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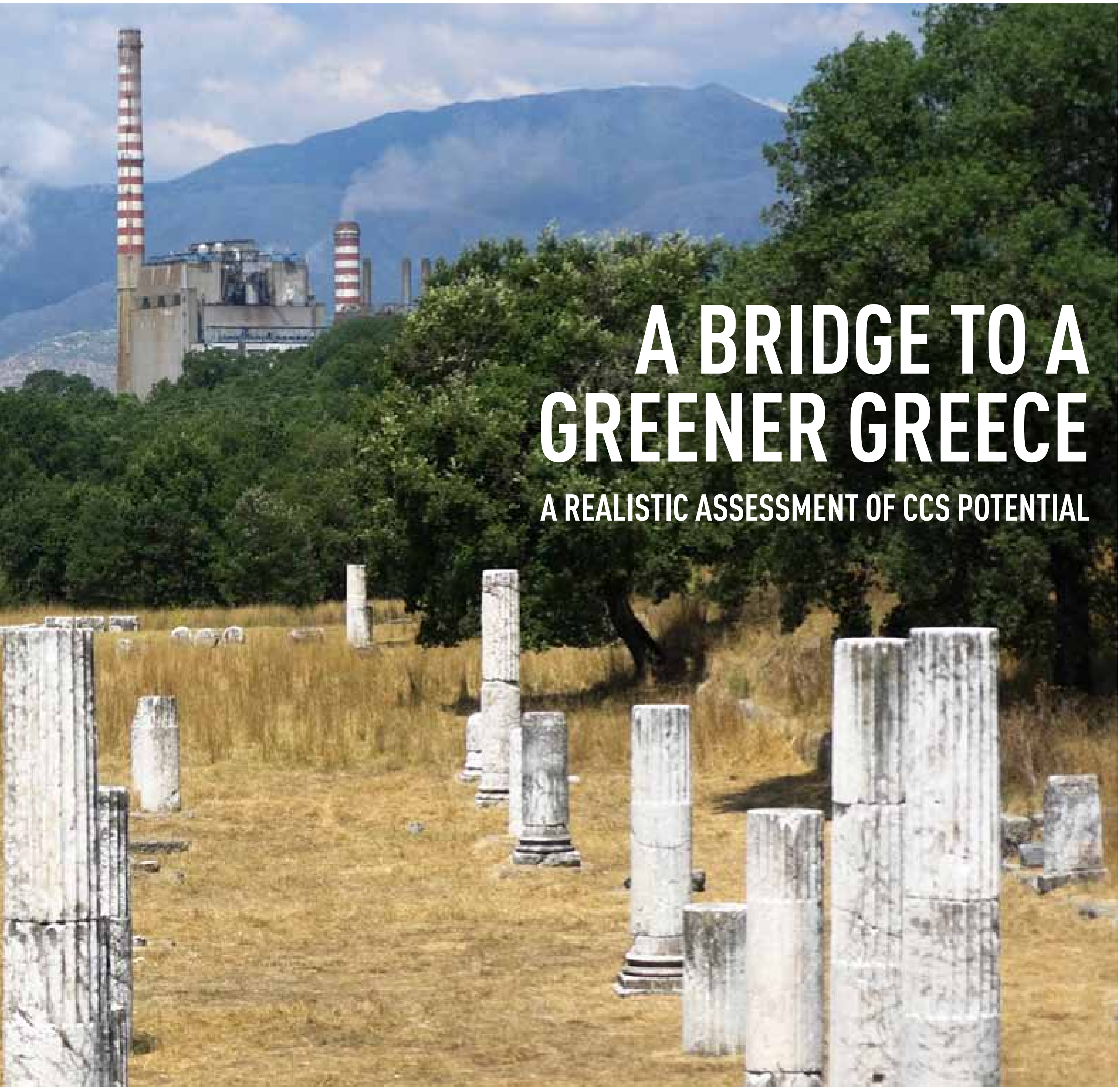

A BRIDGE TO A GREENER GREECE

A REALISTIC ASSESSMENT OF CCS POTENTIAL

BELLONA

Athens, Greece 2010

Acknowledgements and legal disclaimer

The Bellona Foundation, Athens, Greece, 2010

This publication has been prepared by the Bellona Foundation to fuel the debate in Greece on how to meet its emission and energy challenge. It is the result of a year's work both in Greece as well as in-house. The Bellona Foundation would like to thank the Global CCS Institute and other sponsors of the Bellona Environmental CCS Team (BEST) for their generous support. The BEST team is lead by Paal Frisvold and chaired by Frederic Hauge.

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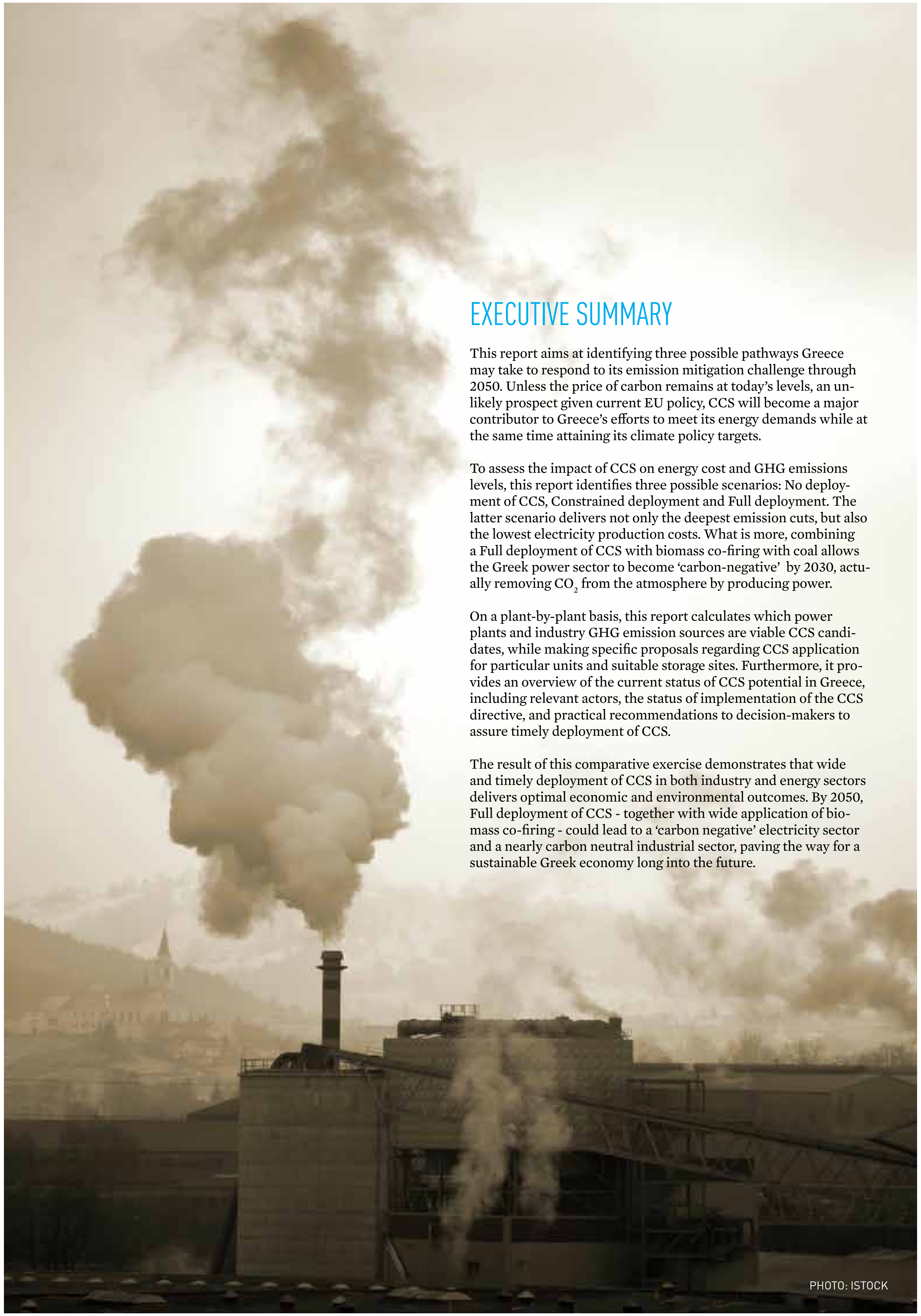

EXECUTIVE SUMMARY

This report aims at identifying three possible pathways Greece may take to respond to its emission mitigation challenge through 2050. Unless the price of carbon remains at today's levels, an unlikely prospect given current EU policy, CCS will become a major contributor to Greece's efforts to meet its energy demands while at the same time attaining its climate policy targets.

To assess the impact of CCS on energy cost and GHG emissions levels, this report identifies three possible scenarios: No deployment of CCS, Constrained deployment and Full deployment. The latter scenario delivers not only the deepest emission cuts, but also the lowest electricity production costs. What is more, combining a Full deployment of CCS with biomass co-firing with coal allows the Greek power sector to become 'carbon-negative' by 2030, actually removing CO_2 from the atmosphere by producing power.

On a plant-by-plant basis, this report calculates which power plants and industry GHG emission sources are viable CCS candidates, while making specific proposals regarding CCS application for particular units and suitable storage sites. Furthermore, it provides an overview of the current status of CCS potential in Greece, including relevant actors, the status of implementation of the CCS directive, and practical recommendations to decision-makers to assure timely deployment of CCS.

The result of this comparative exercise demonstrates that wide and timely deployment of CCS in both industry and energy sectors delivers optimal economic and environmental outcomes. By 2050, Full deployment of CCS - together with wide application of biomass co-firing - could lead to a 'carbon negative' electricity sector and a nearly carbon neutral industrial sector, paving the way for a sustainable Greek economy long into the future.

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PREFACE

There is already some discussion regarding the potential application of CO_2 Capture and Storage technologies in Greece, but most analysts do not go beyond a strict evaluation of an initial demonstration project. The goal of this report is to cover that gap and offer a realistic long-term appraisal of the economic and environmental consequences of broad CCS application in Greece in the power and heavy industry sectors.

To achieve its aim this report studies three potential emission mitigation trajectories based on the level of CCS deployment to 2050. Specific conclusions regarding the economic and environmental outcomes of each CCS deployment path are then extracted, leading to concrete recommendations to facilitate attaining maximum national and public benefit from CCS technologies.

A combination of publicly available official data from Greek and international sources, together with Bellona's own plant-by-plant research and calculations, was used to model the three scenarios for CCS deployment. Although presented now as a complete exercise, the reader is invited to share with Bellona new information or data that may be relevant for this roadmap, which will be updated continuously.

TABLE OF CONTENTS

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1.0 GREECE CLIMATE CHANGE AND CCS TODAY

1.1 CCS AS A CLIMATE AND ECONOMIC TOOL

Greece in the coming decades will face a twofold challenge: respond to the need to limit greenhouse gas emissions by using a portfolio of relevant tools and find ways to encourage positive investment to drive healthy economic development. An even greater challenge is to determine ways to combine these two imperatives. Through early adoption of low carbon technologies, acquisition of know-how and comprehensive long-term planning, this great challenge could well turn into a unique opportunity.

Indeed this chance has been acknowledged by the current Greek government. Green policy is being positively portrayed by the Greek Ministry of Environment, Energy and Climate Change (henceforth Ministry of Environment), not only as a means of tackling CO_2 emissions and achieving ecologically favourable outcomes, but also as a vehicle for economic development. Greece has already created a very positive legal framework to encourage investment in renewable energy sources (RES).

But does CO_2 capture and storage (CCS)[1] have a role to play as part of this policy focusing on green development and economic growth? The main goal of this report will be to offer a realistic answer to this question, and propose paths and solutions to better realise the potential that CCS has in Greece as a tool for climate change mitigation and economic growth in the context of all other climate change mitigation technologies.

1.2 ENERGY MIX TRENDS

Greece is heavily dependent on fossil fuels today. Coal, gasoline, oil and natural gas represent 95% of the total primary energy demand[2]. Although RES are now catching up due to the commitments from the Greek government to invest heavily in their deployment, the Greek economy will remain dependent on fossil fuels for decades to come. That is why this report looks into ways to directly abate fossil fuel emissions in order to achieve a timely reduction of CO_2 emissions before 2050.

Investments in off-shore wind farms as well as other forms of RES, such as photovoltaics, have rightly received significant attention. Apart from that, substantial investments in retrofitting remaining lignite-fired units and building new gas-fired power plants are envisaged by the Greek government until 2025-2030. The following chapter will put these plans into perspective, offering a detailed account of Greece's strategy to respond to contemporary climate and energy challenges.

1 See http://www.bellona.org/ccs/Tema/introductionToCcs
2 See http://www.ypeka.gr/LinkClick.aspx?fileticket=nbmXALB16wE%3d&tabid=37

Figure 1: *Energy demand of Greece in 2010.*

1.2.1 RES BOOST

The Ministry of Environment is currently the main governmental body concerned with the conception, development and implementation of energy and climate change policy in Greece. The current leadership of the Ministry of Environment has made RES development the backbone of its energy and climate change policy.

The EU's renewable energy directive 2009/28/EC set a binding 18% target for RES in Greek final energy consumption, an increase from 5.7% in 2006. Yet the government has set an even higher binding national goal of achieving a 20% share of RES in power production[3]. Furthermore, several initiatives to promote green policies and counteract bureaucratic obstacles previously hindering green investments have been established, including a proposal to establish a one-stop-shop for the fast promotion of investments.

Accordingly, a Ministry of Environment report, looking into ways to accelerate the development of RES, envisions a radical boost in RES capacity, which will be increased from about 4500 MW in 2010 to about 19300 MW by 2030[4]. This 400% increase in RES capacity is projected to come mainly from strong investment in wind energy, with the addition of about 9000 MW in the coming 20 years (see table 1). The Ministry of Environment has announced that it will centrally plan the construction of a number of large off-shore wind energy parks in the Aegean Sea. These parks will subsequently be connected to the mainland electricity grid. Photovoltaics will also receive a considerable boost of more than 3500 MW, while other RES technologies that have not yet been deployed in Greece, such as thermal solar and geothermal energy, will also be deployed.

1.2.2 FOSSIL FUEL PERSISTENCE

According to the predictions of the Ministry of Environment, the vast majority of currently operating but outdated lignite units are expected to be phased-out by 2024[5]. Stricter EU regulations, the increasing price of EU emission unit allowances (EUAs), and diminishing domestic lignite resources are the main reasons behind the projected retreat of lignite in Greek power production. To substitute phased-out lignite-fired units, three new units with higher efficiency rates are projected to be built in the Greek region of Western Macedonia by 2025. Furthermore, two relatively new existing lignite-fired units will be able to extend their operation beyond 2035. The total lignite capacity of Greece is projected to decrease from 4826 MW currently to 2295 MW by 2030. Natural gas is expected to largely cover the gap in Greece's historically lignite-dominated base load electricity supply.

PHOTO: ISTOCK

Indeed, a very significant increase in the role of natural gas in the national energy mix is currently envisioned. According to the Ministry's projections, an additional 6000 MW of natural gas capacity for electricity production is expected to be added by 2030, bringing total capacity to 9259 MW by 2030. This translates into the construction of about 20 additional natural gas-fired units during the coming 20 years. These new natural gas-fired units will progressively serve as base load units alongside their remaining lignite-fired counterparts. Since the recent liberalisation of the natural gas and the electricity market, an array of private companies have expressed strong interest in investing and a number of units have been constructed, rendering the coming switch from lignite to natural gas yet more definite. Furthermore, subsequent Greek governments have followed a policy that aims to position Greece as a path for major international natural gas pipelines projects[6].

These trends indicate that fossil fuels are bound to persist as means of energy production in the Greek energy mix for the decades to come. Natural gas, lignite, as well as petroleum, largely used in small off-grid units in the numerous Greek islands, will still represent a total capacity of almost 13000 MW by 2030 according to the predictions of the Ministry of Environment. Despite these projections, no concrete strategy has been as yet published, defining a path to reduce CO_2 emissions from these fossil fuel energy units. Indeed, this report aims at identifying the tracks Greece may take to bridge its present-day electricity production to a carbon-neutral future.

3 For an English version of the Greek law on accelerating the development of RES according to the 20/20/20 goals see http://www.ypeka.gr/LinkClick.aspx?fileticket=qtiW90JJLYs%3d&tabid=37
4 For the Ministry of Environment report on Energy mix projections in Greek see http://www.ypeka.gr/LinkClick.aspx?fileticket=nbmXALB16wE%3d&tabid=37
5 Estimations on fossil fuel energy capacity projections derive from the Ministry of Environment report on Energy mix projections

6 See Greek Ministry of Foreign Affairs position paper on the role of Greece in the international natural gas pipeline arena http://www.mfa.gr/www.mfa.gr/en-US/Economic+Diplomacy/Energy+Affairs/

ANALYSIS OF ENERGY SCENARIOS FOR THE ATTAINMENT OF 20/20/20 GOALS

Table 1: *Ministry of Environment 'Analysis of energy scenarios for the attainment of 20/20/20 goals', Table 2.3.8, p. 19, Goal attainment scenario.*

2010

CAPACITY (MW)	
184	PHOTOVOLTAICS
1327	WIND
3237	HYDROELECTRIC
4826	LIGNITE
60	BIOMASS/BIOGASS
3456	NATURAL GAS
2146	PETROLEUM PRODUCTS
0	THERMAL SOLAR
0	GEOTHERMAL
15236	TOTAL

2020

CAPACITY (MW)	
2200	PHOTOVOLTAICS
7500	WIND
4531	HYDROELECTRIC
3362	LIGNITE
250	BIOMASS/BIOGASS
7312	NATURAL GAS
1378	PETROLEUM PRODUCTS
250	THERMAL SOLAR
120	GEOTHERMAL
26903	TOTAL

2030

CAPACITY (MW)	
3833	PHOTOVOLTAICS
10000	WIND
4531	HYDROELECTRIC
2295	LIGNITE
500	BIOMASS/BIOGASS
9259	NATURAL GAS
1325	PETROLEUM PRODUCTS
510	THERMAL SOLAR
400	GEOTHERMAL
32653	TOTAL

1.3 EMISSION PROFILE: PRESENT AND FUTURE OUTLOOK

1.3.1 CURRENT MAIN DOMESTIC EMISSION POINTS

Major energy production emission points

The Greek energy sector is currently responsible for almost half of total domestic green house gas (GHG) emissions. The hitherto prevalence of fossil fuels – and especially emission-intensive domestic lignite as the fuel ensuring energy supply and independence – has significantly contributed to the fact that Greece has been among the highest emitters in terms of per capita GHG emissions in the EU[7].

Mainland lignite-fired units are clustered around two main regions: Western Macedonia in the North West and Megalopolis, a city in central Peloponnese in the South (see Map 1). Most lignite-fired units are rather old and many of them are more than 30 years old. The process of shutting down the oldest of these units has already commenced, their termination publicised as the beginning of a new 'cleaner' era for the Greek energy industry[8]. All lignite-fired units are currently operated by the state-owned Public Power Corporation (PPC) which till now had sustained a monopoly in lignite extraction. This de facto state monopoly in coal-mining came to an end with the launch of a recent tender for the Vevi lignite mine[9]. It currently remains uncertain if any of the current or projected lignite-fired units will be leased or sold to private investors in a push for further energy market liberalisation[10].

Since the beginning of this decade a number of less emission-intensive natural gas units have been constructed, and three more are currently in the construction phase. The majority of these units are situated in the area of central Greece in relative proximity to Athens (see Map 1). Individual private actors, such as the Mytilineos Group, as well as joint ventures between domestic business groups and foreign power producers (e.g. GEK-Terna Group with GDF-Suez, Hellenic Petroleum with Edison), operate most domestic natural gas-fired units. PPC also retains a smaller share of this market.

The bulk of existing energy production units that use petroleum bi-products as fuel ensures the energy supply of large Greek islands throughout the year. Given the practical difficulties involved in connecting the numerous remote Greek islands to the mainland grid with the additional need to cover increasing demand during the tourist season, autonomous petroleum-fuelled units have thus far been an essential part of energy production policy.

7 See World Bank carbon dioxide per capita data http://data.worldbank.org/indicator/EN.ATM.CO2E.PC
8 See for instance coverage of recent Ptolemaida 1 shut-down http://www.ana-mpa.gr/anaweb/user/showplain?maindoc=8842082&maindocimg=8841031&service=100
9 See 'Greece invites bid for Vevi lignite mine' http://uk.reuters.com/article/idUKLDE6171Z420100208
10 See 'Greece says to open up its power market' http://in.reuters.com/article/idINLDE67J0JD20100820

PHOTO: ISTOCK

Below is a list of major energy production units in Greece now existing or under construction, based on 2007 data from the European Pollutant Release and Transfer Register (E-PRTR).

MAIN ENERGY PRODUCTION UNITS IN GREECE

Table 2: *Largest CO_2-emitters in power sector. List of main energy production units in Greece existing or under construction, based on data from E-PRTR 2007. The 'First year of operation' column marks the first year(s) of operation of all units at a given plant.*

Emission point sources	Fuel	CO_2 emissions (Mtons/yr)	First year of operation
Ag. Dimitriou SES	**Lignite**	**12,95**	**1984 - 1997**
Agiou Georgiou SES	**Natural gas**	**1,02**	**1998**
Aliveri SES	**Natural gas**	**n/a**	**2012 (tentative)**
Aliveriou SES	**Fuel oil**	**1,04**	**1968**
Amyntaiou SES	**Lignite**	**3,92**	**1987**
Atherinolakkos SES	**Lignite**	**0,39**	**2004**
Chanion SES	**Diesel**	**0,80**	**1968 - 2003**
Chiou AES	**Fuel oil**	**0,13**	**n/a**
Elpedison - Thisvi	**Natural gas**	**n/a**	**2010 (tentative)**
Elpedison -Thessaloniki	**Natural gas**	**0,70**	**2005**
Heron Thiva	**Natural gas**	**0,11**	**n/a**
Kardias SES	**Lignite**	**9,51**	**1975 - 1981**
Kerateas – Lavriou SES	**Natural gas**	**4,19**	**1972 - 2006**
Komotinis SES	**Natural gas**	**1,13**	**2002**
Lesvou AES	**Fuel oil**	**0,17**	**n/a**
Linoperamaton SES	**Fuel oil**	**0,82**	**n/a**
Megalopils, units I, II, III SES	**Lignite**	**5,67**	**1970 - 1975**
Megalopolis, unit IV SES	**Lignite**	**3,33**	**1991**
Megalopolis, unit VI SES	**Natural gas**	**n/a**	**2013 (tentative)**
Melitis SES	**Lignite**	**2,03**	**2003**
Mytilineos - Ag.Nikolaos	**Natural gas**	**n/a**	**2007**
Parou AES	**Fuel oil**	**0,12**	**n/a**
Ptolemaidas SES	**Lignite**	**4,33**	**1959 - 1973**
Rodou SES	**Fuel oil**	**0,55**	**n/at**

Major heavy industry emission points

Greece does not have a large heavy industry sector, hence CO_2 emissions as a result of non-energy production activities are comparatively low, mainly from cement production, oil refining, and aluminium and ferronickel production. The bulk of industrial infrastructure is located near major residential and commercial centres, especially Athens and Thessaloniki.

The Greek cement industry is a vital sector for the Greek economy, given that Greece has relatively high cement consumption rates directed. Greek cement companies also attain remarkable cement export levels. Currently, four private companies operate major cement production facilities in Greece, each located near major residential and commercial areas, namely Athens, Thessaloniki, Patra and Volos.

The three highest-emitting domestic oil refining units are operated by a single actor, Hellenic Petroleum, and are all located in the vicinity of Athens and Thessaloniki. These three units cover 76% of Greece's total refining capacity, which is mainly directed towards covering domestic needs. A fourth refining unit, with a higher concentration on exports, is operated by Motor Oil just south of Athens in Corinth.

Both major existing aluminium and steel production units are situated just north of Athens in the central part of Greece. A major aluminium production unit, strategically located in Agios Nikolaos to exploit local bauxite deposits, is operated by Aluminium of Greece SA in which the Mytilineos Group has a majority stake. The ferronickel production unit, located at Larimna, is operated by state-owned Larco S.A., and is strongly export-oriented.

Below is a list of the largest industrial CO_2 emitters.

1.3.2 GHG EMISSION PROJECTIONS

In the coming decades, Greece will need to devise policies and apply technologies that will allow it to meet stricter GHG emission reduction goals. Possible tighter EU regulations even before 2020 (i.e. the potential increase of the EU emission reduction goal from 20% to 30% compared to 1990), could present the country with much greater limits to CO_2 emissions. Two recent government reports, briefly outlined below, have made projections regarding future Greek emissions trajectories while elaborating on ways to mitigate domestic GHG emissions. Both reports predict mild emission reductions with the largest cuts coming from changes in the electricity sector: wider RES deployment and the incremental switch from lignite to natural gas.

LARGEST INDUSTRIAL CO_2-EMITTERS IN GREECE

Table 3: *List of largest industrial CO_2-emitters in Greece, according based on data from E-PRTR 2007.*

Emission point source	Sector	Place	CO_2 emissions (Mtons/yr)	First year of operation
Aluminium of Greece	**Metals**	**Agios Nikolaos**	**0,52**	**1960**
ELPE Aspropyrgos	**Refined petroleum**	**Aspropyrgos**	**1,63**	**n/a**
ELPE Elefsis	**Refined petroleum**	**Elefsis**	**0,25**	**n/a**
ELPE Thessaloniki	**Refined petroleum**	**Thessaloniki**	**0,42**	**n/a**
Halyps Aspropyrgos	**Cement Manufacture**	**Aspropyrgos**	**0,54**	**n/a**
Heracles Halkis	**Cement Manufacture**	**Chalkis**	**1,43**	**1926**
Heracles Milaki	**Cement Manufacture**	**Aliveri**	**1,25**	**1982**
Heracles Volos	**Cement Manufacture**	**Volos**	**2,85**	**1924**
LARCO S.A.	**Production of ferronickel**	**Larimna**	**0,89**	**n/a**
P.F.I\- N.Karvali	**Fertilizers**	**Kavala**	**0,30**	**n/a**
TITAN Elefsis	**Cement Manufacture**	**Elefsis**	**1,56**	**1902**
TITAN Kamari	**Cement Manufacture**	**Kamari**	**1,96**	**1976**
TITAN Patra	**Cement Manufacture**	**Patra**	**1,10**	**1966**
TITAN Thessaloniki	**Cement Manufacture**	**Eykarpia**	**1,14**	**1962**

The 5th national communication to the UNFCCC

The '5th national communication to the UNFCCC' was published in January 2010 and describes measures to limit GHG emissions as well as concrete future projections . This report lists the following policy tools as means to restrict GHG emissions:

- The European common and coordinated policies and measures (CCPM)
- The European emissions trading system (ETS)
- Financing mechanisms mainly under the frame of the Community Support Frameworks.
- Fiscal measures that support policies and measures that reduce GHG emissions, such as the tax regime of energy products, the registration tax of vehicles, the Motor vehicle circulation fee (road tax), and income tax relief and exemptions.

The 5th communication makes no mention of CCS as a tool to limit GHG emissions, underlining that the wide introduction of natural gas and RES form the heart of the national strategy against climate change until 2020. The national emissions projections given under the 'additional measures' scenario of this report are provided in the table below:

TOTAL GHG EMISSIONS

***Table 4:** Includes the 'with additional measures' scenario of projections, '5th National Communication to the UNFCCC' Table 5.21, p. 164.*

2010

$MtoCO_2eq$ (million tons of CO2 equivalent)

59.41	ENERGY INDUSTRIES
1.78	FUGITIVES EMISSIONS
5.9	INDUSTRY - ETS
3.38	INDUSTRY - NON ETS
23.77	TRANSPORT
10.63	RESIDENTIAL
1.76	TERTIARY
3.06	AGRICULTURE
109.69	TOTAL

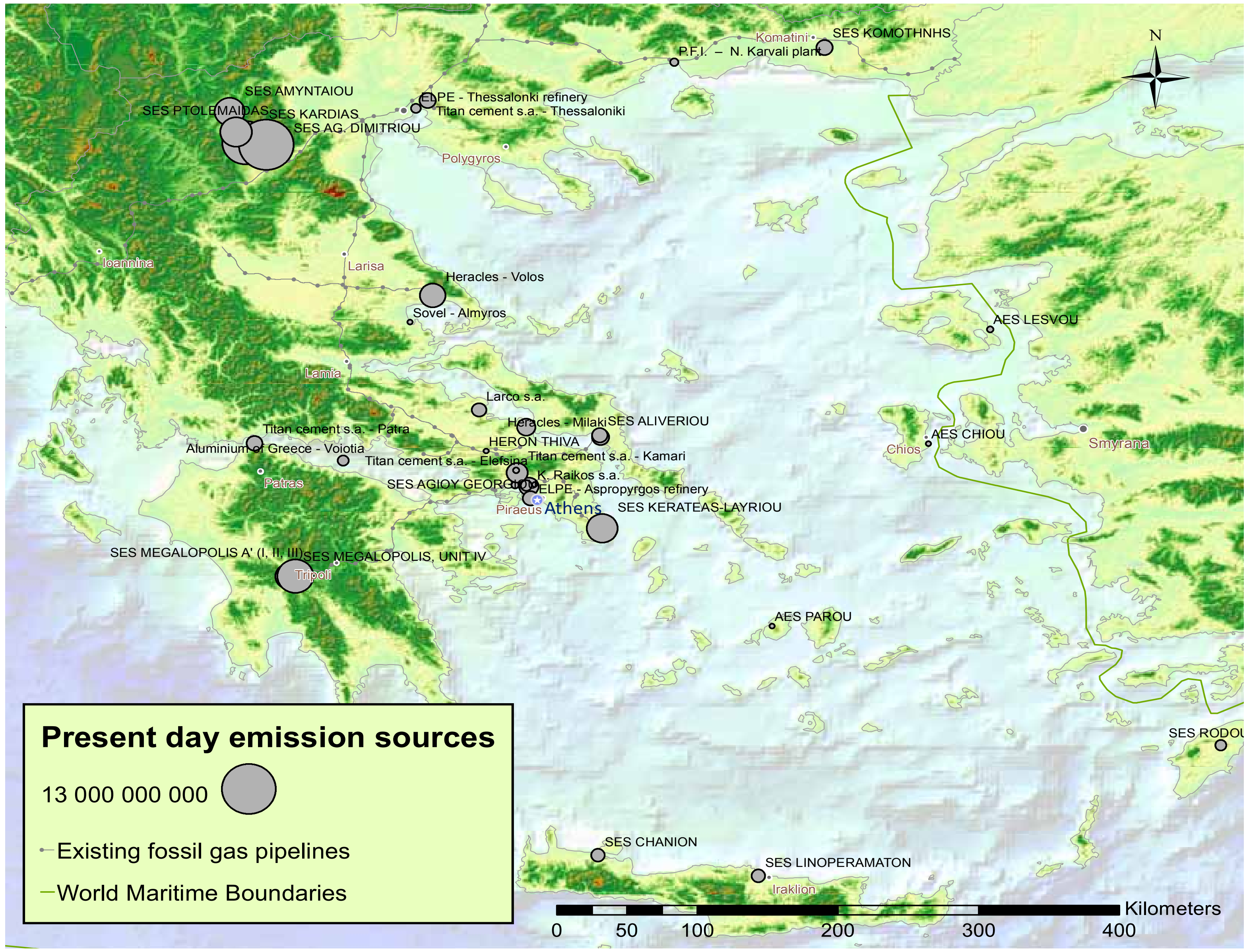
2020

$MtoCO_2eq$ (million tons of CO2 equivalent)

48.2	ENERGY INDUSTRIES
1.33	FUGITIVES EMISSIONS
6.5	INDUSTRY - ETS
3.81	INDUSTRY - NON ETS
26.18	TRANSPORT
9.86	RESIDENTIAL
1.23	TERTIARY
3.03	AGRICULTURE
100.13	TOTAL

PRESENT DAY EMISSION POINTS

***Map 1:** Present day CO_2 emission point sources and existing gas pipelines.*



Long-term energy planning report

The 'Long-term energy planning report', published in 2009 by the now defunct National Energy Strategy Council (NESC), does not foresee a need for radical change in the Greek energy mix through 2020 and describes prudent use of energy and the wide application of RES of all kinds as a pre-condition of achieving energy savings and security as well as environmental protection and sustainable development[11]. The report predicts a relatively modest decrease of CO_2 emissions from power production by 2030, from 90Mtn CO_2 eq. to about 81Mtn in 2020 and eventually 77Mtn by 2030 (table 5).

This report contains a brief mention regarding the potential of CCS in Greece (p.36): *'We note that although Greece ranks second in the production of lignite in the EU, it does not take part in any EU CCS program which does not provide it the chance to enrich the country's experience in the technology of solid fuel combustion, which it has developed with effort and serious investments throughout the last 30 years'.*

11 For a full version of the 'Long-term energy planning report' in Greek see http://old.eurocharity.org/file_library/eurocharity_712_20090730180613.pdf

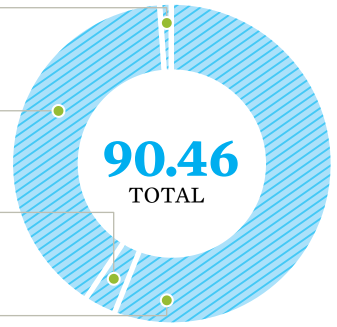
GHG EMISSIONS FROM ENERGY INTENSIVE SECTORS

***Table 5:** National Energy Security Council 'Long-term energy planning', Table 12 p. 60.*

2010

$MtoCO_2eq$ (million tons of CO2 equivalent)

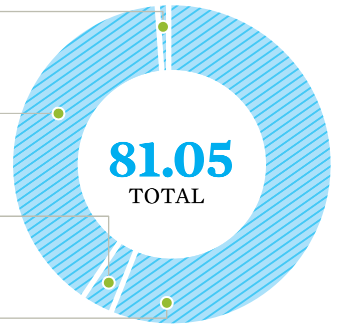
1.21 SOLID FUELS
35.7 PETROLEUM PRODUCTS
2.91 NATURAL GAS
50.63 ELECTRICITY



2020

$MtoCO_2eq$ (million tons of CO2 equivalent)

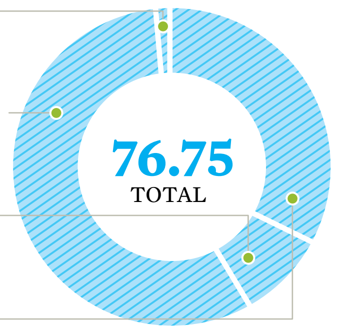
1.21 SOLID FUELS
35.7 PETROLEUM PRODUCTS
2.91 NATURAL GAS
50.63 ELECTRICITY



2030

$MtoCO_2eq$ (million tons of CO2 equivalent)

1.21 SOLID FUELS
43.95 PETROLEUM PRODUCTS
6.86 NATURAL GAS
24.73 ELECTRICITY



2.0 CCS DEPLOYMENT SCENARIOS

In order to assess the potential of CCS application in Greece this report examines three different scenarios based on CCS deployment levels and estimates their environmental and economic effect. As will be explained in the scenario modelling, energy demand, production capacity, expected emissions and cost of avoided emissions are the core variables for these scenarios. The three scenarios to be examined are:

- No deployment: Assumes absolutely no deployment of CCS before 2050
- Constrained deployment: Assumes moderate implementation of CCS until 2050
- Full deployment: Assumes wide, proactive and timely implementation of CCS until 2050

The baseline for the scenarios is constructed from existing projections from the Greek government regarding energy demand, energy mix and major emission points, so as to ensure realism. All modelling of the CCS deployment scenarios was carried out using the Long-Range Energy Planning software (LEAP)[12]. To develop reliable quantitative models of the effects of applying CCS technologies on the Greek power and industrial sectors, the nation's energy economy was modelled in three steps. An explanation of the modelling method used is followed by the description and analysis of scenario results.

No deployment:
- No CCS application until 2050

Constrained deployment:
- CCS on majority of new and CCS-ready lignite plants to be built after 2025
- CCS on some gas-fired power plants and all new gas-fired plants are built CCS-ready after 2025.
- Some biomass co-fired power plants equipped with CCS
- No CCS on industrial sources

Full deployment:
- CCS on all suitable coal and gas-fired power plants with a projected lifespan extending beyond 2025
- CCS on major industrial CO_2 sources (cement, steel, oil refineries, fertiliser industry)
- Widespread biomass co-firing with CCS

12 For further details on the Long-Range Energy planning software please see http://www.energycommunity.org/default.asp?action=47

MAIN PLAYERS ON THE CCS ARENA

Although not seriously considered until recently, CCS is now increasingly discussed as a possible tool to achieve emission mitigation in Greece. Some forums, e.g. a recent one at the lignite region of Western Macedonia, have indeed been organised to assess the potential of CCS and instigate dialogue[13]. Due to the increasing salience of CCS as a key energy and climate change issue, relevant stakeholders have had to adopt more concrete positions regarding CCS. In order to set the ground for the quantitative scenario analysis that follows in chapter 2, a short account is given of the positions that the main actors have taken.

1. GOVERNMENT

The current leadership of the Ministry of Environment has not yet presented a clear policy regarding CCS application in Greece. The Ministry has not yet indicated how it is going to deal with the implementation of the 'Directive on the geological storage of carbon dioxide' (2009/31/EC), despite the fact that this Directive needs to be transposed by all Member States by 25 June 2011[14]. As a result it remains as yet doubtful if Greece will allow domestic storage of CO_2.

The Minister of Environment has commented in a press conference that the solution of CCS application is a hard endeavour, 'especially for a seismogenous country as Greece' adding that it would be a mistake 'if we merely store emissions thus perpetuating the same developmental model'[15].

2.INDUSTRY

Technology providers, private energy companies and other industrial players have at times expressed an interest in CCS but this interest has yet to culminate into a concrete project. What is more, Aegean Energy, the current operator of Prinos, an off-shore mature oil field near Kavala in the Aegean Sea, has indicated that this reservoir has all necessary characteristics to accommodate the injection of CO_2 as part of a CCS project[16].

PPC, which currently operates most large energy emission points within Greece, has an ambiguous stance regarding the application of CCS. Although the company is following all technological developments, it has published no concrete plans regarding the application of CCS in any of its current or projected units. Nor the other electricity producers have issued a specific strategy for CCS application.

3. CIVIL SOCIETY

Major environmental NGOs in Greece approach CCS in an outright negative or suspicious manner.

In the first case, CCS is viewed as a dangerous, expensive and unnecessary tool that could also serve as a pretext for carbon lock-in. The rationale behind the discussion about CCS according to these groups is an effort by major private companies and national governments to retain existing patterns of energy production as well as profiteering by major petroleum groups.

Other NGOs, although acknowledging the necessity of CCS for emission reductions if it indeed appears to be viable, will avoid being vocal about the perspectives of this technology. The lack of any pro-CCS discourse on behalf of these NGOs lays in the supposition that the technology is untested and has not proven to be environmentally safe yet.

4. RESEARCH INSTITUTES AND ACADEMIA

There are research institutes and universities in Greece that have taken an active interest in examining the prospects of CCS in the country, such as the Institute for Geological and Mineral Exploration (IGME), the Centre for Research and Technology Hellas (CERTH) and the Athens Polytechnic.

Especially CERTH and the Athens Polytechnic have developed strong activity within European umbrella organizations, such as the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP), and act as centres of gravity for the dissemination of information and the education of stakeholders. Representatives of several research bodies and organizations have been carrying out studies and research concerning a number of aspects of CCS application in Greece.

13 See for instance the seminar of Institute of Energy for South East Europe(IENE) held at Kozani http://www.iene.gr/page.asp?pid=267&lng=2
14 For the full text of Directive 2009/31/EC see http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF
15 For relevant interview of Minister please see http://news.pathfinder.gr/greece/news/643606.html
16 For an overview of the Prinos reservoir see http://energean.com/Prinos?la=en

PHOTO: ISTOCK

2.1 MODELING OF CCS DEPLOYMENT SCENARIOS

2.1.1 ENERGY DEMAND & EMISSIONS TIMELINE

A complete and consistent picture of energy use in Greece over the next 40 years was assembled using very recent projections of future demand by fuel and by sector from the Greek government (see Tables 6 & 7 below), combined with information from academic sources detailing the use of energy within the residential and industrial sectors[17]. These calculations showed that transportation accounted for the largest share of energy consumption, at almost 40% of the national total. Electricity demand accounted for nearly 25% of total consumption in Greece. Industry and households used most of that electricity, while also directly consuming significant quantities of fossil fuels for on-site processes and power generation in the first case and for home heating in the second. The breakdown of energy use in households and industry is assumed to be constant in time in this model, while the government's demand projections to 2030 are linearly extrapolated to 2050.

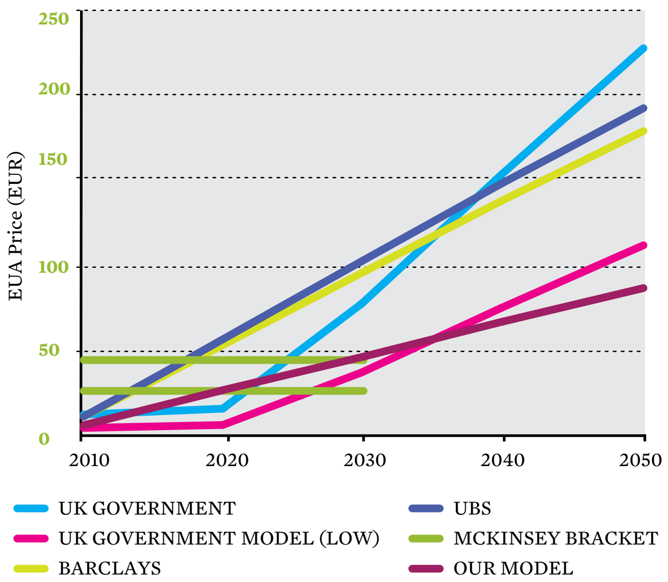
Electricity demand is adjusted in each scenario to reflect the relative elasticity of that demand to electricity price. As will be seen further on, the No Deployment scenario results in significantly higher electricity prices after 2030 compared to the Constrained Deployment case, while the Full Deployment scenario results in significantly lower electricity prices in the same time frame. After 2030, therefore, the government's projections for electricity demand is adjusted to 10% below projected for the No Deployment scenario, and 10% above projected for the low-cost Full Deployment case.

Because CCS can, at present, be economically and practically applied only to large, stationary emission sources, this model treats only the electricity and industrial sectors in detail. Emissions from other sectors are assumed to continue unchanged from the baseline case constructed from government projections. Cost calculations include only those costs directly related to the carbon economy: the cost of CO_2 EUAs under the ETS, and additional capital, fuel, transport, and storage costs attributable to CCS.

17 Tsilingiridis (2009) 'Changes in Greek Industry and their Effect on Air Pollutant Emissions', see http://www.gnest.org/Journal/Vol11_no4/518-527_558_Tsiligiridis_11-4.pdf

SELECTION OF RECENT EUA PRICE FORECASTS

Figure 2: *Includes the assumptions used in this roadmap. Other estimates from: UK Department of Energy & Climate Change (middle and low projections)[18], UBS Bank[19], Barclays Bank[20], and McKinsey & Company[21].*



Because of the large uncertainty in predicting future EUA prices, a simple model that sees the price grow linearly from 10EUR/tonne in 2010, to 50 EUR/tonne in 2030, to 90 EUR/tonne in 2050 is utilised. Such a forecast reflects a relatively conservative future EU climate policy, which imposes a slow and steady reduction in the European cap on CO_2 emissions through 2050. This choice falls toward the low end of government and investor forecasts for the EUA, as shown in Figure 1, with many forecasts envisioning EUA prices well over 100 EUR after 2030. If the EUA price does evolve in that way, the economics presented in this model will become only more favourable to CCS.

18 UK Department of Energy & Climate Change, Updated short term traded carbon values for UK public policy appraisal, June 2010, http://www.decc.gov.uk/assets/decc/what%20we%20do/a%20low%20carbon%20uk/carbon%20valuation/1_20100610131858_e_@@_carbonvalues.pdf
19 Carbon Positive, EU carbon price may triple by 2013, 23 September 2010, http://www.carbonpositive.net/viewarticle.aspx?articleID=2116
20 Alrroya.com, Barclays boosts phase III EU carbon forecast on auction supply, 5 August 2010, http://english.alrroya.com/node/52657
21 McKinsey & Company, Carbon Capture & Storage: Assessing the Economics, 2008, http://www.mckinsey.com/clientservice/ccsi/pdf/ccs_assessing_the_economics.pdf

ANALYSIS OF ENERGY SCENARIOS FOR THE ATTAINMENT OF 20/20/20 GOALS

Table 6: *Ministry of Environment 'Analysis of energy scenarios for the attainment of 20/20/20 goals', Table 2.3.3, p. 18, Goal attainment scenario.*

Final energy consumption (ktoe*)	2010	2015	2020	2025	2030
Solid fuels (non electricity)	453	291	306	306	306
Petroleum products	14148	12928	12899	12608	12669
Natural gas (non electricity)	938	1539	2237	2376	2509
Electricity	4555	4550	5008	5518	5927
Biomass	1120	1514	1839	2283	2479
Heat	62	84	109	115	143
Solar	216	271	355	478	563
Geothermal	24	23	51	67	75
Renewable Heat	17	127	279	384	431
Total	21532	21326	23084	24135	25102

**kilotons of oil equivalent*

Table 7: *Ministry of Environment 'Analysis of energy scenarios for the attainment of 20/20/20 goals', Table 2.3.3, p. 18, Goal attainment scenario.*

2010

FINAL ENERGY CONSUMPTION (KILOTONS OF OIL EQUIVALENT)

1065	AGRICULTURE
4300	INDUSTRY
8355	TRANSPORT
5753	RESIDENCIAL
2059	TERTIARY
21532	TOTAL

2020

FINAL ENERGY CONSUMPTION (KILOTONS OF OIL EQUIVALENT)

1004	AGRICULTURE
4834	INDUSTRY
8447	TRANSPORT
6415	RESIDENCIAL
2384	TERTIARY
23084	TOTAL

2030

FINAL ENERGY CONSUMPTION (KILOTONS OF OIL EQUIVALENT)

1038	AGRICULTURE
5133	INDUSTRY
8889	TRANSPORT
7307	RESIDENCIAL
2736	TERTIARY
25102	TOTAL

2.1.2 POWER SECTOR

The fossil-fuelled segment of the Greek power generation sector is modelled on a plant-by-plant basis, building up the generation and emissions profile based on the capacity, efficiency, and fuel type of each existing and planned power plant. IPCC Tier 1 emission factors are used for emissions from natural gas-based plants, while the CO_2 emission factor applied to the sector's lignite plants is modified from the IPCC value to reflect the particularly high carbon content of Greek lignite (Weisser 2007)[22 23]. These emission factors are listed in Table 9. Individual plant capacities and efficiencies for existing plants were obtained from individual operators and publicly available data. In the case of future plants, these values were derived from published plans when available; otherwise, nominal efficiencies, given in Table 9, were assumed. RES capacity is added to this plant-by-plant model according to the Greek government's composite projections for Wind, PV, Hydroelectric, and Geothermal capacity to 2030, as is capacity from petroleum-based off-grid generation throughout the Greek islands.

This model shows an electricity sector transitioning away from lignite, towards more natural gas-fired generation in the short-term and towards an ever increasing share of RES - particularly wind - in the long-term. It also shows that current and projected nameplate capacity of the electricity sector far exceeds current and projected electricity demand. This reflects both the requirements of peak demand and the increasing share of intermittent RES in the energy mix. In order to accurately model electricity production from this large generation capacity, a load duration curve measured for Greece was filled according to the current dispatch patterns of the Greek electric sector, which uses lignite for baseload generation, natural gas for mid-level demand periods, and RES and natural gas peakers to meet peak requirements. This pattern is modified in the future to reflect the increasing reliability of RES (through energy storage) and the growing dominance of gas for baseload generation.

22 For further information on Tier 1 emission factors see IPCC (2006) '2006 IPCC Guidelines for National Greenhouse Gas Inventories' http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
23 Weisser (2007) 'A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies', see http://www.iaea.or.at/OurWork/ST/NE/Pess/assets/GHG_manuscript_pre-print_versionDanielWeisser.pdf

The electricity supply model is extended beyond 2030 by following the fossil-fuelled plants already in existence in 2030 through their natural lifetimes, and by assuming RES and off-grid capacities remain constant from 2030 and 2050. Though actual capacity values so far in the future are highly uncertain, this simple assumption makes sense given that, even with no new fossil-fired plants and no RES capacity growth after 2030, available capacity easily meets projected demand.

↘ 2.1.3 INDUSTRY

Energy demand in the industrial sector – 20% of the national total – is modelled in more detail in order to identify large point source emissions that might be subject to capture and storage. A recent study of industrial energy use in Greece found that industry sourced 35% of its energy needs from electricity, 25% from petroleum products, 20% from natural gas, 10% from hard coal, 7% from other solid fuels such as lignite, and 3% from biomass[24]. Of the present-day emissions from industry direct-use of fossil fuels, it is calculated here that about 72% arise from the country's largest emission point sources, listed in Table 3. The proportion of industrial energy demand attributable to large emitters is assumed to remain constant in time, and it is this 72% of direct industry fossil-fuel emissions that are considered eligible for capture and storage in this Roadmap, together with all process emissions from large point sources.

Process emissions from industry are modelled using emission data from the large emission point sources of Table 3. For the key Greek industrial sectors - iron and steel production, cement production, refining, and fertiliser production - the share of total emissions attributable to process emissions is taken to be 10%, 66%, 10%, and 70%, respectively. The values for steel, cement, and refining were estimated from the International Energy Agency's Information Paper 'Industrial Competitiveness under the EU ETS', and those for fertiliser were adapted from information publicly available from the International Fertilizer Industry Association[25 26]. Because no projection exists at the point source level for the development of the Greek industrial sector, it is assumed here that the sector – and with it, its process emissions – will grow at the same rate as GDP. The most recent government prediction for GDP growth to 2030 is given in Table 8, and is linearly extrapolated to 2050.

MACRO-ECONOMIC AND DEMOGRAPHIC DATA

Table 8: *Ministry of Environment 'Analysis of energy scenarios for the attainment of 20/20/20 goals' presentation, page.11.*

	2010	2011	2012	2015	2020	2025	2030
GDP (Mill. €)	**204825**	**199500**	**201694**	**215931**	**245738**	**273178**	**305754**
GDP increase per year	**-4.0%**	**-2.6%**	**1.1%**	**2.7%**	**2.9%**	**2.2%**	**1.5%**

24 Tsilingiridis (2009) 'Changes in Greek Industry and their Effect on Air Pollutant Emissions', see http://www.gnest.org/Journal/Vol11_no4/518-527_558_Tsiligiridis_11-4.pdf
25 IEA (2005) 'Industrial Competitiveness under the European Union Emissions Trading Scheme', see http://www.iea.org/papers/2004/Industrial_Competitiveness.pdf
26 For the data used on the fertiliser industry see http://www.fertilizer.org/ifa/Home-Page/SUSTAINABILITY/Climate-change/Emissions-from-production.html).

2.2 APPLYING CCS

↘ 2.2.1 POWER SECTOR

CCS is applied plant-by-plant to the fossil fuel-fired plants of the electricity generation sector according to the timelines given in Figures 3a, 3c. When CCS is applied to a plant, its CO_2 emissions are reduced by 95% and its efficiency is reduced to reflect the energy penalty incurred by the capture and compression processes. Energy penalties for coal and gas capture technologies, given in Table 9, were linearly extrapolated from recent IEA estimates of those values between 2015 and 2030,[27] and assumed to remain constant after 2030. For CCS retrofits, the energy penalty leads to a decrease in the nameplate capacity of the facility. Because of the significant projected overcapacity of the Greek energy system, no new facilities are added to compensate for this lost capacity. In the Constrained and Full Deployment Scenarios, this leads to a 3% and 4% decrease in total nameplate capacity by 2040, respectively.

Modelling the additional costs of CO_2 capture, transport, and storage through 2050 is challenging, given the large uncertainty surrounding the future price of technology and geological storage. The capital costs in this model are based on the most recent estimates in the International Energy Agency's report, 'The Projected Costs of Generating Electricity,' which gives a range of possible additional capital costs for several CCS technologies in 2015 and 2030.[28] From these ranges the average of additional costs for each CCS technology is taken as the nominal value in this model, and the maximum and minimum values as limiting cases for a sensitivity analysis; these values are given in Table 9. These capital cost estimates are also compared with those from a 2007 study carried out by Rubin, Chen and Rao at Carnegie Mellon University, 'The cost and performance of fossil fuel power plants with CO_2 capture and storage,'[29] and was found to comfortably include the Rubin et al. values. The additional capital costs for CCS in retrofits are assumed to be 20% higher than those for new builds.

The capital costs are linearly extrapolated between the 2015 and 2030 IEA estimates, which assume a 20-25% decrease in capital costs for coal plants in that interval. Beyond 2030, the assumption is that capital costs decrease by 10% between 2030 and 2040, and again by 10% between 2040 and 2050. This modest drop in costs after 2030 is quite conservative, and assumes that the majority of technological learning takes place by 2030, with only minor cost improvements in later years.

All capital costs are annualised over the remaining life of the power plant beginning at the time of CCS implementation, and a 10% annual interest rate is assumed. This value is consistent with that assumed by the IEA, and somewhat lower than that assumed in the Rubin et al. study. The impact of a higher or lower

27 IEA (2010) 'Projected Costs of generating Electricity' see http://www.iea.org/Textbase/npsum/ElecCost2010SUM.pdf
28 IEA (2010) 'Projected Costs of generating Electricity' see http://www.iea.org/Textbase/npsum/ElecCost2010SUM.pdf
29 Rubin et al (2007) 'Cost and performance of fossil fuel power plants with CO2 capture and storage' see http://www.cmu.edu/epp/iecm/rubin/PDF%20files/2007/2007b%20Rubin%20et%20al,%20Energy%20Policy%20(Mar).pdf

cost of capital is evaluated in the sensitivity analysis. The costs of transporting and storing CO_2 are calculated per tonne of CO_2 captured. Transport costs are estimated to fall within a range of 2-15 EUR per tonne; this report adopts a nominal value of 10 EUR per tonne. The relatively high cost of CO_2 transport in this model compared to some other estimates is largely due to the higher cost of CO_2 shipping. Storage costs are estimated to fall within a range of 3-20 EUR per tonnes; this report adopts a nominal value of 9 EUR per tonne. That value is in large part determined by the use of Prinos as a storage site for a significant fraction of emissions from the north of Greece. An evaluation of CO_2 storage potential is given in Table 12, and more details on transport and storage costs are given in the annex.

These price estimates for transport and storage are consistent with those in the 2009 WorleyParsons report for the Global CCS Institute, 'Strategic Analysis of the Global Status of CCS'[30].

30 WorleyParsons (2009)'Strategic Analysis of the Global Status of CCS' see http://www.globalccsinstitute.com/downloads/Status-of-CCS-WorleyParsons-Report-Synthesis.pdf

Because no significant technological learning is expected, this report assumes that transport and storage and costs do not evolve in time. However, some cost decrease may in fact be seen in the future as transport and storage infrastructure improves and risk premiums decrease.

Because of the energy penalty of capturing and compressing CO_2, additional fuel costs per kWh of electricity produced are incurred at CCS-equipped facilities. These costs are calculated for each CCS-equipped facility in the model, based on the efficiency loss due to CCS and the fuel prices – assumed constant – listed in Table 9.

KEY MODEL PARAMETERS

Table 9: *High and low values for the sensitivity analysis shown in parentheses.*

Parameter	2010	2030	2050
EUA Price (€)	**10 (10/10)**	**50 (25/75)**	**90 (45/135)**
Lignite Emission Factor (tonnes CO_2/ TJ)	**118.5**	**-**	**-**
Natural Gas Emission Factor (tonnes CO_2/ TJ)	**55.8**	**-**	**-**
Lignite Price (€/GJ)	**2.40 (1.00/4.00)**	**-**	**-**
Natural Gas Price (€/GJ)	**5.50 (2.50/8.00)**	**-**	**-**
New Natural Gas Plant Efficiency (%)	**40**	**45**	**55**
New Lignite Plant Efficiency (%)	**30**	**35**	**40**
Energy Penalty[31] (%pts)			
• Pulverised Coal	**11**	**8**	**8**
• Oxycombustion	**12**	**8**	**8**
• IGCC	**13**	**4**	**4**
• NGCC	**8**	**7**	**7**
Additional Capital Cost (Thousand €/MW)			
• Pulverised Coal	**952 (533/1202)**	**571 (400/1250)**	**391 (324/1013)**
• Oxycombustion	**1500 (557/2071)**	**714 (371/1429)**	**579 (301/1157)**
• IGCC	**905 (457/1214)**	**571 (343/1214)**	**463 (278/984)**
• NGCC	**440 (229/583)**	**250 (171/441)**	**203 (139/434)**
Co-firing Capital Costs (Thousand €/MW)	**161**	**129**	**104**
Transport Cost (€/tonne)	**10 (2/15)**	**10 (2/15)**	**10 (2/15)**
Storage Cost (€/tonne)	**9 (3/20)**	**9 (3/20)**	**9 (3/20)**
Industry CCS Costs (€/tonne)			
• Cement	**34**	**27**	**22**
• Steel	**34**	**27**	**22**
• Fertiliser	**13**	**10**	**8**
• Refining	**34**	**27**	**22**
Cost of Capital (%)	**10 (5/15)**	**10 (5/15)**	**10 (5/15)**
Currency Conversion (USD/EUR)	**1.4**	**1.4**	**1.4**

31 Energy penalty, capital costs and plant operating costs are based on IEA (2010) 'Projected Costs of Generating Electricity' see http://www.iea.org/Textbase/npsum/ElecCost2010SUM.pdf

↘ 2.2.1.1 BIOMASS CO-FIRING

The potential for biomass co-firing in Greece appears significant, even though Greece has only recently begun considering it as an option. Co-firing of fossil fuels with biomass could bring about a number of economic (reduced costs for the purchase of CO_2 credits, increased lifetime of domestic lignite reserves, use of margin lands etc.) and environmental benefits (less emitted CO_2, reduced utilisation of non-renewable fossil fuels etc.) (Grammelis et al, 2009). What is more, the wider introduction of biomass burning for power production in combination with CCS can, in the long-term, lead to carbon-negative fossil-fuel electricity generation.

The real potential of biomass in Greece is further reinforced by the recent commencement of experimentation with co-firing in a lignite unit of PPC in Western Macedonia, as part of an effort to introduce alternative sources of energy[32]. During 2010 about 1700 tones of cardoon were used to test mixed combustion of lignite in the Kardia lignite plant, proving that it is possible to substitute lignite with biomass in existing boilers.

32 Grammelis et al (2009) 'Lignite and biomass co-firing: The case study of Kardia power plant' see http://www.scribd.com/doc/15256209/Lignite-and-Biomass-Cofiring-TEE-110509

Because biomass co-firing seems an advantageous and realistic prospect for Greece, the capacity to co-fire biomass is fitted to Greece's lignite-fired facilities in both the Constrained and Full Deployment scenarios. In the first, 5% biomass co-firing (by energy content) is applied to all lignite plants with remaining significant lifetimes in 2020, and in the latter, a higher 20% biomass co-firing fraction is assumed on the same timeline for the same facilities. The biomass is assumed to be sustainably grown and therefore carbon neutral (i.e. contributes nothing to the emission total) when fired at the plant. However, when biomass co-firing takes place at a plant also fitted with CCS, the biogenic CO2 captured and stored from the biomass-firing is counted as a negative contribution to total emissions.

Estimates of the capital costs for retrofitting existing coal stock to co-fire biomass from the U.S. National Renewable Energy Laboratory33 are used to model the costs of co-firing. These are given in Table 9. The cost of biomass is assumed to be the same as that of coal, per unit of energy. Such cost parity is achievable even now[34] and is likely to become more common as the local lignite supply in Greece decreases and global cultivation of biomass for energy increases.

33 See Biopower. 2000. Biomass Co-Firing: A Renewable Alternative for Utilities. US Department of Energy Energy Efficiency and Renewable Energy Network. http://www.nrel.gov/docs/fy00osti/28009.pdf (23 April 2004).
34 ibidem

↘ 2.2.2 INDUSTRIAL SECTOR

In the Full Deployment scenario, CCS is applied statistically to the energy and process emissions from large point sources in the industrial sector. A deployment timeline that sees 25% of such facilities equipped with CCS by 2020, 50% by 2025, 75% by 2030, and 100% by 2035 is assumed. When CCS is applied, 95% of CO_2 emissions are captured.

Estimates for the cost of CCS in industry are adopted from the 2009 WorleyParsons report 'Strategic Analysis of the Global Status of CCS,' which gives current-day inclusive costs for the capture, transport, and storage of CO2 in four industrial applications: iron and steel production, cement production, natural gas processing, and fertiliser production. The costs in the steel and cement sectors are much higher than those in the gas processing and fertiliser sectors, because the latter already include CO2 concentration, capture, or separation in their industrial process, while the former suffer diffuse CO2 emissions throughout the industrial process. Thus, though no specific estimate of the cost of CCS is given for the refining industry, a key player in Greece's industrial sector, it can be assumed that CCS costs in that sector will be similar to those for the steel and cement industries, as its process also produces diffuse CO2 emissions. These industrial CCS costs are listed in Table 9.

Given the very rough nature of current cost estimates for CCS in industry - and the fact that these estimates are composite calculations that include all capital, fuel, transport and storage costs per tonne of CO2 captured - the cost model does not differentiate between new-build and retrofit facilities. It is assumed that the cost of industrial CCS decreases at the same rate as that of CCS in the power sector (costs fall by 20% by 2030, 10% again by 2040, and 10% again by 2050). Moreover, because of the composite nature of the available cost estimates, the cost of industrial CCS is accounted for as each tonne of CO2 is generated and captured in the model, rather than by annualizing total capital costs as in the power sector.

FOTO: ISTOCK

FIGURE 3A: EMISSION SOURCE TIMELINE FOR FULL DEPLOYMENT SCENARIO

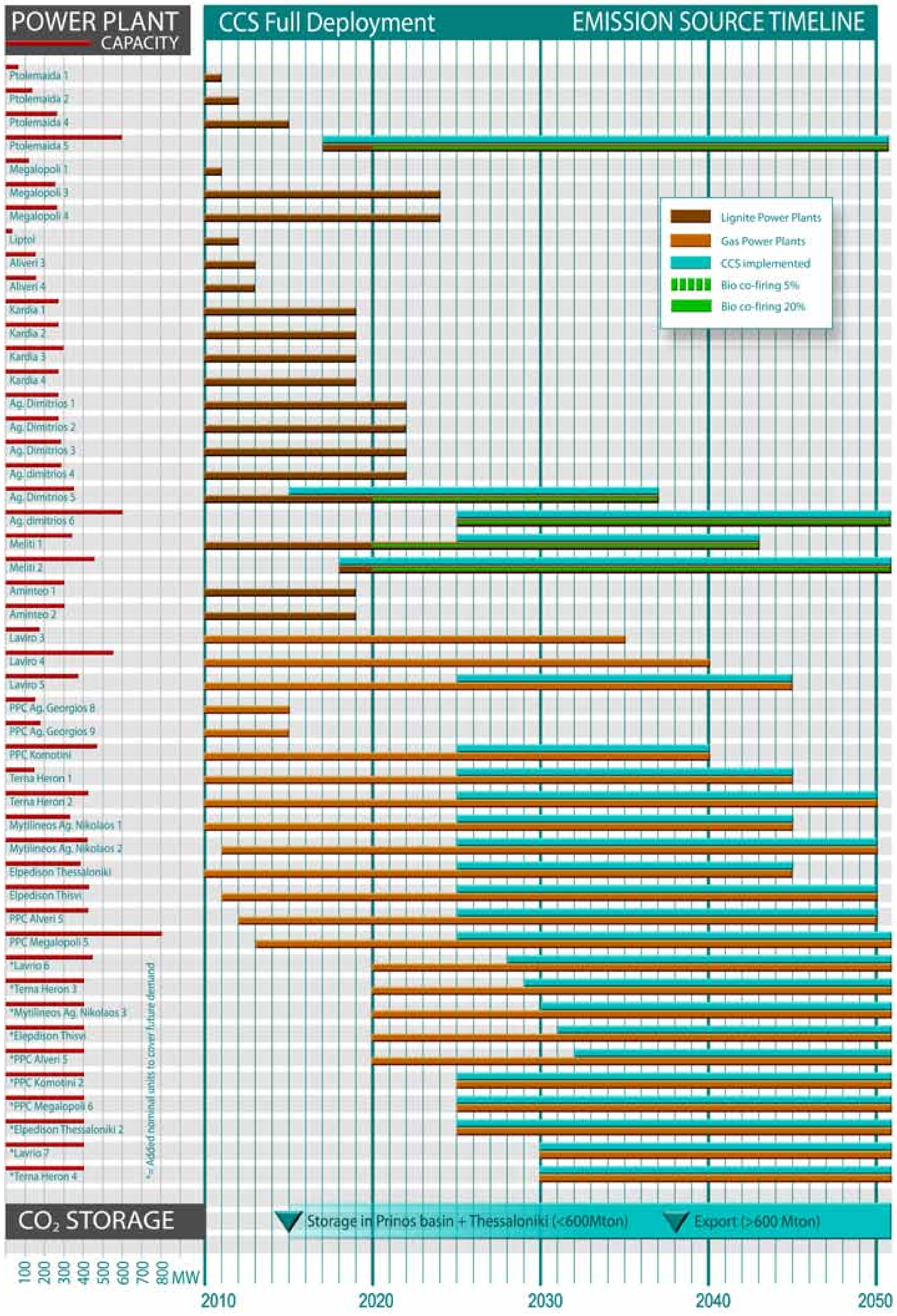


FIGURE 3B: COMPOSITE GRAPHS FOR FULL DEPLOYMENT SCENARIO

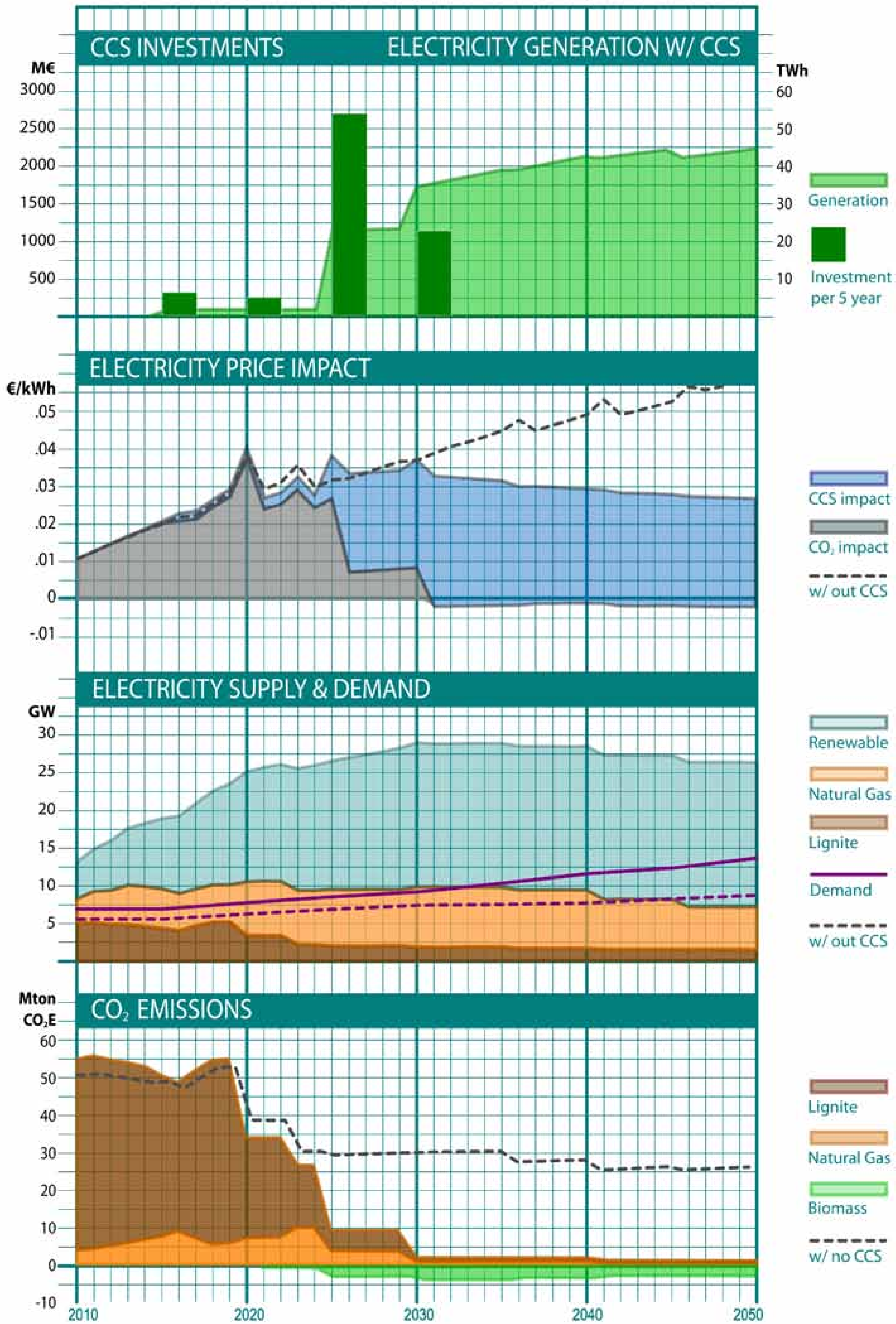


FIGURE 3C: EMISSION SOURCE TIMELINE FOR CONSTRAINED DEPLOYMENT SCENARIO

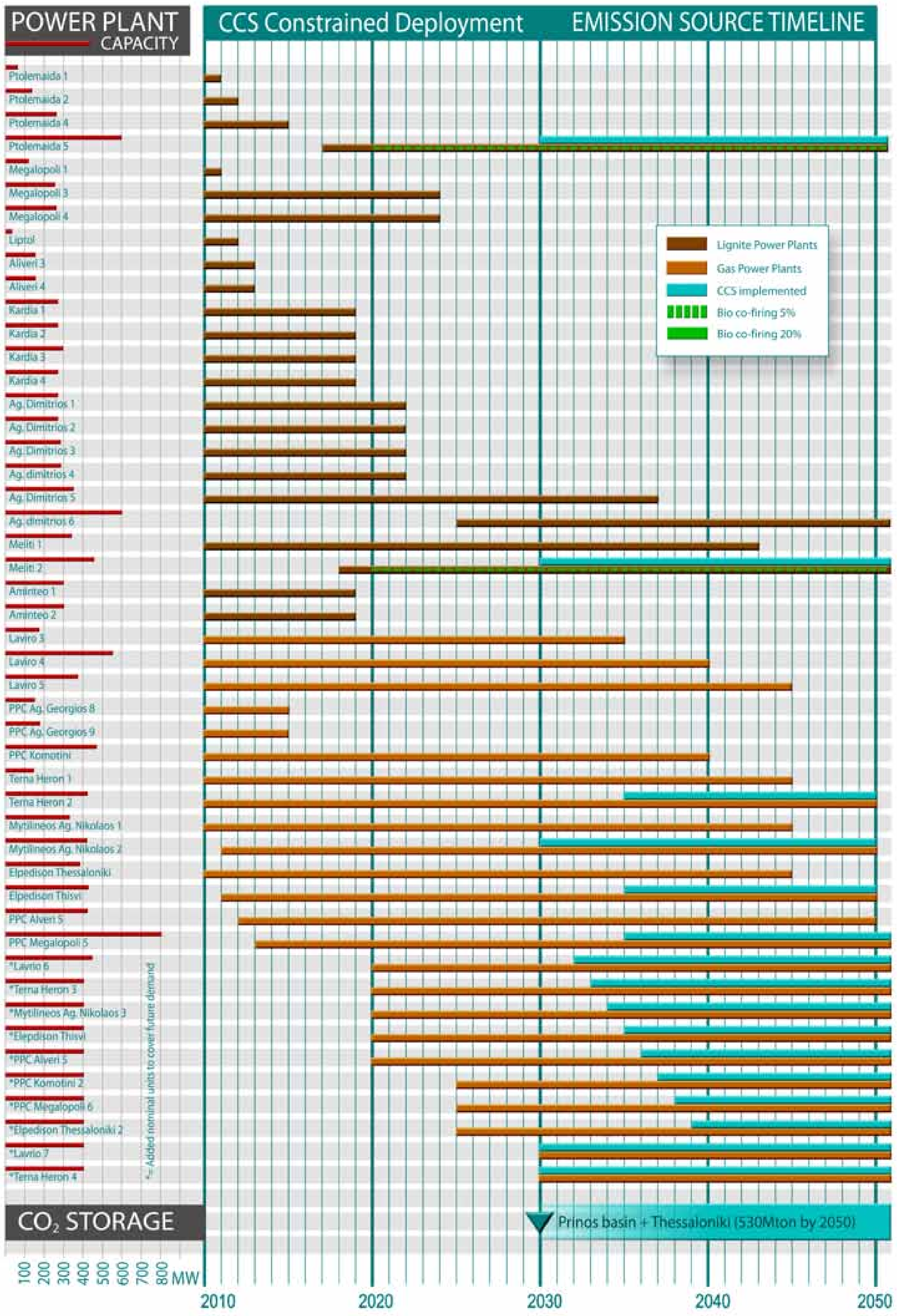
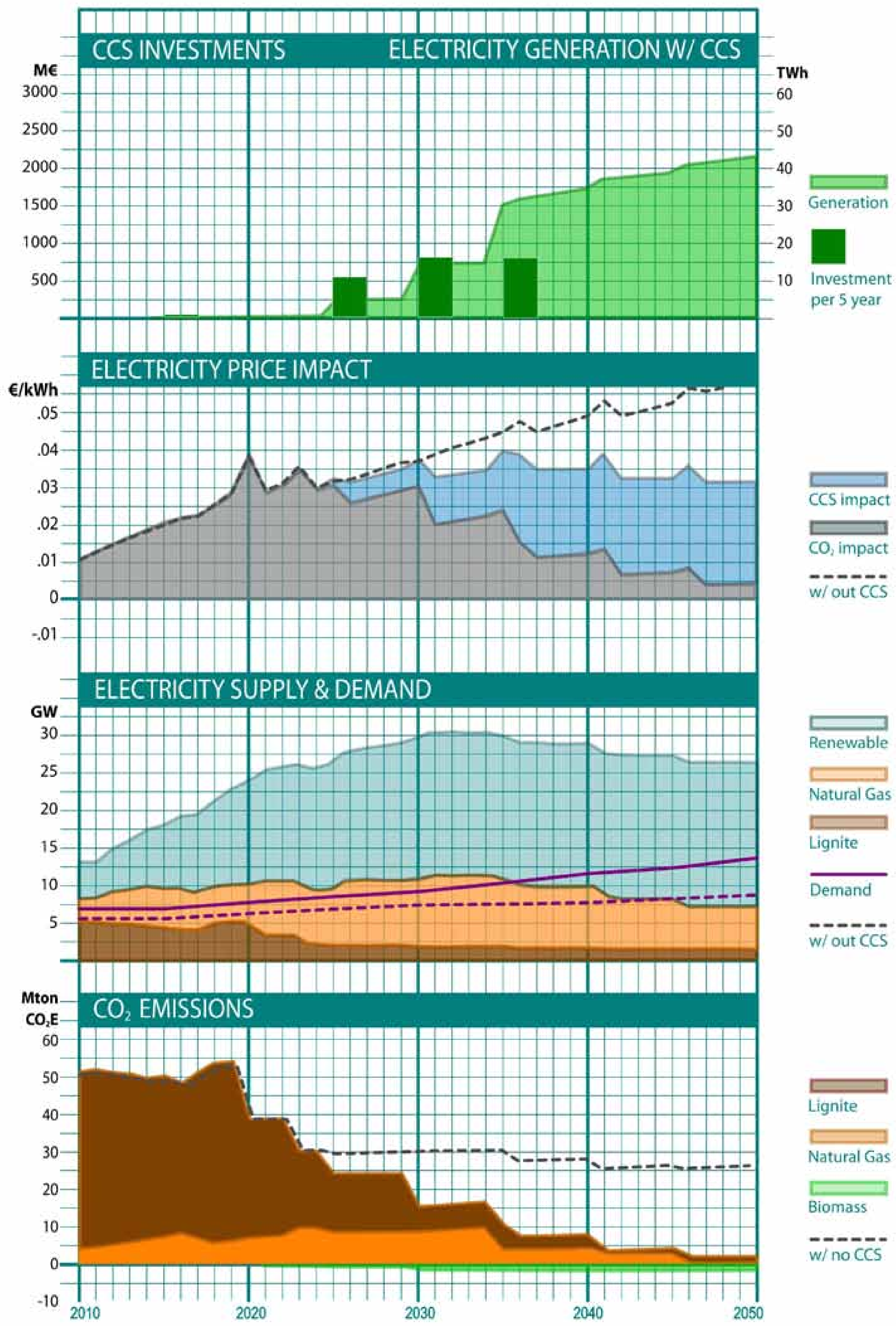


FIGURE 3D: COMPOSITE GRAPHS FOR CONSTRAINED DEPLOYMENT SCENARIO



2.3 SCENARIO RESULTS

Bringing all the pieces of the model together – energy demand, fossil and renewables supply, industry, biomass co-firing, and the application of CCS – allows us to construct a compelling narrative of the economic and environmental impacts of modest and widespread CCS deployment in Greece in the coming decades.

Figures in the centrefolds show the deployment timelines on the left page and the investment costs, CCS capacity, electricity cost impact, electricity demand and supply, and power sector emissions on the right page for both the Constrained and Full Deployment scenarios. The outcomes of each are compared to those of the No Deployment scenario.

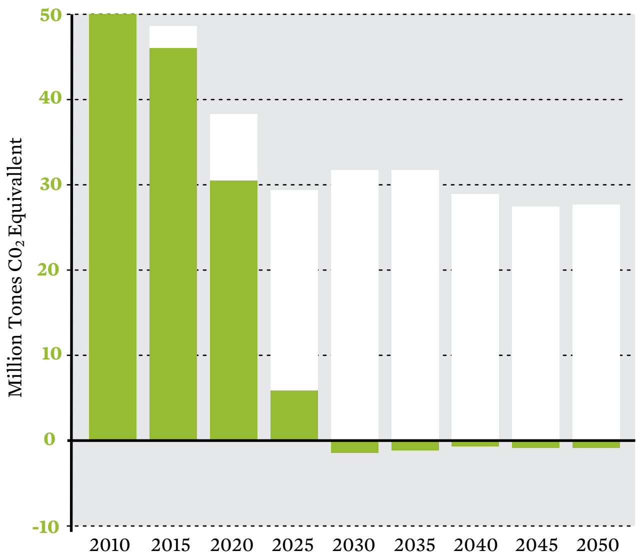
As expected, in both CCS scenarios significant investments are required, concentrated in the 2020s and 2030s. Delaying deployment of CCS, as in the Constrained Deployment scenario, reduces capital costs due to assumed technology learning improvements. However, the total CO_2 cost impact on the price of electricity tells a more complete – and very different – story. Despite the early investment costs required in the Full Deployment scenario, the price of electricity in a fully CCS-equipped energy sector becomes less than that in one without CCS by 2027, and less even than that in a sector with Constrained CCS deployment by 2029. Electricity generation with CCS becomes ever cheaper than generation without, leading to a price penalty of more than EUR 0.03/kwh by 2050 between the Full and No Deployment scenarios. The scenarios further show that more CCS has more economic benefits – compared to its more ambitious counterpart, the Constrained Deployment scenario achieves only slight savings over the No Deployment scenario, of EUR 0.005/kwh in 2050.

By making electricity cheaper, widespread deployment of CCS encourages increased energy demand in industry and households after 2030. And despite slightly reduced capacity in the fossil sector due to the CCS energy penalty, the large projected capacity of the Greek electricity sector is able to easily meet that enhanced demand. By contrast, the high electricity prices in the No Deployment scenario depress demand after 2030.

Even in the face of increasing electricity demand, the Full Deployment of CCS sees a drastic reduction in power sector CO_2 emissions. Indeed, with the inclusion of biomass co-firing in all operating lignite plants, the grid-connected power generation sector becomes carbon negative after 2030, as shown in Figure 3b. In the Constrained Deployment scenario (see Figure 3d), the effects are delayed and less complete, but still significant – by 2030 power sector emissions are 14.8 MT CO_2eq compared to 30.2 in the No Deployment Scenario, and drop to 1.8 MT CO_2eq by 2050, less than 7% of 2050 emissions in a world without CCS.

AVOIDED GHG EMISSIONS

Figure 4: *Avoided GHG emissions in the power sector with Full CCS deployment.*



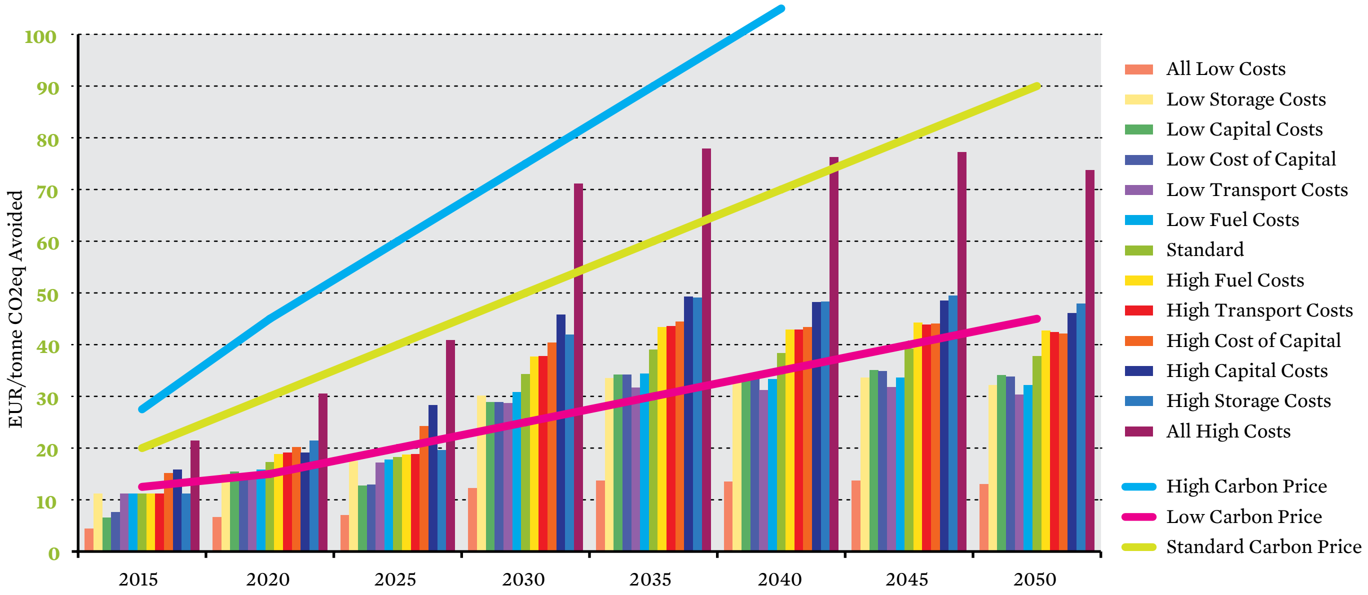
Due to the significant uncertainty surrounding many of the future costs of CO_2 and CCS, a sensitivity analysis was carried out on the impacts of changes in CO_2 price, capital costs, the cost of capital, transport costs, storage costs, and fuel costs for the Full and No Deployment cases. The limits used for each variable are given in Table 9; Figures 5 and 6 show the results of the analysis. [35]

Given a CO_2 price close to or higher than the nominal value adopted in this roadmap, the key result remains the same under even extreme values of any one cost parameter: widespread deployment of CCS becomes profitable sometime between 2025 and 2035. Only in the case when every cost parameter is set to its highest value does this finding change – but even then, CCS becomes money-saving within the timespan of the scenario in 2045. Similarly, in the case of a very low CO_2 price, Full deployment of CCS under our nominal cost model becomes cheaper than not acting by 2045. Only when all economic forces are aligned against CCS – in the case of a low CO_2 price and multiple high CCS costs – does the No Deployment Scenario become less costly than its Full Deployment counterpart. In almost every other case in our analysis, Full deployment of CCS makes economic as well as environmental sense.

35 The capital costs of CCS are further influenced by very local parameters such as cost of land, infrastructure development or interest cost during construction which apply in a different manner to each site.

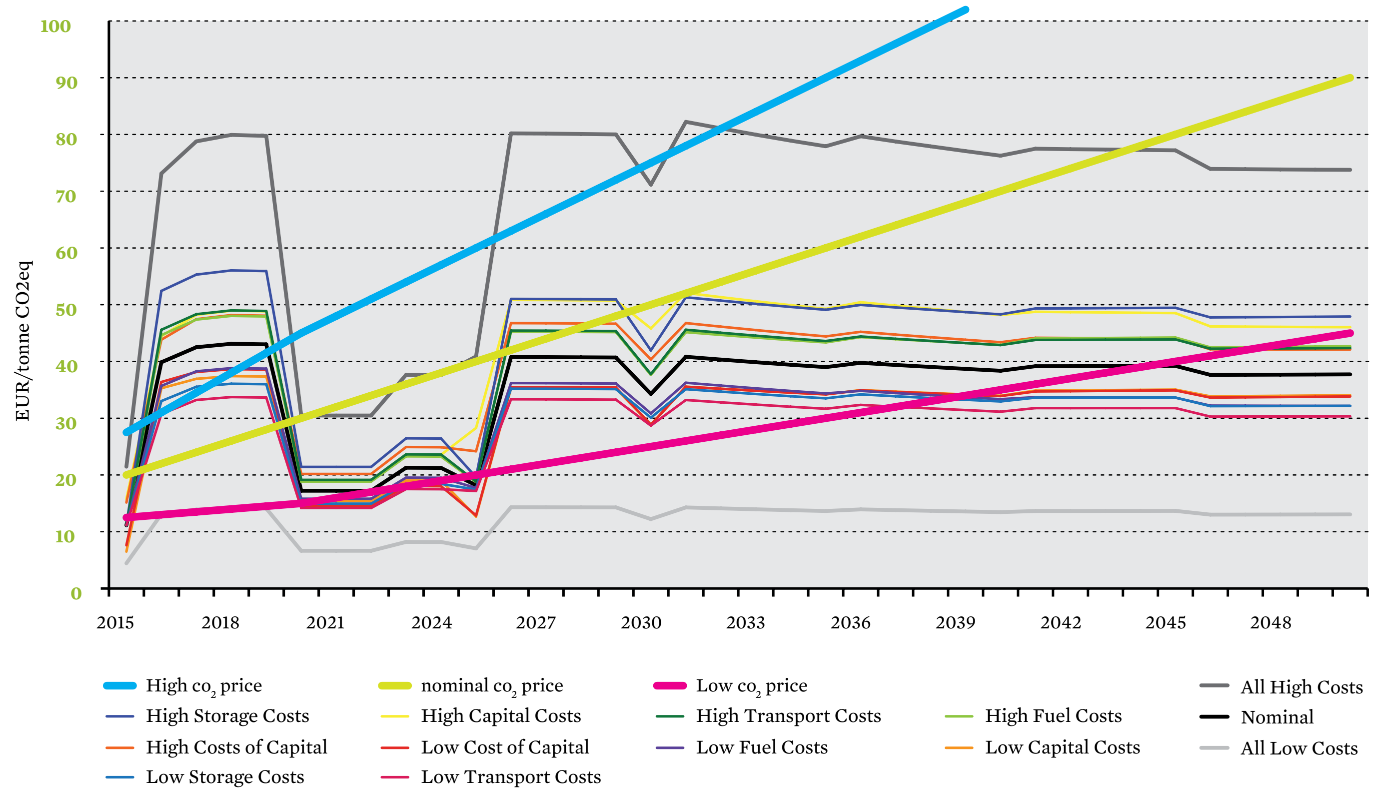
SENSITIVITY OF CO_2 AVOIDANCE COSTS IN THE POWER SECTOR

Figure 5: *Sensitivity of CO_2 avoidance costs in the power sector to key cost parameters.*



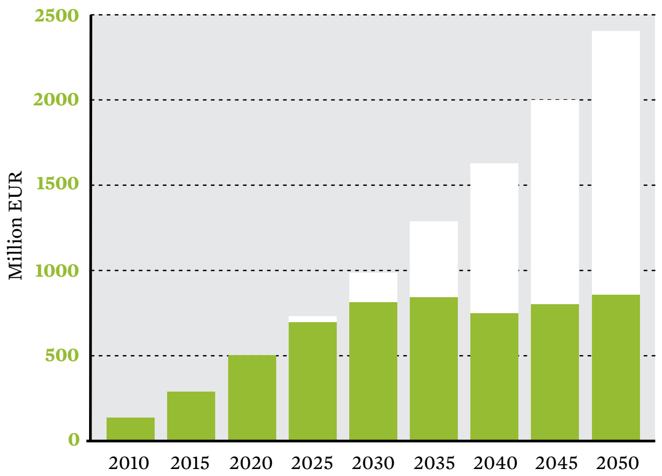
CO_2 AVOIDANCE COST

Figure 6: *Sensitivity of CO_2 avoidance costs in the power sector to key cost parameters.*



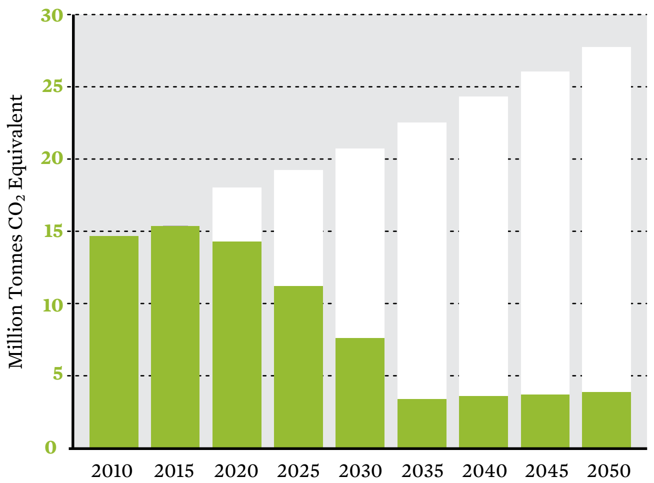
AVOIDED COSTS IN INDUSTRY

Figure 7: *Avoided CO_2-related costs in industry with full CCS deployment.*



AVOIDED GHG EMISSIONS IN INDUSTRY

Figure 8: *Avoided GHG emissions in industry with full CCS deployment.*



2.3.1 IMPACT OF CCS APPLICATION ON INDUSTRY

The Full Deployment Scenario sees a complete application of CCS to large point source industrial emitters by 2035. The economic impacts of this policy are shown in Figure 7; industry with CCS becomes less costly than industry without as early as 2025, with very significant savings – of more than 50% of CO_2 related costs – by 2040. These savings comes from a substantial decrease in sectoral emissions and associated EUA costs, as shown in Figure 8.

In addition to the environmental benefits of reduced emissions, these results suggest that applying CCS widely – both to industry and to the power sector – will reduce both energy and operating costs, making national industry more competitive.

2.3.2 CLIMATIC IMPACT OF CCS APPLICATION

The application of CCS in the power sector and the industry would bring about a significant decrease in the amount of emitted emissions in Greece. Table 10 and Figure 9 present 10-year snapshots of economy-wide emissions, as well as those specifically from the power and industry sectors. Lack of CCS deployment is projected to lead to a stable increase of emissions in the industrial sector in line with economic development and a moderate decrease of emissions in the power production sector mainly due to lignite phase out and RES deployment. Total emissions from both power and industry sectors would decrease by 20%, from 69.7 Mt to 55.3 Mt between 2010 and 2050.

Moderate CCS deployment under the Constrained scenario projections would result in evident emission cuts in the power sector. Modest application of CCS in existing and projected natural gas and lignite units would render possible significant, yet incremental, emission reductions in the energy sector leading to a nearly carbon free energy sector by 2050. No CCS application in industrial units is envisaged in the Constrained scenario, hence emissions as a result of industrial activity are in line with the No deployment scenario.

Wide and swift application of CCS in both the industry and the power sector along with a broad introduction of biomass co-firing, as envisioned in the Full deployment scenario, would lead to emphatic emission abatement. The Greek power sector would become carbon negative by 2030, while the industry would be virtually carbon neutral by 2050. The combined emissions in both sectors would amount to just 2.7 Mt by 2050 compared to almost 70 Mt today.

TOTAL EMISSIONS

Table 10: *10-year snapshots of total emissions under the 'No deployment', 'Constrained deployment' and 'Full deployment' scenarios.*

Total emissions (Mt CO_2eq)		Power	Industry	Total CCS sector	Total Economy
2010	**No Deployment**	**55**	**14,7**	**69,7**	**123,2**
	Constrained Deployment	**55**	**14,7**	**69,7**	**123,2**
	Full Deployment	**55**	**14,7**	**69,7**	**123,2**
2020	**No Deployment**	**40**	**18**	**58**	**111,8**
	Constrained Deployment	**39,2**	**18**	**57,2**	**111**
	Full Deployment	**32**	**14,3**	**46,3**	**96,4**
2030	**No Deployment**	**31,4**	**20,6**	**52**	**108**
	Constrained Deployment	**16**	**20,6**	**36,6**	**92,6**
	Full Deployment	**-1,5**	**7,6**	**6,1**	**49**
2040	**No Deployment**	**29,4**	**24,3**	**53,7**	**113,8**
	Constrained Deployment	**7,6**	**24,3**	**31,9**	**92**
	Full Deployment	**-0,8**	**3,6**	**2,8**	**42,2**
2050	**No Deployment**	**27,6**	**27,7**	**55,3**	**119,3**
	Constrained Deployment	**2**	**27,7**	**29,7**	**93,7**
	Full Deployment	**-1,1**	**3,8**	**2,7**	**42,9**

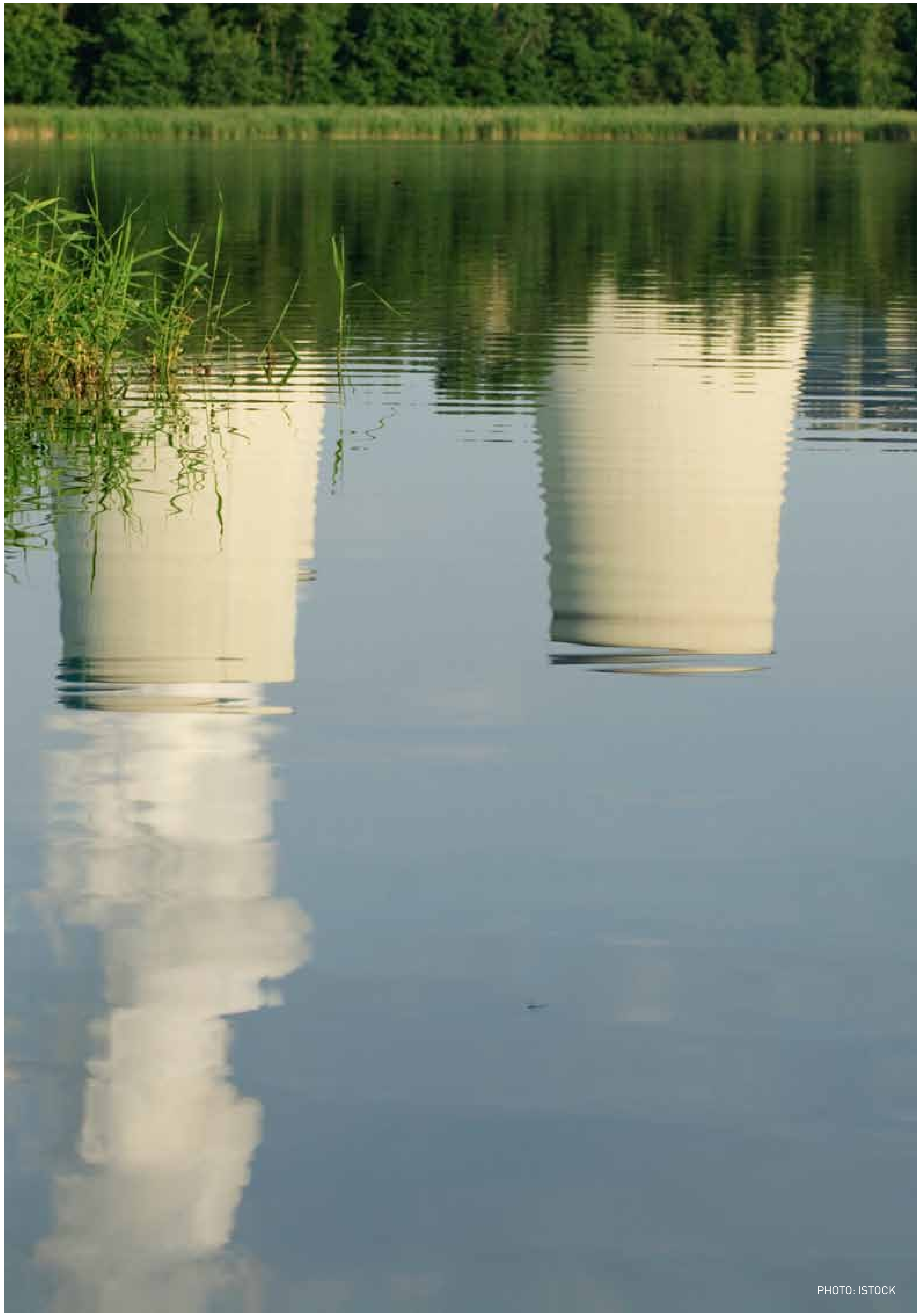
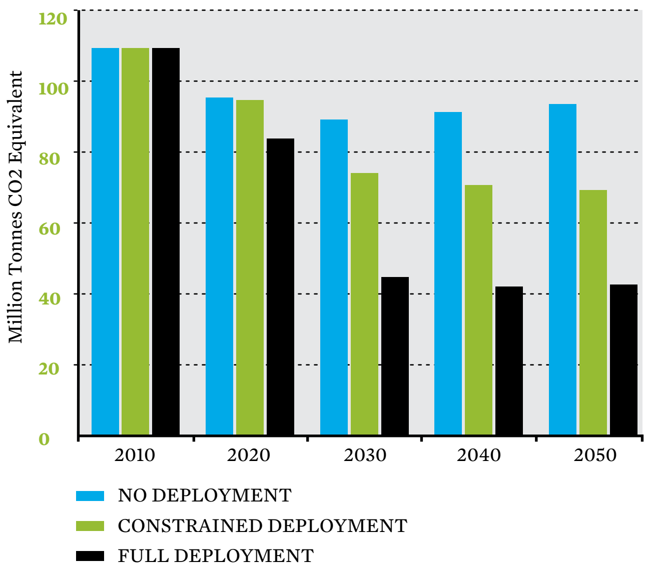


PHOTO: ISTOCK

FULL ECONOMY GHG EMISSIONS

Figure 9: *Full economy emissions for 'No deployment', 'Constrained deployment' and 'Full deployment' scenarios.*



2.3.3 ECONOMIC IMPACT OF CCS

Based on existing long-term projections regarding the cost of CCS and EU carbon prices, the application of CCS in power production and industrial units appears as a rational economic choice. The wider and swifter the application of CCS, the greater the economic benefit is going to be for Greece. Table 11 displays 10-year snapshots of aggregated carbon and CCS costs, while Figure 10 shows the total cumulative CO_2-related costs of each scenario, and Figure 11 compares the impact on electricity price of each scenario.

Absolute lack of CCS deployment in Greece leads to a significant cost increase between 2010 and 2050 given the expected increase in EUA prices in conjunction with the projected continuous operation of several unabated emission intensive units in the country until 2050 and beyond. The 'No deployment' route remains only barely less expensive until 2020 compared to the 'Full deployment' scenario, and eventually becomes two times more expensive than the CCS scenarios by 2050 (see Table 11).

Moderate CCS deployment in the power sector would bring about significant cost reductions in power production. As the Constrained development scenario indicates modest CCS application would become economically appealing from 2030 onwards compared to No CCS deployment. Nevertheless Constrained CCS deployment remains less costly than wide deployment only until 2027.

Indeed, wide deployment of CCS in the power and industry sectors proves to be the most financially beneficial option as indicated by the 'Full deployment' scenario. Proactive and fast application of CCS in all sectors would reap significant economic benefit for the country on a yearly basis from 2025 onwards, constituting it the rational choice in economic terms when compared to the other two examined scenarios.

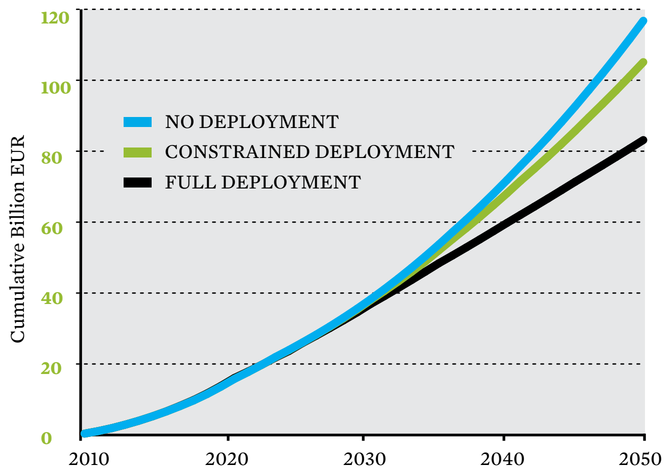
CARBON AND CCS COSTS

Table 11: *Carbon and CCS costs. 10-year snapshots of carbon & CCS costs under the 'No deployment', 'Constrained deployment' and 'Full deployment' scenarios.*

Carbon & CCS Costs (Billion EUR)	No Deployment	Constrained Deployment	Full Deployment
2010	**0.55**	**0.55**	**0.55**
2020	**1.681**	**1.686**	**1.712**
2030	**1.551**	**1.55**	**1.439**
2040	**2.053**	**1.542**	**1.378**
2050	**2.466**	**1.342**	**1.238**
Total Cost	**66.293**	**54.169**	**50.585**

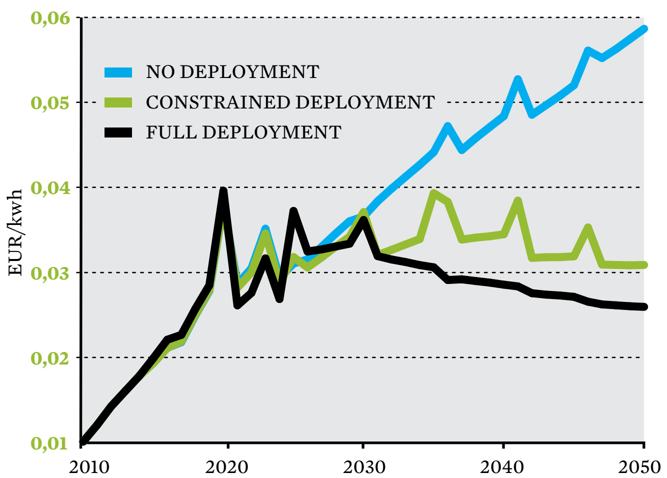
ECONOMY-WIDE CUMULATIVE COSTS

Figure 10: *Economy-wide cumulative costs for 'No deployment', 'Constrained deployment' and 'Full deployment' scenarios.*



ELECTRICITY PRICE IMPACT

Figure 11: *Fossil sector electricity price impact for 'No deployment', 'Constrained deployment' and 'Full deployment' scenarios.*



2.4 CO_2 STORAGE OPTIONS

It has been stated that CO_2 storage within the Greek territory could be difficult due to a relative lack of storage capacity as well as potential complications as a result of high seismicity levels. This statement indicates a need for a strengthening of research and elaboration regarding storage potential in Greece and should not be used as a reason to dismiss discussion altogether. According to current estimations, Greece already has one underground storage site, located in an area with low seismic activity, where CO_2 storage could commence immediately. What is more, overseas CO_2 storage is also an attractive option that could lead to strong intersectoral synergies.

2.4.1 POTENTIAL DOMESTIC CO_2 STORAGE SITES

According to the report carried out under the Geocapacity study for Greece a number of formations could be considered as perspective sites for CO_2 underground storage within the area of Greece[36]. Geocapacity estimates a total storage capacity of 2190 Mt CO_2 in Greece[37]. The candidate geologic formations where CO_2 could be stored in the long term are mostly situated in Northern Greece (see table below). These formations are a part of the Mesohellenic Trough, of the Thessaloniki basin and of the Prinos basin based also on the results of a preliminary assessment of the suitability of tertiary sedimentary basins in Northern, Western and Eastern Greece (Koukouzas et al, 2009)[38]. The locations have a close proximity to main CO_2 emissions sources, namely the lignite-fired power plants situated in Western Macedonia as well as a number of cement factories and oil refineries. Especially the Prinos basin offers adequate infrastructure, due to the ongoing exploitation of hydrocarbon resources conducted in the area. According to most experts CO_2 storage could commence immediately at Prinos, while the W. Thessaloniki basin also offers an attractive CO_2 storage option.

The Kallirachi and the South Kavala oil fields in the Prinos sedimentary basin could be considered for CO_2 storage. Other long term prospective CO_2 storage options are the offshore oil field in the Katakolon area (NW Peloponnese) and the onshore oil field in the Katakolon area (NW Peloponnese) and the onshore gas field in the Epanomi area (near Thessaloniki), both proven deposits that have not yet been developed[39] (Koukouzas, 2007). The onshore East Katakolon and the Epanomi gas fields are considered to be too small to have significant CO_2 storage potential. CO_2 storage in abandoned coal mines does not look as an exceptionally possible option for Greece. According to Geocapacity, out of 27 identified mines, CO_2 storage was deemed possible only in the Kimi and Aliverion (in Evoia island, West of Athens) mines, given that both mines are in a good condition and have sufficient storage potential. Yet according to a report prepared for the Greek Regulatory Authority for Energy (RAE), given the shallow depth of the mines (800 meters), future CO_2 storage there should probably be disregarded[40].

Visualisations of storage potential under the No and Constrained deployment scenarios are presented in Maps 2-5, whereas the Full deployment scenario is presented in chapter 4, on Map 6.

MAIN CURRENT POTENTIAL CO_2 STORAGE SITES IN GREECE.

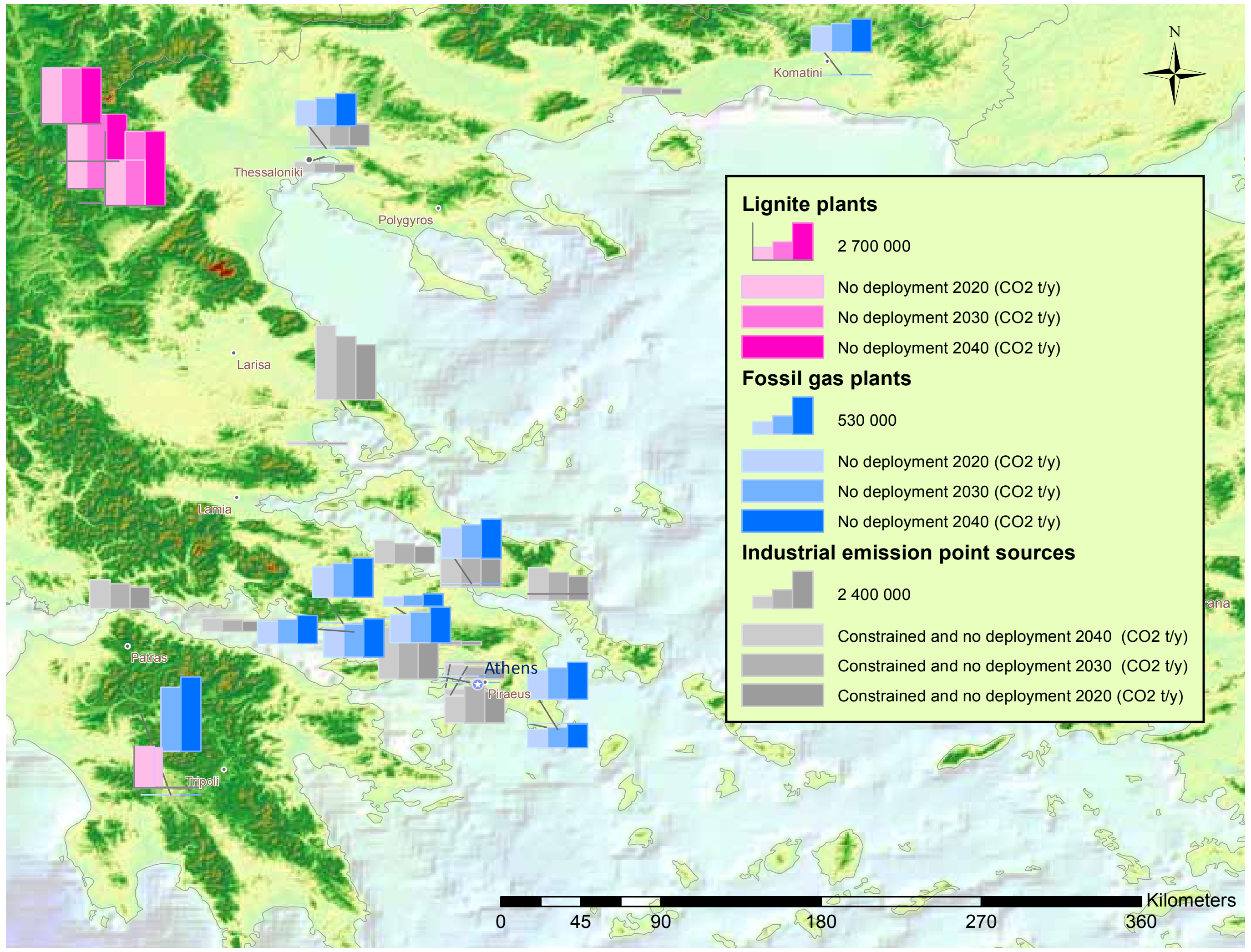
Table 12: *Main current potential CO_2 storage sites in Greece according to GESTCO report with additional data from RWE's 'CO_2 Storage Technologies Overview[15]'.*

Formation name	Depth to top of aquifer (m)	Average thickness (m)	Storage capacity (Mt CO_2)	Average porosity (%)	Average permeability	Top seal quality
Prinos	**2400**	**260**	**1343**	**18**	**50mD**	**v. good**
Alexandria	**900**	**180**	**34**	**8**	**60mD**	**good**
Messohelenic Though	**1000**	**n/a**	**360**	**10**	**estimated to be low**	**good**
W. Thessaloniki Sand stone	**2400**	**21**	**145**	**10**	**n/a**	**v. good**
W. Thessaloniki	**1200-2400**	**100**	**460**	**10**	**60mD**	**v. good**

36 For further information on the Geocapacity project on European potential for geological storage of CO2 please see http://www.geology.cz/geocapacity/publications/D16%20WP2%20Report%20storage%20capacity-red.pdf
37 The total conservative estimate from the Geocapacity study is comprised of 184 Mt in aquifers (effective), 1936 Mt in aquifers (theoretical) and 70 Mt in hydrocarbon fields (effective). Aegean Energy refer to a storage potential of 75 to 95 Mt in their Prionos A, B and C reservoirs in addition to deeper Prinos` horizons and aquifers.
38 Koukouzas et at (2009) 'Preliminary assessment of CO_2 geological storage opportunities in Greece, Int. J. of Greenhouse Gas Control 2009; 3(4):502-513)
39 See detailed information regarding the specific characteristics of mentioned storage sites presentation in presentation by N. Koukouzas (2007) 'CO_2 and CCS potential in Greece' http://www.ccs-net.gr/PDM/Seminar%20PDM%20Overview.pdf
40 For the full RWE report prepared for RAE see http://www.rae.gr/K2/CleanCoal/T2.pdf

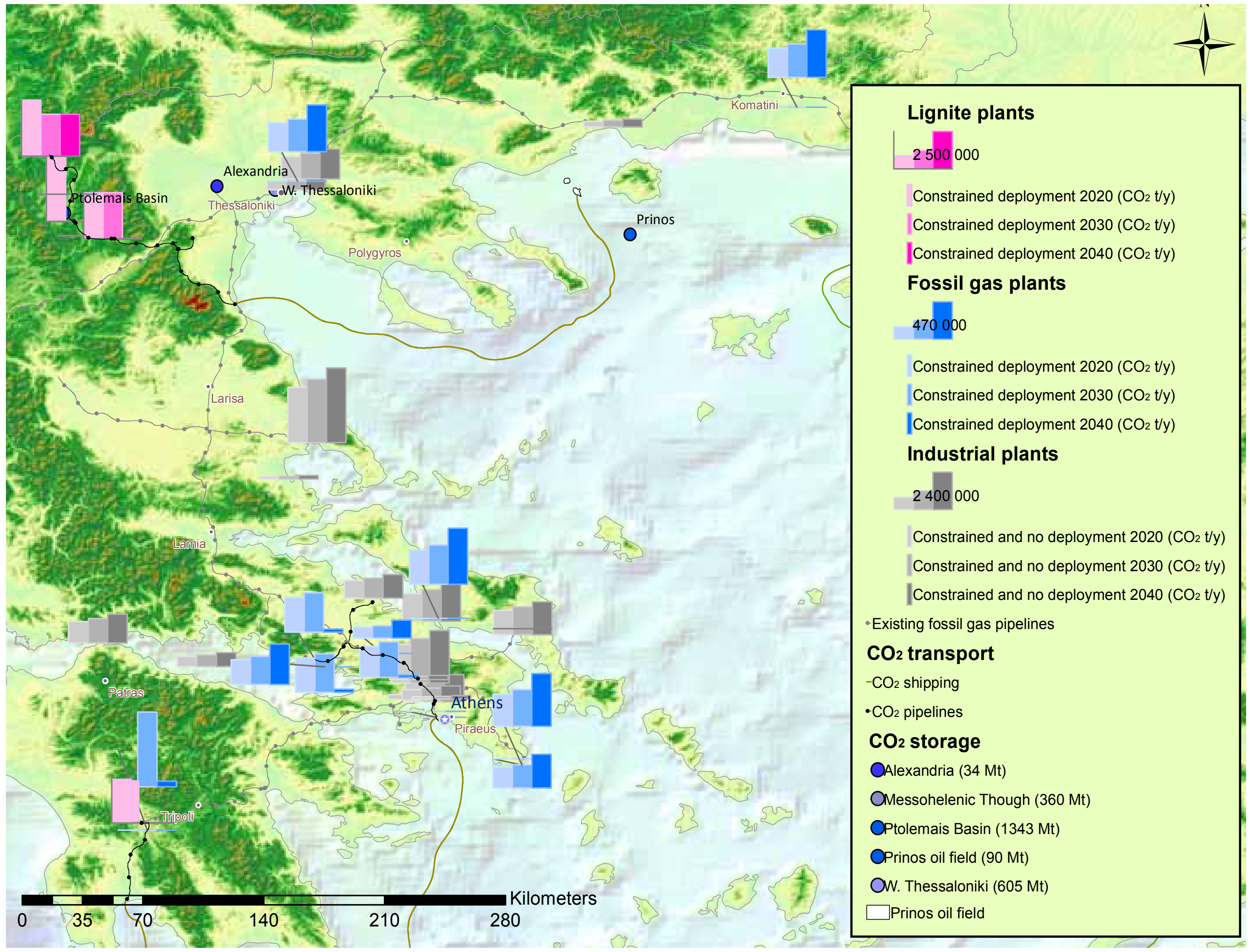
TOTAL CO_2 EMISSIONS UNDER THE NO DEPLOYMENT SCENARIO

Map 2: *The map shows total CO_2 emission scenarios for 2020, 2030 and 2040 given No CCS deployment in Greece. The size of the columns represents the amount of yearly CO_2 emissions, whereas the shades represent 2020, 2030 and 2040 projections.*



TOTAL CO_2 EMISSIONS UNDER THE CONSTRAINED DEPLOYMENT SCENARIO

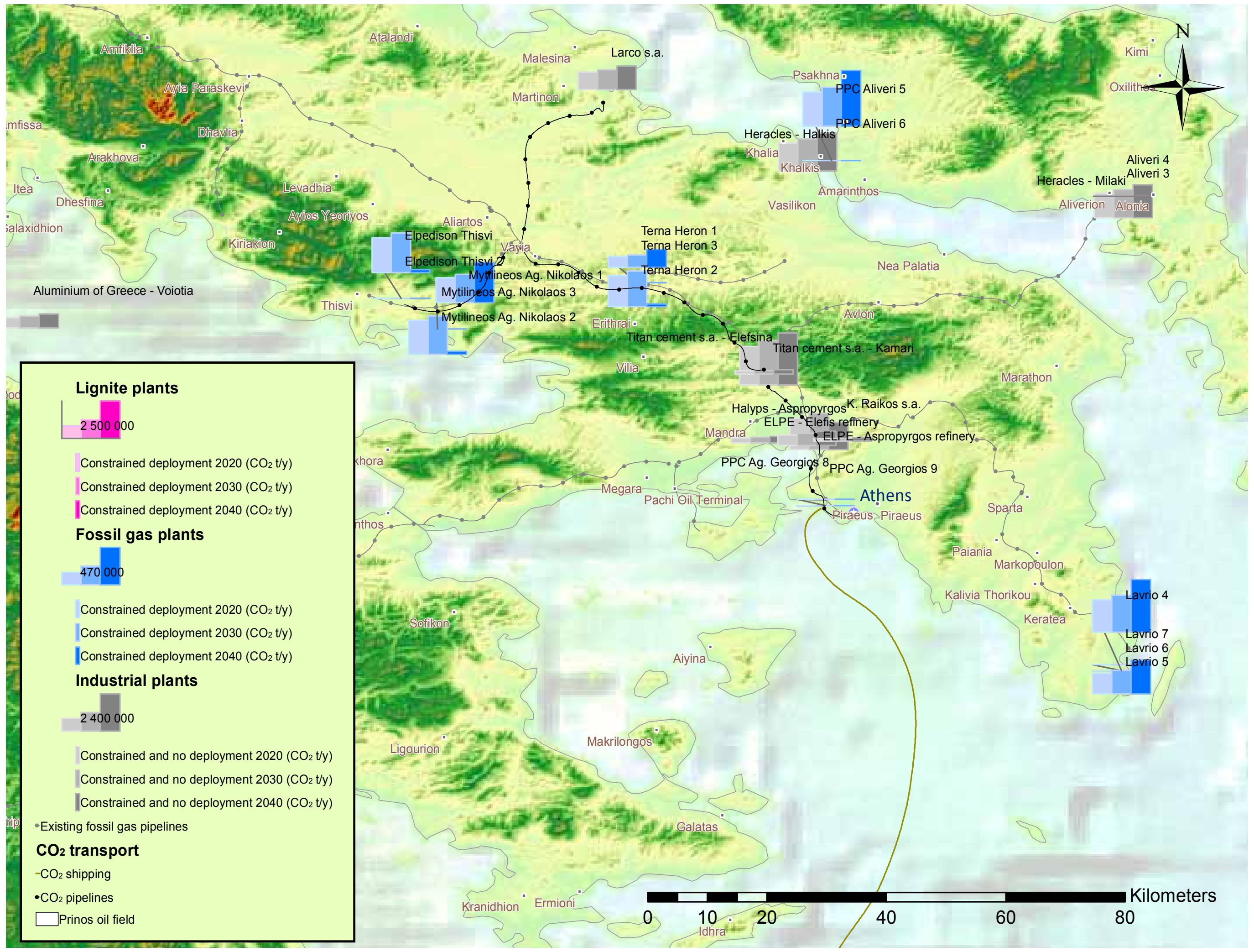
Map 3: *The map shows total CO_2 emission scenarios for 2020, 2030 and 2040 given a Constrained CCS deployment in Greece. Some CO_2 from the Northwestern lignite hub is stored in the Prinos oil field. The remaining captured CO_2 is stored in aquifers in the Prinos and Thessaloniki basins or shipped to storage places abroad.*[41]



41 For more precise information on the current emission sources, please see Map 1. For interactive overview of all major CO_2 emission sources in Greece, consult the interactive map at http://www.bellona.org/ccs.

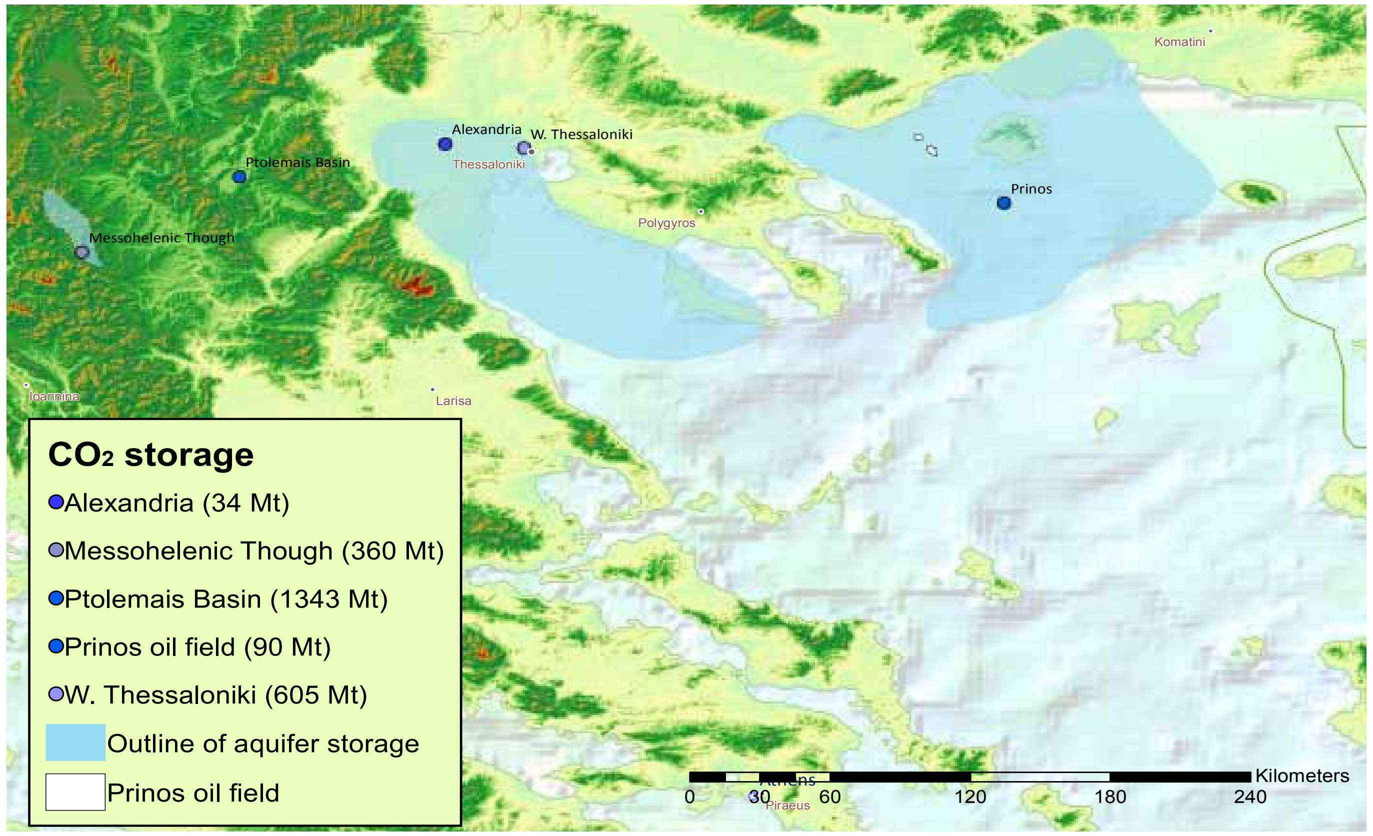
DETAIL OF MAP 3 SHOWING THE MAIN CO2 POINT EMISSION SOURCES IN THE ATHENS AREA

Map 4: *The map shows total CO_2 emission scenarios for 2020, 2030 and 2040 given a Constrained CCS deployment in the Athens industrial region. The captured CO_2 in this area is shipped to North Africa for storage purposes.*



CO_2 STORAGE OPPORTUNITIES IN NORTHERN GREECE

Map 5: *The map shows a close-up of the Prinos and Thessaloniki basins. Both the Constrained and Full deployment scenario includes storage in the Prinos oil field (the outline of the oil-field is marked in white in the NW part of the Prinos Basin).*



↘ 2.4.2 POTENTIAL OVERSEAS CO_2 STORAGE SITES

A very interesting prospect for Greece could well be the overseas transportation and subsequent storage of domestically emitted CO_2. Transportation of CO_2 abroad could take place either via an interstate pipeline network or by specially modified ships. Maritime transport of CO_2 could turn into a highly interesting aspect of CCS for the Greek shipping industry, which is the biggest globally.

Probably the country best equipped to accept Greek CO_2 via an extended onshore pipeline network would be Romania. With its history of hydrocarbon production, Romania offers also an abundance of depleted hydrocarbon fields that could serve as potential storage recipients of Greek CO_2[42]. This option could possibly materialise as part of an extended south eastern European undertaking that would establish a regional agreement for transport and storage of CO_2 from major emission points and would set the ground for the implementation of Balkan CO^2 transportation infrastructure.

As regards CO_2 transportation abroad, maritime transfer of CO_2 could prove a very interesting prospect for the Greek shipping community and lead to significant synergies. Currently a number of the world's operators of gas carriers are studying the possibility of constructing the dedicated CO_2 carrier fleets that the anticipated CCS schemes would require[43]. The carriage of the CO_2 yield from CCS projects is indeed anticipated to open up a large new market for gas carrier operators from which the Greek shipping community should not be absent.

Gas and oil producing countries of Northern Africa would be in a position to store Greek CO_2 excesses transported via ships. Algeria, for instance, is a Northern African state that has already begun seriously testing CCS on its territory. [44]

↘ 2.4.3 AN EARLY OPPORTUNITY FOR CO_2 STORAGE

An opportunity to deploy achieve CCS in a faster an more economical way is to use the anthropogenic CO_2 as a resource to enhance petroleum production. The deployment of CO_2 for EOR[45] has the potential to kick off the Full deployment of CCS. CO_2 for EOR makes CCS projects profitable, or, for low oil prices at least less costly. Studies estimate that an incremental oil recovery of 3-18.9% is achievable by CO_2 for EOR, depending on lithologies and heterogeneity of the producing reservoir (Ferguson et al. 2009 and Aam et al. 2010)[46].

Aegean Energy refers to an estimate for the stored amount of the CO_2 associated with EOR operations of 75 to 95 Million tones of CO_2. CO_2 in EOR operations could be permanently stored at a greater proportion under suitable CO_2 pricing conditions or under stricter CO_2 emissions regimes.

42 For a detailed account of Romanian storage potential see www.zeroemissionsplatform.eu/downloads/465.html
43 See for instance partnership of Maersk, Hyundai and DNV to collaborate on the design and risk assessment of tankers for shipping CO2 http://www.marinelink.com/news/tankers-maersk-design334807.aspx

44 See more about the In Salah project http://www.insalahco2.com/index.php?option=com_content&view=frontpage&Itemid=1&lang=en
45 Enhanced Oil Recovery is a generic term for techniques for increasing the amount of crude oil that can be extracted from an oil field. Injection of CO2 in mature fields can be used for enhanced oil recovery.
46 R. C. Ferguson, C. Nichols, T. Van LeEuwen, and V. A. Kuuskraa. Storing CO2 with enhanced oil recovery. Energy Procedia 1, pages 1989-1996, 2009. GHGT-9 Proceedings.
K. Am, F. Al-Kasim, N. Bjerkedal, A. C. Gjerdseth, S. E. Kindem, A. Skauge, T. Skjaerpe, B. A. Sund, J. J. Saetre, and R. Wiborg. Increased production on the Norwegian continental shelf. Technical report, Oil and Energy department – Norway, 2010.

3.0 CHALLENGES AND RECOMMENDATIONS

The scenarios described in the previous chapter are all possible outcomes. Which scenario the future will resemble the most will depend on a huge number of factors. Many of these are beyond the reach of climate and energy policies – such as population and economic growth, or technological breakthroughs. On the horizon of 2050, these may well prove to be the most significant for the greenhouse gas emissions in this model. However, under the assumptions used for the scenarios in this report, certain factors are more significant than others for ambitious climate change mitigation and widespread deployment of CCS in Greece.

These factors point to a set of challenges for CCS. Some challenges need to be overcome immediately for a first demonstration project, possibly co-financed under NER300. Others are more relevant for the later deployment phase, when technological and financial uncertainties have been resolved. Overcoming demonstration phase challenges is of course essential to move on the deployment phase. But tackling challenges to deployment now by providing certainty on long-term incentives will also encourage private investment in demonstration projects.

3.1 SEEING IS BELIEVING: MAKING DEMONSTRATION A REALITY

As has been suggested, timely application is key towards wider and effective deployment of CCS. An early CCS project in Greece, possibly co-financed by the EU under the NER300[47], is an immense opportunity as well as a big challenge.

3.1.1 PUBLIC FUNDING

A potential CCS (transport and storage costs included) project at 'Ag.Dimitrios 5' could cost about €900 million in capital expenditure and operating expenditure over the next 10 years, on a net basis after taking account of avoided EUA expenditure/sales of EUAs. At present, there are no firm pledges to fill this gap. If a Greek CCS application under NER300 is successful, 50% of the €900 million net funding gap could be filled. Large power companies, such as PPC, with a significant amount of high-carbon assets in their portfolio could be willing to meet some of the remainder as part of a hedging strategy against future EUA price hikes. In all likelihood, however, investors will require government action to contribute as well. This is the real reason why some politicians and NGOs argue against CCS - a fear that CCS demonstration projects will divert limited public resources. Environmentalists have argued that such projects would divert resources away from renewable energy sources and energy efficiency.

47NER300 is a financing instrument managed jointly by the European Commission, European Investment Bank and Member States setting aside 300 million emission allowances in the New Entrants' Reserve of the European Emissions Trading Scheme for subsidizing installations of innovative renewable energy technology and CCS. CCS projects which are selected for support through the NER300 mechanism will have 50 per cent of their "relevant costs" funded which are defined to mean "additional costs", being those costs that are net of operating costs and benefits, arising during the first 10 years of operation. For further information see http://ec.europa.eu/clima/funding/ner300/index_en.htm

PHOTO: ISTOCK

Is this really so? How can the Greek government at a time of economic recession and extreme budgetary crisis be convinced to allocate funding to a costly project whose benefits will only appear some years ahead hence? And how can this be done without diverting resources away from other climate change mitigation options?

Firstly, loan guarantees could have a significant cost reducing impact for the project. Effectiveness assessments of the different public support schemes point out that the first CCS demonstration projects may be largely equity-financed as commercial debt is not an option for such first of a kind projects (Al-Juaied, 2010)[48]. Equity requires a much higher rate of return than the interest rate on debt, and CCS projects will have significant capital expenditure over several years before revenue streams commence. If the government can provide a loan guarantee, the debt/equity ratio may be significantly increased, the interest rate further reduced and overall costs significantly lowered. Al-Juaied (2010) finds that even if a 7.5% risk premium is charged for the loan guarantee, the overall cost reduction is as high as 30% compared to the base case for a CCS demonstration project.

Secondly, there are public international funding streams potentially available as they carry certain strings with them that could make CCS demonstration projects good candidates. Greece will receive up to €20.5 billion in EU structural funds for the period 2007-2013. Absorption rates of the 2007-2013 structural funds in Greece thus far have been exceptionally low. In case not used otherwise, funds for the region of Western Macedonia under the European Regional Development Fund could be used to co-fund a CCS project in the region that would be both environmentally friendly and ensure the sustainment as well as creation of jobs in the region. Greece will be an eligible recipient for EU structural funds for the next period of 2014-2020.

Thirdly, a dedicated CCS levy could be introduced on electricity bills, as is planned in the UK. The collected funds would pay for CCS demonstration projects, to be selected through a competitive process. It would put an extra cost on electricity consumers but would not divert resources from other climate change mitigation tools. It would in effect work like a combination of green certificates and feed-in tariffs to stimulate renewable energy sources: Like feed-in tariffs, it would be targeted at CCS, and somewhat like the market for green certificates, the competitive process would ensure best value for public money.

3.1.2 MAKING CO_2 STORAGE LEGAL

Establishing a solid legal framework for CO_2 storage is of outmost importance in order to create the necessary certainty and confidence for investors and companies to realise an early CCS project and subsequently set long-term plans. The EU has addressed that need by adopting Directive 2009/31/EC on the geological storage of carbon dioxide which needs to be transposed by all Member States by June 2011. The Directive lays down extensive requirements to address all potential risks to human health or the environment covering the entire lifetime of a CO_2 storage site. The Directive requires EU Member States to determine whether and where CCS will take place on their territory.

For the moment, the political stance of the Greek government regarding Directive 2009/31/EC is unclear and no steps whatsoever have been taken for its transposition. Furthermore, there is as yet no indication as to whether Greece will eventually decide to allow domestic CO_2 storage. Quick and positive disambiguation of this situation is urgently needed. The Greek government has to take rapid and decisive steps to transpose Directive 2009/31/EC in such a way that allows safe CO_2 storage in selected areas within its borders paving the way for an early CCS project. Several Member States, such as Spain, have already adopted this directive and their experience may be valuable for Greece to adopt a text that would best suit its specificities[49] .

3.1.3 REAPING LOW-HANGING FRUITS

EOR at Prinos could be important in rendering an initial Greek CCS project financially viable. Prinos oil fields in the waters off Eastern Macedonia-Greece are mature oil fields with declining oil production presently 'approaching the field economic limit' (Tingas et al 2008)[50]. 'Water-flooding has been implemented to the Prinos oil field from the production start-up' (ibid.). High residual oil saturation indicates significant EOR potential by injection of gases, such as CO_2, which may bring about an incremental oil recovery of 10-15% , which translates into about 30 million barrels or €1.9 billion with current oil prices (Aegean Energy (Aegean Energy, 2010)[51 52].

Given that oil extraction from Prinos is declining, CCS with EOR could result in a significant prolongation of the lifetime of the field while producing important economic benefit. Currently, Aegean Energy has a permit to operate the Prinos oil field until 18/06/2013 after which time part of the current infrastructure at Prinos might be dismantled rendering future CO_2 storage in the area with the added benefit of EOR yet more complicated[53] . Hence based on declining oil reserves in Prinos and an expiring operation permit, the time looks right for a CCS project now. What is more, an extension of the permit to the current operator of Prinos would provide the necessary certainty and prepare the ground for a Greek project under NER300.

48 Al-Juaied (2010) 'Analysis of Financial Incentives for early CCS Deployment' http://belfercenter.ksg.harvard.edu/files/Al-Juaied%20Analysis%20of%20Financial%20Incentives%20web.pdf

49 See http://www.bellona.org/news/news_2010/spain_EU_directive
50 Tingas et al (2008) 'Synergies and Environmental Benefits of Lignite Gasification in Ptolemais with Combined CO2 Sequestration and Enhanced Oil Recovery in the Prinos Oil Fields in Macedonia-Greece' http://www.onepetro.org/mslib/servlet/onepetropreview?id=PETSOC-2008-175&soc=PETSOC
51 Aegean Energy (2010) 'Corporate Overview' http://www.energean.com/assets/files/images/Profile/Aegean%20Energy%20Corporate%20Profile.pdf
52 Oil price extracted from Bloomberg index see http://www.bloomberg.com/energy/
53 See permit prolongation in Greek here http://www.ypan.gr/docs/d.t(16%204%2008)paratasi%20adeiwn%20ekmetaleusis.doc

Furthermore, when no more oil can be extracted from the Prinos oil-field and if its operation is not prolonged, through the use of means such as CO_2 injection, then the relevant law (N 2779/99) for reasons of environmental protection would oblige the Greek state to seal the existing 52 wells and dismantle standing infrastructure. This would bring about public costs amounting to about €60-70 million. This would also automatically mean that future CO_2 storage at Prinos would require new investments in drilling and infrastructure, such as platforms.

Hence, based on declining oil reserves in Prinos and an expiring operation permit, the time looks ripe for a CCS project now. An extension of the permit to the current operator of Prinos – given a government requirement to the operator for using CO_2 for EOR - could save the Greek state from additional costs and prepare the ground for a Greek project under NER300.

3.1.4 ENSURING PUBLIC SUPPORT

CCS would not make much sense to the public if not put into perspective of general climate change policy and its economics. Taking into account low current levels of awareness, a timely development of sincere dialogue with the local communities where a CCS project could be built has proven essential to the existing demonstration projects. There are several examples such as that of Barendrecht in the Netherlands, Schleswig-Holstein and Schwarze Pumpe in Germany that have shown how local opposition to CO_2 storage projects may effectively delay projects. Conversely, successful CCS projects such as Otway in Australia or Ivanic in Croatia have shown that true dialogue is possible and key to projects' success.

A concerted dialogue to ensure public and most importantly local support for CCS, for instance in the lignite hub of Western Macedonia, is an essential precondition for investment decisions. There must also be an answer to the question 'what's in it for us?' asked by communities living in proximity to storage sites. For EOR, there will be jobs. But if there are no jobs, there may be a need for introducing a mandatory storage fee that falls to local municipalities or land-owners. This is the approach taken in Poland and Germany in the implementation of the EU CO_2 storage directive 2009/31/EC.

It is crucial that outreach activities on issues such as storage safety and monitoring or pipeline construction and permitting is done mainly by independent technology and communication experts, not by the companies that have a self-interest in the projects and should begin at very early stages of project planning. As a very first step, outreach material on CCS in Greek would be a very beneficial way to give local communities and the public at large the opportunity to explore CCS and its climate and economic benefits.

3.2 REALIZING THE POTENTIAL: DEPLOYMENT

The first full-scale CCS demonstration project will naturally be an essential stepping stone for further deployment of CCS. The experience gained will probably lead to changes in CCS deployment plans of companies as well as of the government. It may demonstrate that some challenges have been exaggerated, while other unknown challenges may appear. Yet, a number of likely challenges and avenues for overcoming them can already now be pointed out.

3.2.1. ELECTRICITY PRICES

In the absence of climate change legislation, power generation with CCS will always add costs compared to unabated fossil alternatives. It is highly unlikely that the Greek Treasury in the foreseeable future will be able to foot this bill. It means that widespread CCS deployment could be made competitive through market-based mechanisms, such as CCS subsidies paid over electricity bills or through a CO_2 tax on top of the EUA price. Currently, electricity rates in Greece are regulated and among the lowest in the EU as they do not fully include CO_2 emission costs[54]. The result of a CCS levy or a CO_2 tax would be higher electricity prices. This might encourage investment diversion to Turkey, Albania or FYROM with no climate policy constraints on fossil power generation, or even to Bulgaria with which there is already a 650 megawatt interconnection line. To counteract this, obligations (such as payment of a CCS levy or CO_2 tax) could be put on each kilowatt-hour of electricity distributed, not generated. Foreign and domestic electricity producers would then have a level playing-field.

This could, however, create a competitive disadvantage for some electricity-intensive industries, mainly aluminium and steel plants, as their products would become more expensive compared to those of foreign competitors. In Greece, this would mainly concern the two existing aluminium and ferronickel production units (Aluminium of Greece and Larco) located just north of Athens (see Map 1). The unabated operation of these units though could, however, become financially unattainable with rising EUA prices although this will depend on future allocation methods of EUAs.

54 See comparative report of EURtat 'Electricity Prices for second Semester 2009' http://epp.EURtat.ec.europa.eu/cache/ITY_OFFPUB/KS-QA-10-022/EN/KS-QA-10-022-EN.PDF

3.2.2 COMPETITIVENESS OF INDUSTRY

CCS for processing industries could both be amongst the first and the last types of CCS applications. Steel and cement industries[55] offer a large potential for CCS. Costs are yet uncertain, as plants need complete reconfiguration for CCS: CO_2 concentrations are high (up to 20-25%) but take place at different steps of the manufacturing processes. In any case, it is likely that the cost will not be too unlike that of CCS at coal-fired power plants. CCS deployment may therefore require incentives additional to the emissions trading scheme (ETS) on this side of 2030.

Just like incentives for CCS in the power sector, this may increase costs significantly compared to steel and cement producers outside Greece. This competition distortion could be counteracted by border tax or other adjustments to the price of both imports and exports so as to create a level playing-field between domestic and foreign producers and invites for joined EU action. Carbon Trust (2010) finds that such adjustments would be straightforward to do in a non-discriminatory manner for the cement sector, where production processes and products are very uniform[56]. For the steel sector, such adjustments would be a bit more complicated as production processes vary more.

As research moves forward, it is fair to estimate that CCS on industrial processes will be a well-explored field by the time CCS is applied to industrial processes in the Full deployment scenario.

3.2.3 A CO_2 TRANSPORT AND STORAGE MASTER PLAN

Large-scale transport infrastructure in Greece - whether roads, railways, electrical grid or gas pipelines - were built with heavy involvement of the state. The construction of the natural gas transportation grid of Greece, which currently has a total length of 1200 km, is one of the largest energy infrastructure projects to have taken place in Greece in recent years[57] . The establishment of Greece's natural gas transmission system and the establishment of a comprehensive regulatory framework, despite lack of domestic gas supplies, was the result of a strong national decision to modernise Greece's energy industry and diversify its energy sources[58].

CO_2 transport and storage will require similar planning. A national master plan for CO_2 infrastructure should be established for facilitating subsequent permitting of pipelines in particular. The Dutch CO_2 transport and storage strategy is an example of how this should be done[59]. The actual construction may also be planned and financed by a dedicated public body so as to ensure that this new infrastructure maximises future uses. It could be in the public interest to oversize pipelines more than it will be in the private interest to do. Also, a public body may be better placed to plan for flexible future usage, e.g. making sure that pipelines can also transport methane or hydrogen for future energy networks.

3.2.4 MAKING SURE CCS READINESS 'BITES'

In the period 2015-2025, three new lignite-fired and several natural gas-fired units are planned to start operating, as old coal-fired units retire - pushed particularly by more stringent EU legislation applicable for classic pollutants from 2016 under the Industrial Emissions Directive[60]. PPC has already instigated specific actions for the construction of two lignite-fired units: 'Ptolemaida 5' - 600MW projected to be built by 2017 - and 'Meliti 2' - 450MW projected to be built by 2018. A tender has already been issued by PPC for 'Ptolemaida 5', while the construction of 'Meliti 2' is still dependent on the result of the auction for the neighbouring Vevi lignite mine[61] [62]. As the units are being planned as we speak, investment decisions will be taken well before there is much experience with the CCS demonstration plants in Greece or elsewhere. Both of these units are going to be capture-ready, yet no plan exists as to how or when CCS will be applied to these units. Such a plan is strongly needed.

Any new coal-fired units will need to be easily and cost-efficiently retrofitted with CCS at around 2020. Ensuring the plants are built as truly CCS-ready will therefore be crucial. The best definition of what this would imply is provided by the GCCSI/ICF (2010) in 'Defining CCS Ready: An Approach to An International Definition' which defines three levels of increasing stringency for CCS-ready projects[63]. For new coal-fired power plants, requirements at level 2 and 3 should be imposed. It would require for instance detailed assessments of how to retrofit a capture unit (although the choice of technology should await results from demonstration projects), the project should obtain rights of way for transport routes and geological exploration should have taken place to identify a suitable storage site. For gas- and biomass-fired units, requirements at levels 2 and 3 of the GCCSI/ICF recommendations would be needed.

55 For information about CCS on industrial processes, see for example http://www.bellona.org/news/news_2010/CCS_steel_cement_paper
56 See Carbon Trust (2010) 'Tackling carbon leakage: Sector-specific Solutions for a World of unequal Carbon Prices' http://www.carbontrust.co.uk/SiteCollectionDocuments/carbon_news/Tackling%20Carbon%20Leakage.pdf
57 Natural gas grid data extracted from National Natural Gas Company (ΔΕΠΑ) website
http://www.depa.gr/
58 For details on regulatory framework see
http://www.internationallawoffice.com/newsletters/detail.aspx?g=0b6ffe04-43f8-4ea4-bf10-848eb943bf6b
59 See http://www.ebn.nl/files/ccs_advice_ebn-gasunie_eng.pdf
60 For the full Industrial Emissions Directive see
http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P7-TA-2010-0267+0+DOC+XML+V0//EN
61 See tender announcement of PPC for Ptolemaida 5 in Greek
http://www.dei.com.gr/Images/ΑΝΑΚΟΙΝΩΣΗ%20Ε_Ε_Λιγνιτική%20Πτολεμαϊδας%20660%20MW.pdf
62 See article on PPC's invitation to investors for the exploitation of Vevi
http://in.reuters.com/article/idINLDE6171Z420100208
63 ICF International/GCCSI (2010) 'Defining CCS Ready: An Approach to an International Definition' http://www.globalccsinstitute.com/downloads/Full-Report-Intl-Def-CCS%20Ready-23Feb-FINAL.pdf

PHOTO: ISTOCK

4.0 THE BRIDGE TO A GREENER GREECE

The aim of this roadmap is to answer the question: does CCS have a role to play as part of a policy focusing on green development and economic growth in Greece? To answer this question three scenarios were examined - one envisioning a rapid and widespread deployment of CCS in the power and industrial sectors, one a more modest deployment of CCS exclusively in the power sector, and one no CCS deployment at all - and calculated the economic and environmental impacts for each. The results were conclusive: an ambitious deployment of CCS, as foreseen by the 'Full deployment' scenario, brings the best economic and environmental outcomes for Greece. The roadmap provides a description of this scenario and includes recommendations on how to proceed with implementing it and making it part of a concerted long-term strategy to ripe the greatest possible benefit from the application of CCS in Greece.

4.1 GETTING STARTED

A way of achieving a quick and effective start of CCS deployment, in line with the 'Full Deployment scenario', will be to decisively take advantage of the available external funding offered under the EU's NER300 financing instrument. A Greek CCS project that involves CO_2 storage at the mature Prinos oil field for enhanced oil recovery could be ready by 2017. Such a project could realistically be awarded funding under the second round of NER300, decisions for which should be issued by the end of 2013. That will allow a Greek unit, fitted with CCS, to enter operation in around 2017. Following the withdrawal of the Finish FINNCAP project in November 2010 there are at present no known EOR CCS candidate projects under the NER300, which opens up an opportunity for Greece. EOR would reduce significantly the funding needs compared to competitors[64]. Also, given the EU's intention to address geographical imbalance in the second round of NER300 calls, a Greek project would have an increased possibility to be selected. A Greek CCS project could thus be well positioned for selection under the NER300. In parallel with pursuing the NER300 financing opportunities, alternative means of financing such as the EU structural funds or CCS subsidies paid over electricity bills should be explored, in order to further strengthen the feasibility of funding early CCS deployment.

64 See more details on the FINNCAP project here http://www.finncap.fi/en/

PHOTO: ISTOCK

4.2 FULL DEPLOYMENT OF CCS

Since projected new lignite units will realistically enter into operation in 2017, or even later than that year, an initial project will most probably involve a CCS retrofit in an existing energy production unit. Based on their long operational lifespan, ideal candidates for an initial CCS retrofit project funded under NER300 would be the lignite-fired units 'Ag. Dimitrios 5' (350MW) or 'Meliti 1'5' (330MW) both located in Western Macedonia. An alternative project candidate could be the 485MW natural gas-fired unit of Komotini which started operating in 2002 and is projected to remain in operation approximately until 2045. The Komotini unit is in relative proximity to the Prinos reservoir. However, the capture of CO_2 from a gas power plant is from an emissions perspective considerably more expensive than for CCS of a lignite-fired plant.

In the case of 'Ag.Dimitrios 5' and 'Meliti 1', CO_2 could be transferred via an approximately 100 km pipeline eastwards and from then on via ships to Prinos. Pipeline infrastructure constructed for this first project could then be used for CO_2 transportation for more CCS projects in the region given the concentration of many emission intensive lignite units in the region of Western Macedonia. In the alternative case of Komotini, a CO_2 pipeline comprising of an on-shore (100km) and an off-shore (20km) segment would suffice (Koukouzas at al, 2006)[65].

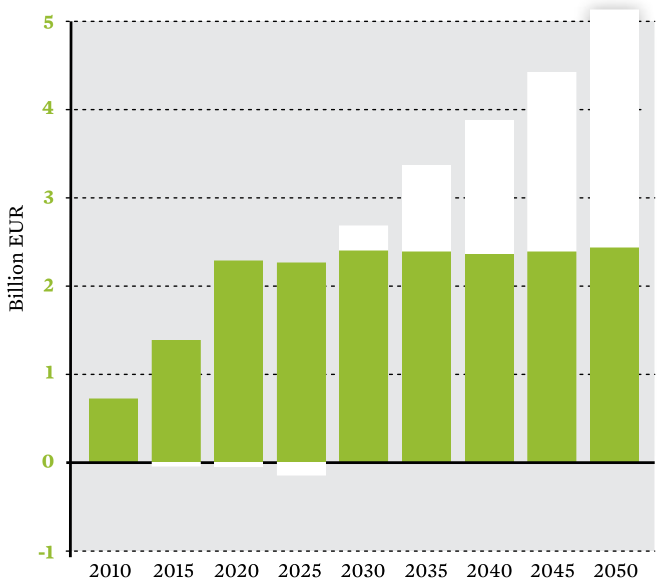
The three lignite units projected to be built by 2025 (namely 'Ptolemaida 5', 'Meliti 2' and 'Ag.Dimitrios 6') all in the region of Western Macedonia, will need to apply CCS immediately. All lignite units with a projected lifespan beyond 2035 (namely Ag. Dimitrios 5 and Meliti 1) will need to have been CCS retrofitted by 2020. CO_2 storage will take place at Prinos and other defined potential CO_2 storage sites (for instance the W. Thessaloniki basin) based on the results of necessary further research. When available domestic CO_2 storage capacity no longer suffices, CO_2 could be transported and stored overseas (see chapter 2.4.2 for further details) through CO_2 maritime transportation to Algeria or Egypt. Greece imports all its LNG supply from these two northern African countries and hence they both appear as especially attractive destinations for Greek CO_2 with strong potential for a combination of LNG and CO_2 maritime transport. Map 6 shows the likely maritime transport routes from Greek ports. An alternative to maritime transport could be CO_2 transport via an on-shore CO_2 pipeline to Romania.

4.3 TOWARDS A SUSTAINABLE ENERGY ECONOMY

The period from 2025 to 2050 will see a full application of CCS in the energy and industry sectors in Greece. Between 2025 and 2035 all operating natural gas-fired units will be retrofitted with CCS, while from 2025 onwards all newly constructed natural gas units will apply CCS from the first day of operation. CCS will also, from 2025, be introduced to the most emission intensive industry units, such as cement factories and oil refineries, and progressively to all emission intensive industry units. See below Figure 12 which portrays avoided costs of the entire economy in the full deployment scenario.

ECONOMY-WIDE AVOIDED COSTS

Figure 12: *Economy-wide avoided carbon & CCS costs in the Full deployment scenario.*



Continued capacity for CO_2 storage will be ensured during this time period through the transportation of domestic CO_2 abroad. CO_2 transportation abroad will be conducted either by ship or pipeline, or a combination. Regarding maritime CO_2 transportation, domestic knowledge and experience will have been gained through prior application of CO_2 maritime transport to Prinos, and probably also from similar projects abroad.

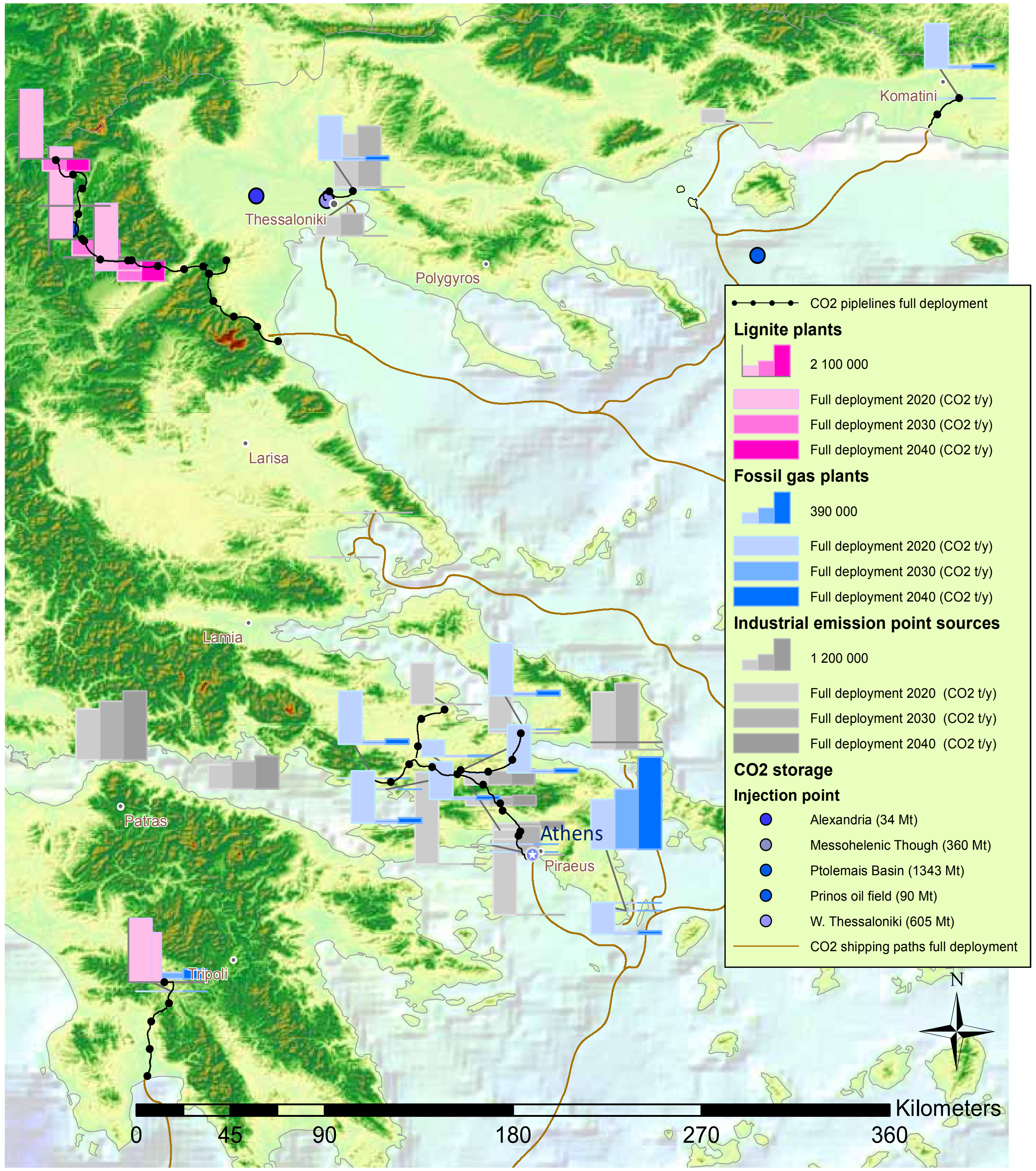
Wide introduction of biomass co-firing from 2020 onwards will pave the ground for a carbon-negative power sector from 2030, and an almost carbon neutral industry sector beyond 2040. On average, all Lignite power plants will in the 'Full Deployment' scenario be fuelled with 20% of biomass in this whole period, a level which does not require major modifications to the power plants.

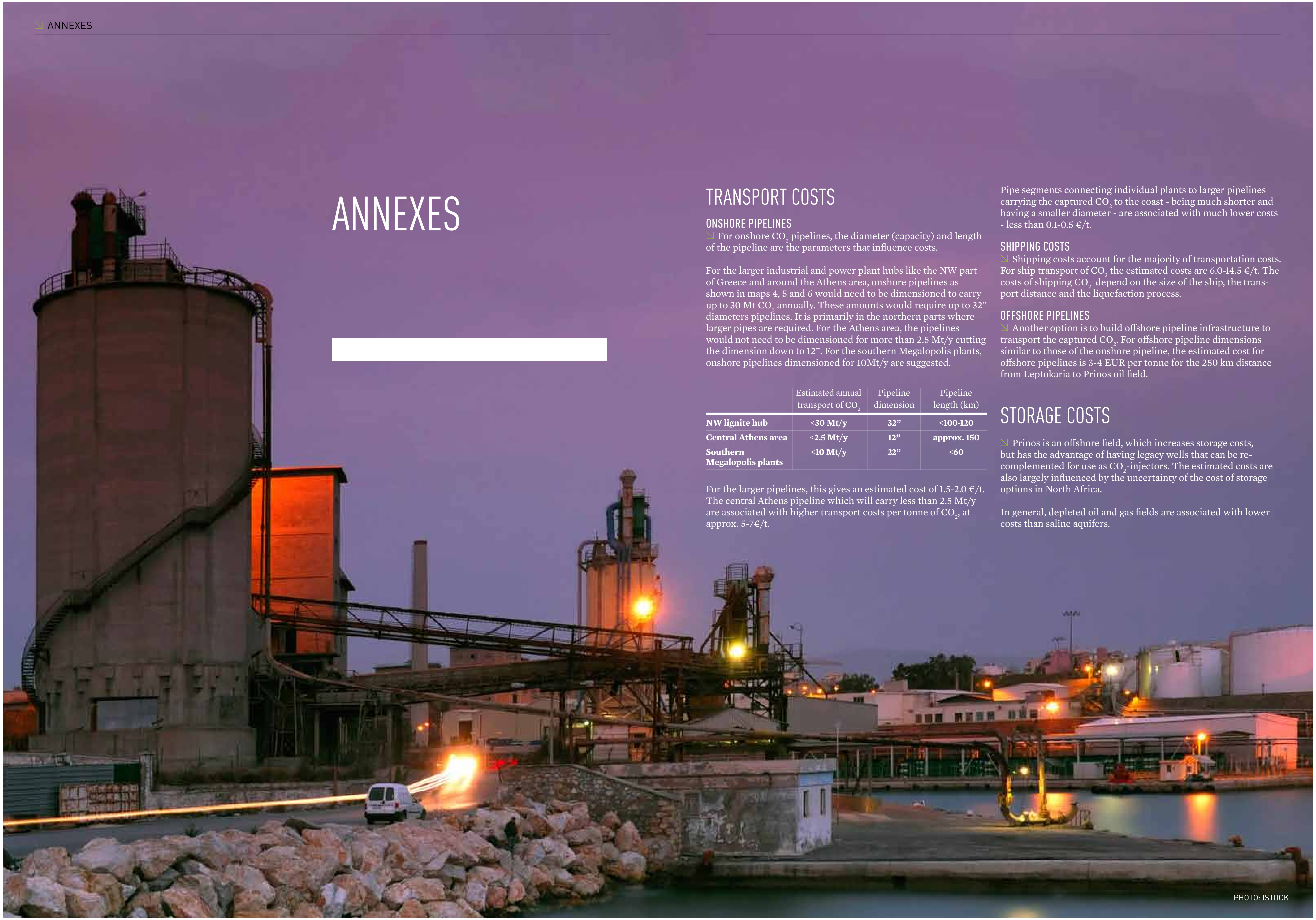
By 2050 the emissions of the Greek economy will only be a fraction of what they would have been without any deployment of CCS. Between 2050 and 2070 all fossil fuel power plant units currently projected by the government will be at the end of their operational life. These units will be phased out and replaced by truly sustainable sources of energy production. RES together with expected improvements in energy storage potential and a better integrated electricity grid with the rest of Europe and Turkey will supply the energy needed for the Greek economy.

65 Koukouzas et al (2006) 'CO2 Capture and Storage in Greece: A case study from Komotini NGCC Power Plant' see http://www.doiserbia.nb.rs/img/doi/0354-9836/2006/0354-98360603071K.pdf

FULL DEPLOYMENT OF CCS WITH EMISSION POINTS, STORAGE SITES AND TRANSPORT OPTIONS

Map 6: *The map shows total CO_2 emission scenarios for 2020, 2030 and 2040 given an extensive CCS deployment in Greece. Some CO_2 from the Northwestern lignite hub and the northern industrial areas are stored in the Prinos and Thessaloniki basins. Possibilities for transporting CO_2 exceeding storage capacity in the NW Greece to North Africa are drawn on the map. Another possible storage option for the northern Greece is transporting captured CO_2 to Romania by onshore pipeline. This option is not included in the map.*





ANNEXES

TRANSPORT COSTS

ONSHORE PIPELINES

For onshore CO_2 pipelines, the diameter (capacity) and length of the pipeline are the parameters that influence costs.

For the larger industrial and power plant hubs like the NW part of Greece and around the Athens area, onshore pipelines as shown in maps 4, 5 and 6 would need to be dimensioned to carry up to 30 Mt CO_2 annually. These amounts would require up to 32" diameters pipelines. It is primarily in the northern parts where larger pipes are required. For the Athens area, the pipelines would not need to be dimensioned for more than 2.5 Mt/y cutting the dimension down to 12". For the southern Megalopolis plants, onshore pipelines dimensioned for 10Mt/y are suggested.

	Estimated annual transport of CO_2	Pipeline dimension	Pipeline length (km)
NW lignite hub	**<30 Mt/y**	**32"**	**<100-120**
Central Athens area	**<2.5 Mt/y**	**12"**	**approx. 150**
Southern Megalopolis plants	**<10 Mt/y**	**22"**	**<60**

For the larger pipelines, this gives an estimated cost of 1.5-2.0 €/t. The central Athens pipeline which will carry less than 2.5 Mt/y are associated with higher transport costs per tonne of CO_2, at approx. 5-7€/t.

Pipe segments connecting individual plants to larger pipelines carrying the captured CO_2 to the coast - being much shorter and having a smaller diameter - are associated with much lower costs - less than 0.1-0.5 €/t.

SHIPPING COSTS

Shipping costs account for the majority of transportation costs. For ship transport of CO_2 the estimated costs are 6.0-14.5 €/t. The costs of shipping CO_2 depend on the size of the ship, the transport distance and the liquefaction process.

OFFSHORE PIPELINES

Another option is to build offshore pipeline infrastructure to transport the captured CO_2. For offshore pipeline dimensions similar to those of the onshore pipeline, the estimated cost for offshore pipelines is 3-4 EUR per tonne for the 250 km distance from Leptokaria to Prinos oil field.

STORAGE COSTS

Prinos is an offshore field, which increases storage costs, but has the advantage of having legacy wells that can be re-complemented for use as CO_2-injectors. The estimated costs are also largely influenced by the uncertainty of the cost of storage options in North Africa.

In general, depleted oil and gas fields are associated with lower costs than saline aquifers.

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