Union countries. Oil imports currently cost ~€10 billion per year. During the last decade, a general increase in demand and the construction of new gas-fired power stations significantly increased demand for natural gas. Most comes by pipeline from Russia and Azerbaijan (via Bulgaria) and Turkey. Forecasts for 2016 suggest that imported gas will cost ~US$ 2.39 billion.

Around 16% of Greece's electricity is generated by gas-fired power plants. However, in 2014, the market model changed and new gas-fired power plants lost the protection that had been in place for the previous five years. This led to a steep decline of gas-fired power plant output. This was replaced mainly by imported electricity from Bulgaria and Italy.

Key priorities and binding policies are in place to encourage the generation of electricity from renewable sources. Electricity produced by renewables is incentivised and supported by means of combinations of feed-in tariffs (FITs), subsidies, tax exemptions, and a net metering scheme. Where electricity is supplied to the grid, it is given priority. Against the background of the country's economic problems, this has proved expensive. By February 2013, FITs had created debts of nearly €302 million for the Greek government; steps have since been taken to weaken or remove some incentives.

Renewables encompass wind, solar, hydro, biomass, and geothermal. So far, most renewables-based electricity has been generated by the private sector, although some is also produced by PPC Renewables. At the end of 2013, the Greek electricity sector included more than 3 GW of hydro-based generating capacity, plus a further 3.6 GW based on other renewables. In the period up to 2020, assuming economic conditions allow, electricity generation from most forms of renewable energy is expected to increase.

Greek coal

Greek coal reserves are almost entirely made up of lignite. This is abundant in several regions, with proved reserves of between 3.9 and 5 billion tonnes. It is of strategic importance and used almost extensively for power generation. However, the quality of most deposits is poor. Productivity levels are high and extraction costs low – electricity is generated relatively inexpensively. The use of indigenous lignite significantly reduces energy import requirements. Recent lignite production has varied between 54 and 60 Mt/y. In 2013, in terms of EU production, Greek lignite production ranked third after Germany and Poland, and 6th in the world.

The Public Power Corporation (PPC) is Greece's largest power generator, electricity supplier and lignite producer. PPC's current power portfolio consists of conventional thermal, hydroelectric and other renewables-based power plants – combined, these make up approximately two thirds of Greek installed capacity. Seven major PPC lignite-fired power plants represent 24% of the country's total capacity and generate almost half of its electricity. Most of the country's lignite is produced by PPC, the third largest producer in the EU. The company has significant operations in Western Macedonia and the Peloponnese region. In 2012, total Greek production amounted to 61.9 Mt. There are also a small number of privately operated mines; in 2014, these produced a total of 2.6 Mt of lignite. Some private sector output is supplied to PPC.

Greek lignites are characterised as low rank coals. Many have low CV and high ash and moisture levels. Depending on the source, properties can vary widely, both within and between different geographical regions. Characteristics between individual layers can fluctuate significantly. As a result, the quality of mined lignite can vary considerably in all timescales.

Greece has no hard coal reserves and therefore none is produced. It relies entirely on imports to meet its requirements. However, only a modest amount is imported – in 2012, it amounted to 240 kt. This was used mainly by the cement sector and in metals production. Small quantities are also sometimes used as support fuel, added to power plant lignite feed.

Greek power generation sector

Much of the Greek electricity system was developed post-1960, with the main aim of electrifying the country through the use of domestic sources of energy. On the grid-connected mainland, most demand came to be met by a combination of lignite-fired and hydroelectric power plants. Many of the Greek islands, lacking connection to the mainland grid, were supplied by stand-alone oil-fired plants.

PPC is responsible for generating much of the country's electricity. This includes the Ionian and some of the Aegean islands that are now connected to the mainland and form part of the Interconnected System. Most of PPC's production capacity is concentrated in the north of the mainland, close to the large lignite mines that are the main source of fuel. The low cost of mining, the stability and security of supply, plus the fixed/controllable price, has made lignite a strategically important fuel for PPC and the country as a whole. Although there is now some private sector involvement in the power sector, the biggest player by far remains PPC. This is made up of four companies with separate legal and managerial identities: the parent company PPC S.A plus its three subsidiaries, ADMIE, DEDDIE and PPC Renewables (PPCR). The group holds assets in lignite mines, power generation, transmission and distribution. With a market share in supply of ~98%, PPC is the biggest power producer and electricity supplier in Greece.

PPC's power portfolio consists of conventional thermal plants (lignite-, gas- and oil-fired), and hydroelectric power plants, as well as other renewable-based installations. Combined, these account for ~64% of Greek total installed capacity. In 2014, PPC's lignite-fired plants generated 22.7 TWh of electricity; a further 2.8 TWh was imported – combined, this covered around two thirds of total demand. In 2014, lignite plants generated 48.1% of Greek electricity (total Greek generation of 53.5 TWh). In that year, PPC customers (nearly 7.4 million) consumed 97.9% of the total electricity supplied.

The Hellenic Electricity Transmission System (the 'Interconnected System') covers much of mainland Greece. Some islands (such as the Ionian Islands and some Aegean islands) that lie in close proximity to the mainland are included in the Interconnected System as they are connected via sub-sea cables. The Interconnected System has a capacity of ~18 GW. This includes ~5 GW of lignite-fired plants, 4.9 GW fired on natural gas, and 700 MW based on oil. Some 3 GW comprises large hydropower and 4.3 GW, other renewables. On the non-interconnected islands, the installed capacity consists of 1.78 GW of oil-fired generators plus 448 MW of renewables. Thus, the total national installed capacity is ~19.6 GW (61% thermal power plants, 15% large hydropower plants, and 24% other renewables).

In the Interconnected System, a significant proportion of generation capacity is located in north western Greece, close to lignite mines that are the primary fuel source. There is also gas-fired capacity and during the past two years, two new, state-of-the-art gas-fired plants have been built in the southern part of the Interconnected System. All remaining islands (the 'Non-Interconnected Islands') are served mainly by autonomous oil-fired power plants, although with some, demand is partially covered by renewables. The largest power plants in the Non-Interconnected Islands are located on Crete and Rhodes (with total thermal capacity >1 GW).

Greek electricity prices were fully liberalised in July 2013 although so far, effective entry into the market has been limited and PPC remains the dominant supplier. Since 2001, PPC's monopoly on generation has been reduced and the market opened up to private generators. From that time, licences have been issued for ~2.8 GW of private thermal generating plants. However, even before the full onset of the economic crisis, many failed to find adequate funding.

During the past decade, the use of natural gas for power generation increased significantly. The appearance of IPPs in the marketplace helped reduce PPC's market share from nearly 100% pre-2009, to the current level of ~72%. Gas-fired IPPs have achieved a share of ~20%. There are now private power plants with a combined capacity of ~2.2 GW.

Since 2010, the contribution of lignite-fired power plants has decreased. In 2010, they generated 51.2% of the country's electricity – in 2014, it was 48.1%. The input from gas-fired stations has fluctuated more widely; in 2014, gas-fired plants (PPC and IPPs) generated a total of 7.46 TWh – excluding electricity imports, this equated to 15.8%.

In 2014, Greece experienced a steep decline in electricity demand, with gas-fired plants being more affected more than lignite units. The decline in output from gas plants was replaced by electricity imports: these are normally ~4%, but in 2014 they rose dramatically to 16%.

Given the continuing economic crisis and the adoption of austerity measures, it is difficult to predict precisely what the longer term holds for the Greek energy sector. Recent years have seen various forecasts made regarding the future scale and make-up of the power sector. However, the on-going financial crisis will undoubtedly have a major impact on events. The power sector seems set to undergo major changes although many uncertainties remain. Many centre on the future of PPC and associated privatisation plans – this would have a major impact on the structure and operation of the company, its generation assets, and the Greek electricity supply business as a whole.

Environmental issues

Greek environmental policy in general is based largely on EU environmental regulations and directives. Greece has passed important environmental legislation and transposed a number of EU directives into national law. The Ministry of Environment and Energy has responsibility for the definition and implementation of national energy and environmental policy, as well as coordination of the energy sector. It is responsible for the formulation of policies concerning environmental protection, and for the coordination of implementation efforts.

A significant proportion of Greek emissions to air emanate from the energy sector. The widespread use of poor quality lignite in thermal power plants is responsible for a significant proportion of the country's emissions of SO_2, NOx, particulates, and CO_2. For some years, PPC has been working to improve the efficiency of its power plants and upgrade their associated pollutant control systems. Major investments have been made to reduce emissions; efforts to reduce levels further continue. In 2013, emissions of SO_2

and NOx fell. This was attributable largely to reduced overall power generation, changes in the fuel mix adopted, plus longer hours of operation for FGD plants. However, particulate emissions increased slightly.

As many Greek lignites have a high ash content and low CV, and are burned in large quantities in power plants, considerable quantities of combustion by-products are generated. The biggest amount comprises ~10–11 Mt/y of fly ash. Of this total, ~7.6 Mt originates from power plants in northern Greece, and ~2.5 Mt in the south (predominantly Megalopolis). In 2012, PPC plants generated nearly 10.9 Mt of fly ash, although only 300 kt of this was recycled – the remainder was deposited in specially designated areas. Ash utilisation in Greece is much lower than the European average rate. Depending on the location, the bulk is used for the restoration and reclamation of exhausted opencast lignite mines and slope stabilisation of the overburden.

12.1 Clean coal technologies (CCTs)

Several forms of CCTs are in operation or under development in Greece. These comprise:

- **Supercritical (SC) pulverised coal power plants**. PPC's existing lignite-fired fleet comprises conventional subcritical-based units, although there is also one SC plant currently in operation (Meliti). Prior to the onset of the country's financial crisis, new SC plants were being considered for several areas. However, at the moment, only one new 660 MW SC plant (Ptolemais Unit V) is being developed; this is forecast to come on line in 2019-20. A second project (Meliti 2) has also been proposed by PPC but is currently on hold.
- **Fluidised bed combustion (FBC)**. Although there are no commercial scale lignite-fired FBC-based power plants operating in Greece, there was a proposal to build a 450 MW plant in Kozani-Ptolemais. Some Greek lignites have been evaluated (in a range of test facilities) and confirmed as suitable fuels for FBC plants. Cocombusting with several forms of biomass was also deemed feasible.
- **Gasification and IGCC**. Over the past decade, largely in response to the country's high dependence on imported natural gas, the production of SNG via the gasification of lignite has been examined. A number of projects have been undertaken and several candidate technologies evaluated – some have been shown to be technically robust. However, there are currently no commercial scale plants operating. A Greek organisation (Helector S.A) has coordinated a multi-partner project to develop an RDF-fuelled fluidised bed gasifier in Germany. A larger unit is planned for Imathia in Greece. A number of studies have examined the suitability of Greek lignites for use in IGCC cycles combined with CO_2 capture. These suggest that pre-drying would be a pre-requisite for their use in such applications as incorporation of this step would significantly increase overall process efficiency. But there are currently no commercial IGCC facilities operating in Greece.
- **Cocombustion.** A number of Greek biomass-derived materials have been assessed for possible cocombustion with lignite. Testing has encompassed olive prunings, wood, glycerol, cotton residue, olive and peach kernels, pine needles, cardoon, RDF and sewage sludge. Various studies have assessed the behaviour and combustion performance of each (blended with lignite). Some have been confirmed as suitable for cocombusting.

- **Cogasification.** The possibility of cogasifying Greek lignite with other solid materials such as RDF or MSW has been investigated. This included a feasibility study for a lignite/RDF co-fuelled IGCC plant to be located near Kozani. Recent work has included studies carried out by CERTH/ISFTA on the fixed bed cogasification of lignite/biomass blends.
- **Underground coal gasification (UCG).** CERTH/CPERI was a member of a multi-partner project that examined deep underground coal gasification coupled with the permanent storage of CO_2. The main objective was to evaluate the potential of deep coal/lignite seams (depth >1200 m) for the development of UCG, and to confirm that the UCG boreholes could be used for the injection and storage of CO_2. Assessment focused on coal deposits in Bulgaria, although it was considered that data obtained would also be applicable to appropriate lignite reserves in Greece. Other studies have examined the possibilities for UCG in the Kozani lignite deposits.

CCS activities

Within the EU, the energy and carbon intensity of the Greek economy is not considered to be exceptional. However, the carbon intensity of energy production is one of the highest, due mainly to the heavy reliance on lignite. Although the country has met its Kyoto targets (and assuming that significant economic growth can be achieved within the next few years) some projections suggest that there could be a shortfall in the 2020 target for the non-ETS sector. However, as with other aspects of the Greek energy sector, this may be influenced by the country's current and future economic issues. The economic crisis appears to have pushed the issue of climate change down the political agenda.

To date, most Greek CCS-related activities have been limited largely to studies and small scale R&D, although useful work has been undertaken both via national research projects and through the participation of Greek organisations in various EU Framework programmes. Technology providers, energy companies and other industrial players have at times expressed an interest in CCS, but this has yet to culminate in a major project.

Emissions emanating from the energy sector make up a significant proportion of the country's GHG total (roughly half). In 2012, this amounted to 54.7 Mt CO_{2eq} – CO_2 made up the bulk of this. Of this total, ~46% was generated by public power and heat plants. Between 1990 and 2010, emissions from the electricity sector increased by 20%, reflecting the high share of oil and coal in the energy supply mix. However, in the past few years, overall levels have fallen.

Irrespective of future political events and changes that may occur in Greek energy policy, it seems likely that, for some years, fossil fuels will continue to play a major role in the country's energy supply. Forecasts from MEE suggest that lignite, gas and oil will continue to provide a major part of the country's energy, particularly for electricity generation, at least up to 2030. The present government's previously stated intention of increasing reliance on domestic lignite (and further gas-fired capacity) appears to have softened – emphasis may be switching again towards a greater reliance on renewables. Following the most recent election (of September 2015) the new Minster of Energy announced that the energy policy of the newly-elected government would focus on the gradual reduction of fossil fuels in the Greek energy system, and the further promotion of renewables.

For some years, CO_2 emissions from the PPC generating fleet have declined. The Generation Division has had an investment programme in place, focused on reducing its GHG emissions. Reductions have been achieved mainly through improvements to existing lignite-fired units (sometimes coupled with restricted hours of operation), retirement of some old lignite-fired generating capacity, and the greater use of natural gas and renewables in the generation mix. With regard to lignite-fired operations, between 1990 and 2011, the programme contributed towards reducing PPC's CO_2 emissions (per unit of electricity generated) by nearly 30%. PPC maintains an interest in CCS technology and its potential. With this in mind, the new lignite-fired 660 MW Ptolemais V will be built CCS-ready. Other major CO_2 point sources are associated mainly with cement production, oil refining, and aluminium and ferronickel production. Much of the country's industrial infrastructure is located in the regions around Athens and Thessaloniki.

A number of Greek organisations have been involved in CCS-related RD&D projects. This area was included as a high priority research topic in the *Greek National Energy Programme 2007-2013*. Greece has been represented in many related multi-partner EU projects. Different capture systems and their potential for application within a Greek context have been examined. Most studies have focused on post-combustion capture using amines or oxyfuel technology. Both greenfield and retrofit situations have been considered. CO_2 storage and transport issues have also been examined by Greek research providers and others.

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