TCCS-6

Energy policy scenarios of CCS implementation in the Greek electricity sector

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Abstract

The energy balance of Greece is strongly dependent on imported oil. The rather late introduction of natural gas has increased the diversity of the energy mix while the share of renewable sources in primary energy supply still needs to increase according to the existing potential. Yet, Greece as one of the most of the EU developed countries encounters a serious task: the need to increase its electricity production of almost 5% per year but at the same time to reduce the CO_2 emissions according with the National and International (20-20-20) regulations and allocation plans. Therefore reducing CO_2 emissions has become a major priority for national government. In addition, from 2013, there will be the full implementation of the wholesale market in the European Trading Scheme (ETS) which is currently in the last stages of a transition phase.

In Greece electricity is mainly generated from lignite, thus making the electricity sector one of the main contributors to GHG emissions with a level above 40% of the total country and higher than the corresponding average of the rest of the EU countries. The possible implementation of Carbon Capture and Storage (CCS) technologies would then become very decisive due to the large use of the lignite as fuel in the country electricity mix. CCS technology has the potential of increasing the flexibility on the achievement greenhouse gas emissions reduction by allowing to continue to use fossil fuels, which still guarantees feasibility in the energy sector. This work presents a roadmap with the modeling of the main technologies associated to the CCS and its implementation into the Greek energy system considering existing National and International Strategic energy plans under different scenarios. The implementation of CCS technologies would have a large influence on the national electrical power production, having the responsibility for large shares of the emissions reduction that can potentially achieved in this sector. For this purpose, TIMES (The Integrated MARKAL/EFOM System) has been chosen as the principal tool for building a techno-economic model of the Greek energy system and its possible evaluation over time (2040).

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1. Introduction

The high energy dependency of Greece [1] and especially from that of the lignite used in the electricity sector that further results to an increased amount of GHG emissions - while at the same time trying to keep this strategic solid fuel source in its energy mixture, makes the Greek government facing a serious problem. The solution could come through CCS which although is not yet a fully commercial technology and only some pilot plants are currently under construction it would be really beneficial if applied to the case of Greece as it will be shown in this work. Although the enabling technologies of CCS are well known, their optimal mounting at the level of a large scale power plant still involves uncertainties regarding technical performances and costs. In addition, uncertainties also exist regarding transport infrastructures and storage. Reaching maturity of CCS technology can be accelerated if there is confidence about the prospects of large scale deployment of CCS applications in the future. There are only few works [2-4] related to the implementation of CCS technology in Greece and the electric sector, thus the objective of this study is to show the influence of CCS penetration in the Greek electricity sector for the next 40 years. A previous work was performed using a different tool (PRIMES) under a shorter time period (2000-2030) under the Strategic Plan [1] by the Greek State with its first priority the EU (20-20-20) agreement. There were considered two policy measures at that time with questions if these measures had to be applied on new coal and lignite plants or also on new gas-firing plants. This work will first present an overview of the reference energy system (RES) in Greece followed by the proposed used energy equilibrium model. Next, the current situation and characteristics of the lignite power plants are described while at the end energy scenarios are discussed related with the implementation of CCS in the energy mixture of the country and the required policies.

2. Reference Energy System (RES) of Greece

In Greece, the total installed capacity at the end of 2009 was 14,584MW (12,884MW in the "interconnected system" and 1,700MW in the "non-interconnected system" ("Autonomous Islands"). This production was based on the Lignite with 4,953 MW on 22 Present Power Plants, Natural Gas with 3,349MW, Oil with 2,109MW, and Renewable energy with 4,339MW (Hydro: 3,170 – Wind: 1087MW - Solar: 42MW – Biomass: 40MW, Geothermal: 0 – Concentrated Solar Power: 0). Between 1995 and 2009 total nominal installed capacity of the electricity generation system in the interconnected system rose from 9,198MW to 12,884MW. However, because of the high increase in electricity demand, Greece is currently lacking sufficient power capacity. Investment in power generation, particularly during the past seven years, which coincide with the first steps of market liberalization, as it has not been sufficient to allow for a normal reserve margin. The main energy form used up to now to generate power in the interconnected system is indigenous lignite extracted from surface mines located in the northwest part of Greece (Ptolemaida/Kozani) and secondarily in Peloponnese (Megalopolis). Lignite plants cover mainly the base load. The Reference Energy System (RES) describing the current energy situation in Greece is the backbone of the TIMES modeling approach. From the RES, the optimization model chooses the least-cost energy system, representing energy technologies and energy flows for a given time horizon and given end use energy demands.

3. Establishment of scenarios and results

For the entire design of national energy systems, it is necessary to consider specific factors including regional resource endowments, conversion technologies, information, time, prices and investment finance, operating costs or age of infrastructures. Therefore the TIMES model has been used to perform scenarios of the Greek energy system described below and its evolution until 2040.

3.1. The TIMES model

TIMES is a bottom-up partial equilibrium optimization model used to estimate energy dynamics in local, national or multi-regional energy systems over a long-term, multi-period time horizon, developed in Energy Technology Systems Analysis Program (ETSAP) [**5**]**.** The model is built through a detailed description of technologies and commodities that characterize the energy system. Then, it computes the minimum cost solution that is capable of providing the modeled energy demands by making decisions on equipment investment and operation, primary energy supply and energy trades. It is a partial equilibrium model as the quantities and the prices in each time period are such that the suppliers produce exactly the quantities demanded by the consumers, which means that the total surplus is maximized.

3.2. Business as Usual (BAU) and Scenarios (A and B) Results

The base year of the model is 2005 with the horizon up to year 2040 and resolution of one year period of time. The model has been calibrated for the base year of 2005 and validated by experimental runs from 2005 to 2008. Upon application of moderate boundaries the model showed a supposed behaviour on the real performance of electricity system in this period of time. The supply side of the model covers electricity production including fossil fuel power plants, cogeneration power plants, and other power plants. At the base year each fossil fuel power plant is interpreted as an individual technology since it is the focus of this study, including the possibility of retrofitting with capture technologies. The techno-economic data interpreting the supply side technologies are installed capacity, technical lifetime, electrical efficiency, availability factor, capital costs, fixed costs and variable costs [**1, 7**]. A homogenous discount rate of 5 % is applied for all economic values. In order to satisfy required demand for electricity it is allowed the import of electricity from the Balkan market, while the electricity price is designed to have a linear growth up to 55 €/kWh in 2040. In addition, assumptions are considered on fuel prices, resources availability and CO_2 permits trade [**8**] until the year 2030 and then maintained constant.

Table 1 summarizes the evolution of the estimated prices for electricity and fuels. Across the whole presented period it is considered the import of all fossil fuels without limitations. The model also does not consider any limitations on availability of domestic natural resources. In order to force the environmental trend of our scenario, regulatory restrictions were included for CO_2 emissions produced by the centralized electricity system, based on the Greek National Allocation Plan [**1**]. The national targets till 2020 as stated from various sources related to the increase of rewnewable energy sources in the energy mixture of Greece and completing also the EU targets of 20-20-20 are the following:

Table 1: **Assumption on prices (€/TJ)**

	2005	2010	2015	2030	2040
Electricity	11111	11574	12037	13426	15278
Coal	1400	1339	1243	1249	1249
Natural Gas	4830	4361	3955	3966	3966
Lignite	1104	1104	1104	1104	1104

a. 1,500 MW/year of RES will be installed from the current 4,410 MW of 2010-2020 (15,000MW).
b. Wind 7,500MW, 2,500MW PVs-solar, 250 MW biomass and another 120 MW from geothermal sources.
c. From 2012 up to 2020 the oil price to be kept on the 90-100 $/barell.

d. Strategic gradual future retirement design from 2010-2024 of 24 Units of PPC electricity power plants of a Total capacity of 5,378MW, of which 4,288MW are corresponding to present 20 Lignite Units (out of the total 22) and 1,100MW of 4 Units of Natural Gas.

Initial results according the use of the model for the above rewnewables energy mixture are presented in **Table 2** where from 2010-2015 a steady linear progression is used for the wind, PVs, biomass and geothermal energy when to be installed .

Table 2:. Forecasted future installed capacity

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Wind	1042	1694	2346	2999	3651	4303	4942	5582	6221	6861	7500
PV	184	401	618	836	1053	1270	1529	1789	2048	2308	2567
Biomass	60	72	84	96	108	120	146	172	198	224	250
Geo	0	4	8	12	16	20	40	60	80	100	120
Hydro	3237	3313	3388	3464	3539	3615	3798	3981	4165	4348	4531
Others	0	539	1078	1617	2156	2695	3067	3439	3811	4183	4555

The BAU scenario [**9**] assumes no CO_2 taxation of any order as well as no price and no limits for CO_2 emission. Within this work, two main scenarios (A and B) are examined implementing CCS technologies and policy measures to the new power plans licensed to be constructed (**Table 3**):

(1) **Scenario A**: The lignite/hard coal power plants that are already licensed to be built, are assumed to have CCS.

(2) **Scenario B**: CCS will be available for the power plants in Scenario A plus on all the power plants from 2015 and onwards that are approved and that use Lignite/hard coal/Mazut fuel. The power plants without license and without a defined year for starting will be considered not having CCS.

Each of these main scenarios has 3 sub-scenarios with different taxations and permit prices for CO_2 emissions, described in **Table 3**.

Table 3: Price evolution for taxes and permits (€/t)

		SC1	*SC2*	*SC3*
2005-2007	*Tax*	*0*	*0*	*0*
	Permits	*n.a*	*n.a.*	*n.a.*
2008-2012	*Tax*	*0*	*0*	*0*
	Permits	20	20	20
2013-2019	*Tax*	20	20	20
	Permits	20	20	20
2020-2029	*Tax*	20	50	50
	Permits	20	50	50
2030-2050	*Tax*	20	50	80
	Permits	20	50	80

In scenario A as can be seen in **Figure 1** for SC1, 2, 3 the common characteristic is that as a function of the CO_2 price (tax), the energy mix presents an early disappearance of the lignite/hard coal while in SC 2,3 the power tower plants are progressing rapidly and are generating almost half of the required energy. Additionally, the energy imports are only eliminated after the year 2040. The corresponding cost of these energy mixture technologies under the referred scenario is 50.8, 53.4 and 53.5 (B€) respectively. In **Figure 1** scenario SC1 of Scenario B suggests the use of natural gas after the elimination of imports by 2031. Comparing SC1 with SC2,3 we can observe differences in imports and the use of lignite that is eliminated by 2025 in SC2,3 but in SC1 it continues until the end of the time horizon. The costs now for

generating electricity as a function of the carbon price under this mixture of technologies that have been involved within the model for 2030 and of SC1, 2, 3 are 53.8, 55.5 and 55.8 (B€) respectively.

4. Conclusions

The implementation of CCS to the new licensed power plants from 2010 and onwards can reduce significantly the use of lignite production which would be replaced either by cheaper imported electricity and/or higher penetration of renewables (more in Scenario A than in B), especially from wind and CSP. The cost of a CCS energy policy implementation under a CO_2 tax issue will add an extra 6.25 B€ up to 10.2 B€ to the electricity generation cost compared to the BAU scenario while completing the suggested energy mixture targets of the Greek Ministry of Environment, Physical Planning & Public Works and the CO_2 emissions reduction according to the EU regulations.
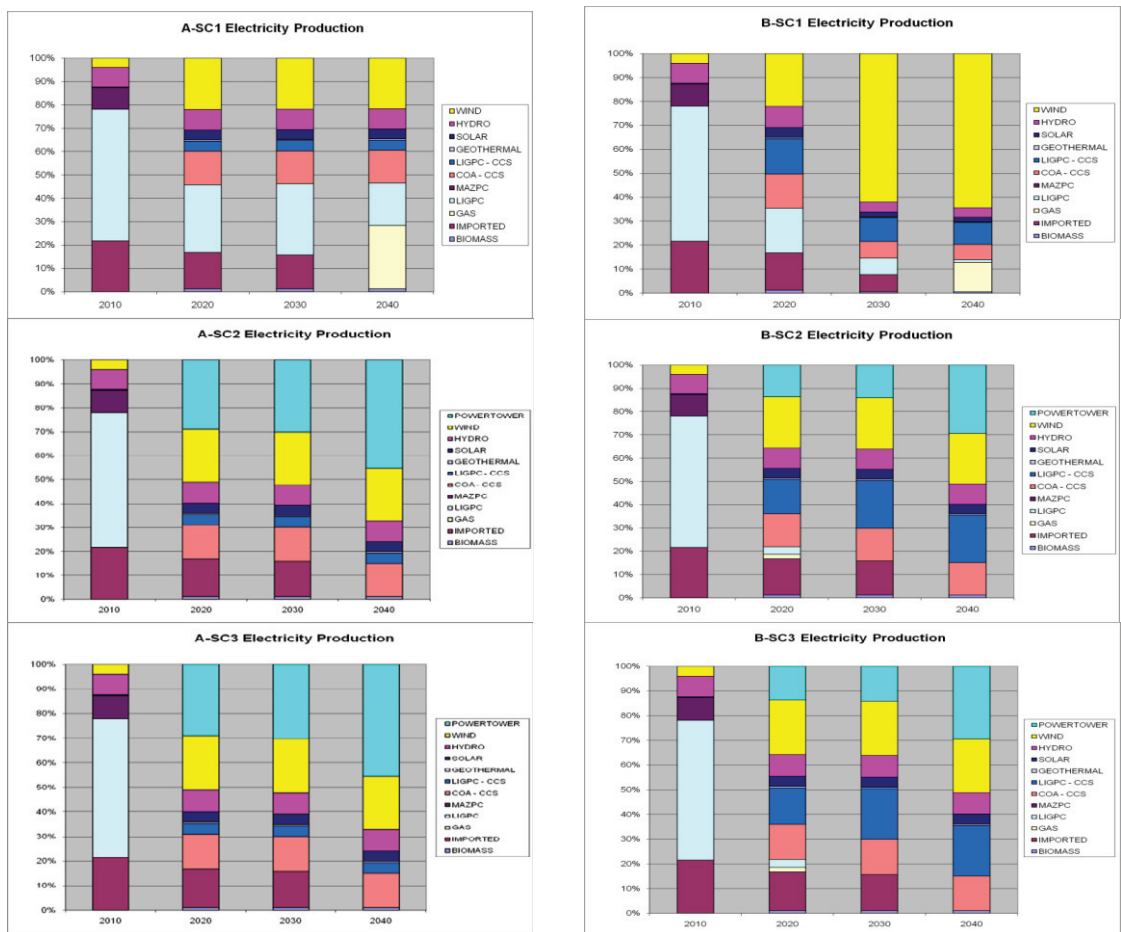

Figure 1 - Electricity generation by technology groups accordingly to scenarios A (left) and B (right).

Acknowledgements

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