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A blueprint for an energy policy in Greece with considerations of climate change

Kalliopi Chatzizacharia, Vasilis Benekis, Dimitris Hatziavramidis *

School of Chemical Engineering, National Technical University of Athens, 9 Heroon Polytechniou, 15780 Zografos, Athens, Greece

HIGHLIGHTS

- Climate change and energy variables for Greece are forecasted for the next 25 years.
- Aforementioned variables are cointegrated to check causality and stationarity.
- Power generation by methods of reduced CO_2 emissions is set as optimization problem.
- Energy production with wind power and lignite with zero-emissions option is optimal.

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ABSTRACT

An approach for a plan to meet the energy needs of the state of Greece in conjunction with assumed responsibilities to confront global warming is presented. Time series of climate indicators like average temperature and rain precipitation together with energy consumption and CO_2 emissions are examined for stationarity and causality. Predictions of energy needs for the next 25 years and CO_2 emissions are made. With these predictions, production of energy from renewable sources like wind turbines and photovoltaic panels as well as from lignite with CO_2 capture and sequestration systems attached to power-generating units is formulated as an optimization problem with financial and environmental constraints.

1. Introduction

Since the last quarter of last century, scientists have warned us of global warming caused by human activities that result in Greenhouse Gas (GHG) emissions. Throughout the 21st century the atmospheric temperature is projected to continue to rise in most areas of the planet and the average atmospheric temperature is expected to increase by 1.8–4 °C by 2100, depending on developments in the concentration of GHG emissions. Future precipitation is more difficult to estimate because local factors including terrain affect the amount of rainfall but it is generally expected to increase at mid and high latitudes and also in the Intertropical Convergence Zone, and to decrease at tropical latitudes [1].

Rainfall, air temperature and sunshine are major climate indicators. Local topography plays an important part in the shaping of the climate. In Greece, a country surrounded by sea on most sides, with regions having high mountains and mountain ranges spanning in different directions, considerable regional differences in air temperature, rainfall levels and sunshine have been observed. Winters are milder in regions where the mountain configuration blocks the inflow of cold winds from the North, and much colder in areas where the geomorphology allows these cold air masses to penetrate. The tempering influence of the sea also accounts for the milder climate (milder winters and cooler summers) of the coastal regions and islands, compared with nearby regions situated inland. The mean annual temperature range (the difference between the monthly mean temperature of July or August and the monthly mean temperature of January or February) is more than 20 °C in Northern Greece, characteristic of a continental climate, but much smaller in the southern regions. In the southern islands, in fact, it is typically below 15 °C. The mean annual temperature is about 10 °C in the mountains of the Peloponnese and about 5 °C in the mountains of Northern and Central Greece. The rainfall pattern typical of Mediterranean coastal areas is, of course, predominant, with dry spells in summer and a rainy season from mid-autumn to

* Corresponding author.
E-mail address: dthatzia@central.ntua.gr (D. Hatziavramidis).

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mid-spring. Mean annual precipitation for Greece as a whole is roughly estimated at 800 mm, but the geographical distribution of the annual amount of precipitation and of the yearly rainy season generally follows Greece's geomorphology. As already mentioned, the Mediterranean winter is determined by high pressure systems over Eurasia and the North Atlantic. These systems steer respectively cold dry or warm moist air masses toward the Mediterranean, thereby creating centers of cyclogenesis or rejuvenation of low-pressure systems in winter winds, while the same conditions roughly prevail in autumn and spring [2,3].

Southern Europe and the wider Mediterranean region have been identified as vulnerable to the impact of anthropogenic climate change because they are situated at the edge of semi-arid zones; therefore a northward shift of baroclinic instability due to climate change could bring about drastic changes, particularly in the balance of precipitation in the Mediterranean.

The global warming of the last 150 years has been largely attributed to the increase in anthropogenic GHG [4]. As for the changes of the last few decades, human forcing, e.g., air pollution, but also natural variability and processes in the atmosphere–hydrosphere system have played their part, as evidence from the geological record is consistent with the physics that shows that adding large amounts of CO_2 to the atmosphere causes the temperature to rise ('greenhouse effect'), which in turn leads to higher sea levels, changed patterns of rainfall, increased acidity of the oceans and decreased oxygen levels in seawater.

The global concentration CO_2, main component of GHG, is currently at 390 ppm, having increased by almost 35% in the last 200 years, with half of this increase having occurred in the last 30 years. It has been estimated that a doubling of CO_2 concentrations in the atmosphere translates into a temperature increase of the order of 2–4.5 °C, with a best estimate of about 3 °C (climate sensitivity) [2].

Interestingly for Greece, with regard to the future use of renewable energy sources, average solar irradiation is expected to increase at a national level, while the force of the etesian winds is expected to increase by 10% by the end of the 21st century. Energy production is dominated by the state owned Public Power Corporation and although almost half of its power is generated using lignite, there is an actual tendency of gradual increase of renewable energy sources share in energy consumption in the last years, as shown in Table 1 [5]. In 2008 renewable energy accounted for 8% of the country's total energy consumption, a rise from 2006 but still below the European Union (EU) average of 10% in 2008. In line with the European Commission's Directive on Renewable Energy, Greece aims to get 18% of its energy from renewable sources by 2020 [6].

Climate change in terms of temperature and precipitation extremes results in increased demand for electricity, high risk of fire, decline in species abundance and biodiversity as well as public health, and rise in poverty and social problems, especially in urban centers. Thus, the need for a well-specified adaptation policy that would cover all sectors arises urgently.

Cumulative anthropogenic emissions of CO_2 from fossil fuel use, a major cause of climate change, generated by various countries including Greece, are shown in Table 2.

Although the European Union (EU) contributes only 12% to the total CO_2 emissions and Greece 0.28%, specific emission reduction targets have been allocated to each member state, including Greece, within the EU according to Kyoto Protocol [7].

Table 2
Carbon dioxide emissions from burning of fossil fuels and manufacture of cement.

Country name	Percent of world CO_2 emissions (%)	CO_2 emissions (metric tons per capita) 2010
China	26.43	6.19
United States	17.33	17.56
European Union	13.33	7.33
India	6.41	1.67
Russian Federation	5.55	12.23
Japan	3.73	9.19
Iran	1.82	7.68
South Korea	1.81	11.49
Canada	1.59	14.68
Saudi Arabia	1.48	17.04
South Africa	1.47	9.04
Mexico	1.42	3.76
Indonesia	1.38	1.80
Brazil	1.34	2.15
Australia	1.19	16.93
Greece	0.28	7.67

Since transition to an economy of low GHG emissions concerns all sectors of economic activity, consumption and energy production, long-term energy planning is the core of a climate change mitigation policy which reckons in the renewable energy use as well as financial and environmental factors. In this regard, a small country like Greece, which faces a major financial crisis for the last 6 years but has already began to adopt renewable energy sources, belongs to EU, and has an advantageous topology and morphology, constitutes an interesting case study where important conclusions can be withdrawn for the global problem of climate change for which the solution needs to be global.

Studies of energy generation or consumption in connection with GHG gas emissions and other factors have been made for Italy and Turkey, countries neighboring Greece [8–10], and comparative data of this type were reported for various European countries [11]. Our work shares with the work in Refs. [9–11], the method of cointegration for energy, GHG emissions and other variables, in search of stationarity and causality. The differences between our work and Refs. [9–11] are in cointegrated variables other than GHG emissions. In the former, these variables are of climate-change type, e.g., average summer and winter temperatures, in the latter, the same variables are economic growth, political stability and competition. Our study is of technical and economic feasibility nature, the studies in Refs. [9–11] are in the realm of political economy.

Although our work is technical in nature it cannot ignore another factor. In today's Greece social problems arising because of the financial crisis and the austerity measures that have been following are exacerbated by the human-induced climate change. A rational approach to the climate change and energy problem, in addition to environmental and financial considerations, must take into account the social problems that have risen in the past four to five years. This approach can be formulated as a solution to a multi-criteria optimization with regard to economy, environment and society, and its formulation will be the subject of a study to follow [12].

Table 1
EU and Greece% share of renewable energy in gross final energy consumption.

Country/year	2004	2005	2006	2007	2008	2009	2010	2011	2012
EU (28 countries)	8.3	8.7	9.3	10.0	10.5	11.9	12.5	12.9	14.1
Greece	6.9	7.0	7.2	8.2	8.0	8.5	9.8	10.9	13.8