ELECTRIFYING GREECE WITH SOLAR AND WIND ENERGY

by

Dimitris MENTIS*

Division of Energy Systems Analysis, Department of Energy Technology,
KTH Royal Institute of Technology, Stockholm, Sweden

Original scientific paper
DOI: 10.2298/TSCI1403709M

Ensuring energy security, reducing GHG emissions and boosting the competitiveness of a country's economy by attracting investments and technical knowhow are of paramount importance considering the targets of "20-20-20" set by the European community. Being the cradle of civilization, Greece appears today as a country caught in a prolonged hard economic and social crisis, the way out of which its citizens are looking forward as well as the entire European Union. Establishment of the leading renewable energy sources like solar and wind in Greece will not only increase the independence of its own electrification but will also provide with a foundation for developing the market of international trade of "green" energy. This paper initially highlights the current status of photovoltaics and wind turbines in Greece. Furthermore, this study evaluates whether a higher penetration of the above mentioned green energy sources would have positive impact in the economy of the country or not and in what extent they could decline the CO_2 emissions until 2020, comparing to the corresponding levels in 2010.

Key words: *solar, PV, wind, lignite, oil, electricity consumption and demand, environmental assessment*

Introduction

Climate change and increasing demands for affordable energy are challenges that society faces today. No one can deny the fact that the extensive fossil fuels consumption has raised undesirable consequences like air pollution, loss of biodiversity, ocean acidification and threats to energy and food security that were not experienced before in the known human history [1]. Solutions to these problems demand a large-scale shift to a greener, everlasting and steady-going energy system without compromising when it comes to the efficiency matter. Two concentrative alternatives can reduce the amount of fossil fuels consumption and lead to a lower dependence of a country's energy system on imported fuel. Solar and wind energy resources have been addressed to be the fundamental means for covering the global energy demand – for heating, cooling, electricity and transport - while simultaneously they do not enhance, in a large extent, the climate change.

Objectives

To replace coal and oil based electricity generation in Greece, two technologies are to be applied in this analysis: solar photovoltaics (PV) and wind turbines (WT). In order to implement these two technologies, this project's main objectives are:

* Author's e-mail: mentis@kth.se

- to analyse and compare current renewable energy systems in Greece to shape a general view for project implementation,
- to simulate two different, BAU – Business-As-Usual, and GR – Green, future energy scenarios (explained in detail in the following chapter), and compare their economic viability, and
- analyse the environmental impact, and basic steps to minimize it.

The perspective penetration of solar and wind energy is ascertained in the project to meet electricity demand in Greece, a Mediterranean country with arguably high solar and wind potential. Despite the high potential for both of these resources the field of Renewable Energy Sources (RES) in Greece is not yet as developed as in North and West Europe. Another important objective of the study is to assess the environmental and economic benefit of increasing the PV and WT penetration in the Greek energy system.

Methodology

There have been many studies performed recently about estimations for the mid-term (2030) and long-term (2050) electricity demand and the feasibility of photovoltaic and wind turbine technologies to cover this demand at least in a large extent as a basic supplementary for the oil and coal power generation. However the first target to be achieved by Greece as one of the EU member is to cover 20% of its energy demand with renewable energy resources by 2020. Based on journals' articles and published reports from established European and international organizations and institutions like the European Photovoltaic Industry Association (EPIA), the European Commission for Energy & Innovation, the International Energy Agency (IEA) and others, this analysis compares two possible scenarios for approaching "20-20-20" target. The triple targets of the "20-20-20" are envisioned to play a key role in ensuring country's energy security, reducing national GHG emissions and boosting the competitiveness of the economy.

For the applied data to be as precise as possible, statistics related to fuel consumption and production, GDP and growth rates were taken from credible and reliable up to date databases like the CIA World Fact book, the European Commission for Energy & Innovation, the International Energy Agency (IEA), the Hellenic Association of PV companies as well as the Hellenic Scientific Association of Wind Energy.

The whole report is divided into several chapters. The project introduction explains the urgency of the subject and includes the statement of the general objectives of the report along with the additional goals that have to be fulfilled. The statement of the main objectives is followed by methodological description of data collection, calculation analyses, and principles of charting, justification of assumptions. The perspective penetration of wind and solar power for the Hellenic region is based on a submitted report from the Hellenic Ministry of Energy, Environment and Climate Change. The environmental assessment chapter ascertains the environmental viability of the whole proposal taking into consideration the CO_2 emissions' reductions. The analysis of the results obtained from the proposal is provided in the results and discussion chapter followed by made conclusions.

Concerning the penetration proposal of the wind and solar technologies for the electricity production for the Hellenic region, the report "National Renewable Energy Action Plan in the scope of Directive 2009/28/EC" (technical inputs at: Analysis of Energy Penetration Scenarios of RES in the energy system and achieving national targets in 2020 with the use of models MARKAL, ENPEP, WASP, COST", 2010") was taken into consideration, especially

as regards to particular data related with intended installed capacity, electricity production, CO_2 tax emissions, demographic and macro-economic indicators and national fuels' prices.

Due to the data provided by Hellenic Ministry of Energy, Environment and Climate Change, coal and oil are two of the three most used energy resources for electricity production in the country. The combustion of these two resources is the most polluting and leads to high GHG emissions. Based on the above factors, in this project, electricity produced from coal and oil will be replaced with electricity produced from solar and wind energy resources.

There are two resources replacement scenarios considered in the project. One of the proposed scenarios is business-as-usual scenario (BAU). All the calculations and graphs for BAU scenario (both for energy consumption and sources usage) were made by applying the average annual consumption change rate for years 2000-2010 with a linear extension until year 2020. There is no BAU scenario presented for PV electricity production because until 2008 the presentation of that technology to the Hellenic market was limited due to its privatization and no-grid-connection.

Another scenario considered in the project is called Green scenario (GR) as it provides with higher electricity production from two concerned renewable technologies – solar photovoltaic and wind turbines. For this scenario with some exceptions (to be indicated further) the default targets set by the Hellenic Ministry of Energy, Environment and Climate Change were used. To plot electricity consumption graph for the GR scenario, it is assumed that the annual change of electricity consumption is correlated to GDP annual change concerning that a number of previous studies indicate that an increase in income (GDP) will increase the use of, and demand for, electricity. In this analysis it is suggested a one-for-one relationship between these variables [2].

According to the Hellenic Ministry of Energy, Environment and Climate Change, and following the EU 20-20-20 directive, 7,500 MW of wind and 2,200 MW PV energy capacity should be installed in Greece until 2020. It is to be investigated whether it is viable to invest in wind turbines and solar PV technologies by comparing the two considered scenarios. As mentioned above, the two sources that are to be partly substituted are coal (lignite) and oil, since they are the most pollutant ones in terms of GHG emissions. Taking into consideration the CO_2 emission factor for burning oil and lignite, tons of CO_2 would be eluded (comparing 2020 and 2010), and hence savings for the Hellenic government should be calculated by avoiding the CO_2 tax [3]. Furthermore, Greece is going to save money by reducing the oil import and since the lignite is free in Greece (the Public Power Corporation exploits the lignite deposits) power plant operating and maintenance (O&M) costs will be added so as to come up with more accurate results for savings. On the other hand, the Hellenic government buys the electricity produced by PV and wind turbines, which are installed by private investors, at fixed prices (FiT), as shown later on.

At the first part of the economic evaluation, it is examined the feasibility of the proposal. Is it profitable or not to invest in wind and solar energy? The tax, the feed-in-tariffs (FiT), the O&M costs, as well as the learning rates of the 2 technologies are introduced in order to reckon the installation costs for the wind turbines and the PV. For instance, the learning rate for wind turbines is 12% [4]. This means, for every doubling of the installed wind energy capacity, the installation cost per kW will be reduced by 12%. The respective number for the PV is 20% [5]. Economic indicators, such as internal rate of return (IRR) and payback period (PBP), are applied in order to point out the viability of the project. Subsequently, the savings for the Hellenic government are estimated for both scenarios.

Overview of electricity production in Greece

Energy sources used for electricity production

Lignite is considered to be the dominant source in Greece for electricity production, with oil and natural gas to follow up. As regards the natural gas, due to the growth in the electricity demand and the subsequent construction of new gas-fired power stations, its demand has been steadily increased and stood at $4.2 \cdot 10^6$ m^3 in 2008 (11.5 million m^3/day) [6]. Roughly three-quarters of gas are supplied from Russia and Turkey by pipeline, and the remaining portion is imported in the form of liquefied natural gas (LNG), largely from Algeria [7]. In general the natural gas (NG) imports for 2009 accounted for 3,560 million m^3, while the production and consumption reached 9 and 3,530 million m^3, respectively. It is worth mentioning that the NG proved reserves for the year 2010 are around 1,000 million m^3 [8].

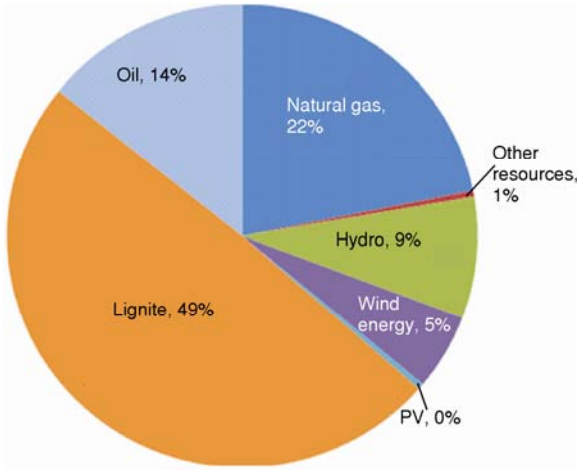

Figure 1. Electricity production by resource, [GWh], [6] (for color image see journal web site)

Electricity imports and exports have been registered to be around 7.57 and 1.97 million kWh [9]. Particularly, lignite holds the lion share in electricity generation reaching 49% of the total electricity consumption, while natural gas and oil accounts for the 22% and 14%, respectively. Other sources like hydropower, wind energy and PV share the rest. Figure 1 is identical for the segmentation of the resources for the electricity production, for 2010.

Current photovoltaic electricity production

EPIA and the Hellenic Association of PV companies state that Greece have showed an impressive increment at the installed capacity with 987 MW power for the first 9 months of 2013 while the cumulative installed and operated capacity was registered to be around 2,419 MW, both for off and connected to the grid [7, 10, 11]. Despite the financial crisis, the Hellenic PV market keeps on rising significantly from 2009 and onwards.

Regarding the installed capacity, 38% of the grid-connected systems account for 20--150 kWp of power, while the rest are shared among the rooftop < 10 kWp (19.4%), 150 kWp to 2 MWp (25.7%), > 2 MWp (12.9%) and the smallest percentage of application < 20 kWp (4%).

This unexpected deployment despite the unprecedented financial crisis, has come as a result from the bold governmental initiatives regarding the residential solar systems with not only generous financial incentives but also simplifications about the authorization procedures as well. However, it is still not “a piece of cake” when it comes to bigger commercial PV systems. New renewable energy legislation (Law 3851/2010) has brought important changes in the legal-administrative framework. Banking sector’s initiatives have also facilitated the installations of residential PV systems. Practically every bank in Greece now offers up to 100% financing of those systems. Moreover, a 150 €/kWp bank guarantee is needed for ground-mounted systems up to 1 MWp before the signing of a grid connection contract.

The first Hellenic legislation for PV was introduced in 2006 offering generous feed-in-tariffs and setting the details for authorization of PV systems. Regarding the feed-in-tariffs (550 €/MWh for rooftop systems <10 kWp, 351.01 €/MWh for mainland grid >100 kWp, 394,88 €/MWh for both mainland grid <100 kWp and for autonomous islands grids), the segmentation of the PV installations is 4% residential, 1% commercial/industrial and the rest 95% accounts for ground mounted installations. The immediate target for the 2015 from the Hellenic government is an installed capacity of 1.27 GW and 2.2 GWp for 2020 which, although the second best in Europe on a percentage basis, seems rather conservative when considering the current boom [11].

Policy makers state out that PV is probably the only sector which shows strong development trends in Greece. This sector has created about 4,250 full time jobs the last four years in the manufacturing and installation of PV systems. Six manufacturing plants are now operating in the country and hundreds of companies are offering their services in trading, procuring and installing photovoltaic.

Current wind turbine electricity production

According to the Ministry of Environment, Energy and Climate Change the total expected wind energy contribution to the electricity demand, so as to meet the binding 2020 targets and the indicative interim trajectory for the shares of energy from renewable resources in electricity, heating and cooling and transport, will be covered by onshore wind power plants with cumulative capacity of 7,200 MW and 300 MW off shore [6].

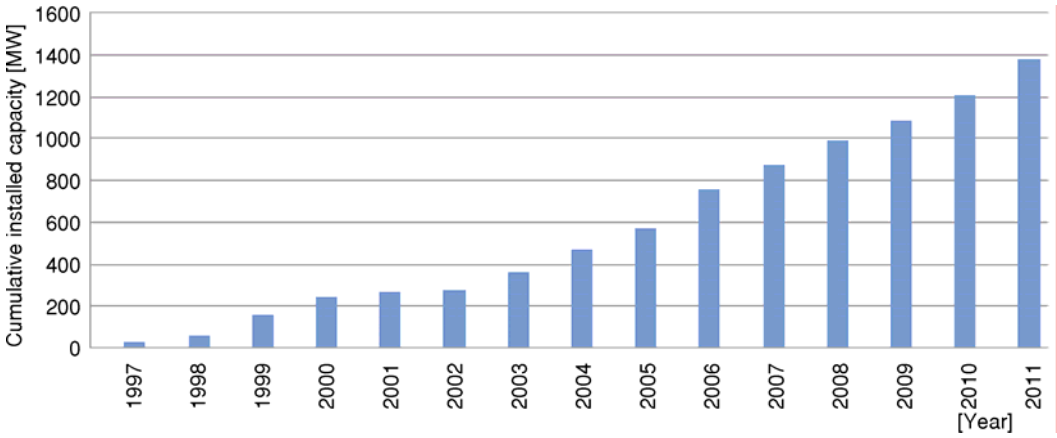

Figure 2. Cumulative wind energy capacity installed in Greece from 1997 till today [MW], [12]

The wind capacity installed at the end of 2011 will, in a normal wind year, produce approximately 3,135 GWh of electricity, representing 3.7% of the Hellenic gross final electricity consumption. Greece is the country with the 7th highest penetration of wind power in electricity consumption in Europe (Wind power in 2010 European statistics February 2011, European Wind Energy Association (EWEA). According to the recent law for Renewable Energy Sources in Greece (L.3851/2010), the feed-in-tariffs for the wind energy produced is 87.85 €/MWh for the interconnected system as well as for the interconnected islands and 99.45 €/MWh for the not connected to the grid islands (autonomous power plants), [13, 14].

Results and discussion

From fig. 3 an increase of electricity consumption by 2020 is traced for both BAU and GR scenarios. The green scenario shows a considerable drop in electricity consumption until year 2013 which is correlated to the negative GDP growth rate due to the economic crisis. Thereafter until 2020 electricity consumption has an ascending profile. However electricity consumption by the end of the considered period in GR scenario is less than in BAU scenario which requires subsequently less energy sources.

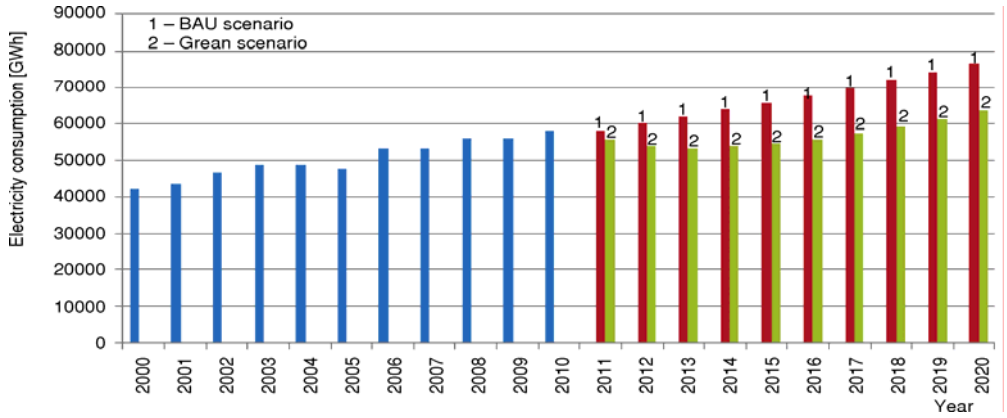

Figure 3. Electricity consumption business-as-usual *vs.* green scenario

As fig. 4 shows, BAU scenario projects an 11.8% decrease at electricity production from coal (lignite) and oil between 2010 and 2020, while for wind based electricity production estimations account for an increment about 404%. GR scenario projects a two-fold decrease at electricity production from coal and oil until 2020 (around 52%). The penetration of these green technologies is projected to represent the 28.8% of the total electricity production, whereas the corresponding share in 2010 was only 5.5%.

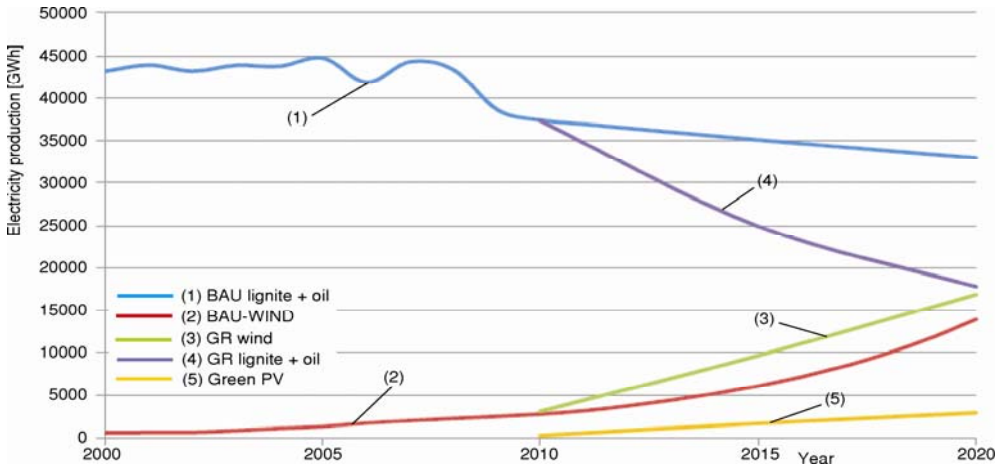

Figure 4. Electricity production business as usual *vs*. green scenario [3]
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According to the GR scenario, the wind and PV capacity to be installed are 5,825 MW and 1,994.60 MW, respectively, whereas the BAU one sets the installation of 4,834 MW wind turbines and no extra installation for Photovoltaics, since the penetration of this technology to the Hellenic electricity system was limited until 2008, due to its privatization and off-grid-connection. As above mentioned, the installation costs of these two technologies are dependent on their capacity. Thus, it is implemented the learning rate as shown in fig. 5.

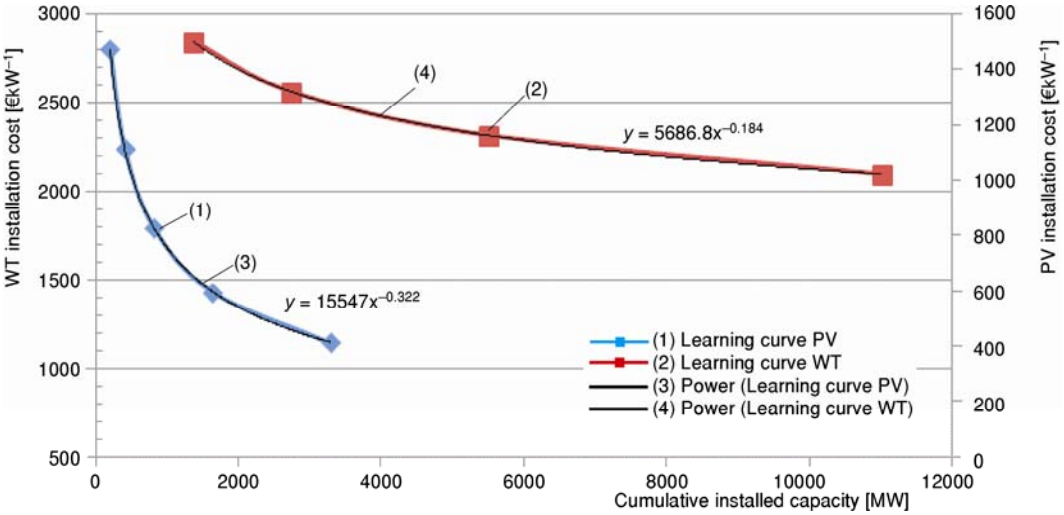

Figure 5. Learning curve for wind turbines and solar photovoltaic
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The viability of this project will be concluded based on economic indicators, such as the IRR, and the PBP. The IRR is a return rate used in capital budgeting to measure and compare the profitability of investments. The IRR of an investment or project is the "annualized effective compounded return rate" that makes the net present value (NPV) of all cash flows (both positive and negative) from a particular investment equal to zero, whereas the Pay The PBP is defined as the length of time required to recover the cost of an investment [15].

For every doubling of complementary installed capacity, the installation costs decrease 12% in case of wind turbines and 20% in case of solar PV [4, 5]. The plotted learning curves illustrate this dependence and facilitate the selection of the optimal amount of installations on the basis of available funds.

Table 1 provides with details of some of the project's features for both scenarios as well as economic indicators. It can be concluded that the GR scenario is more feasible than the BAU, because the PBP in GR scenario is shorter than the BAU scenario. The PBP indicator illustrates that the higher installed capacity, the more yielding the whole project. However, the PBP method ignores any benefits that occur after the PBP and, therefore, does not measure profitability. Thus, the method of IRR, another method of capital budgeting, is preferred. Also the IRR illustrates that the GR scenario is the most beneficial one.

Table 1. Data for investors

	Green scenario	BAU scenario
Wind energy to be installed [MW]	5,825	4,834
Cumulative installed capacity [MW]	7,500	6,209
PV to be installed [MW]	1,994.6	0.0
Cumulative PV installed capacity [MW]	2,200	205.4
Total electricity production from wind [GWh]	16,797	13,907
Total electricity production from PV [GWh]	2891	242
Pay-back tariffs wind energy [€/kWh]*	0.08785	0.08785
Pay-back tariffs solar energy [€/kWh]**	0.351	-
IRR	11.7%	7.7%
PBP [years]	8.16	10.06

* Off-shore FiT

** FiT for installations >100 kW not included

In figs. 6 and 7, profits for the government are compared between 2 years; 2010 and 2020, so as to conclude whether the project brings desirable results for the Hellenic state or not. Regarding the GR scenario, the final profit for the country in 2020 is just about 933 million euros less than in 2010. This reduction can be compensated with the assumption that the government decides to start trading the lignite resources. At this point the overall profits for the country, in 2020 reach around 3 billion euros more than in 2010. Trying to be realistic, lignite has been mined without charges. This is an inhibitory factor for the implementation of wind and PV technologies in Greece. Lignite's mining is not any more sustainable and concerning the CO_2 emission taxes, exporting can be considered as a major source of revenues for the Hellenic government.

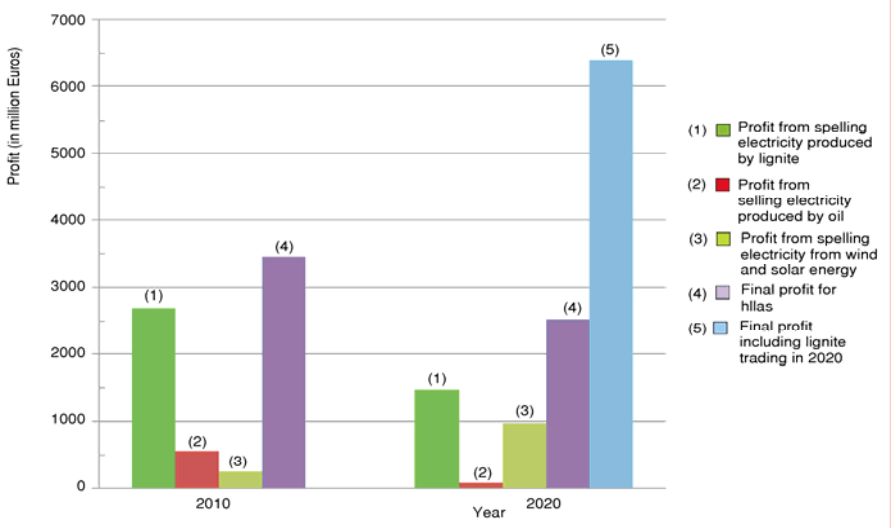

Figure 6. Profits for the country for GR scenario
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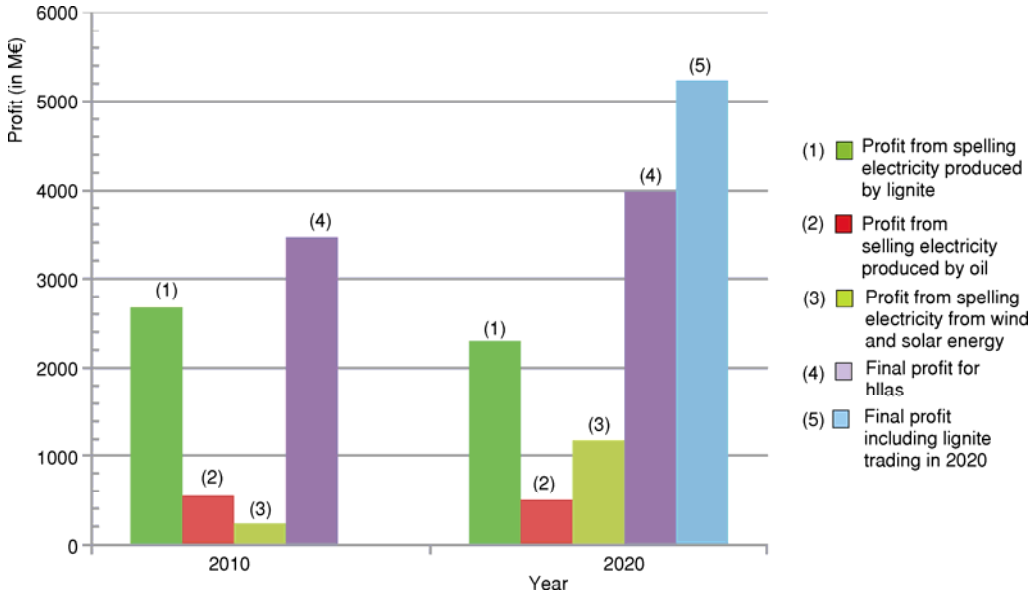

Figure 7. Profits for the country for BAU scenario
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Regarding the BAU scenario, it is obvious that the final profit for the Hellenic government would be higher in 2020 than in 2010. To illustrate, the final profit for Greece in 2020 would be 4 billion euros, instead of 3.5 billion € in 2010. If the lignite trade is implemented, the total final profit would exceed 5.2 billion € (extra revenues 1.2 billion euros from lignite trade). By comparing the two scenarios, it must be concluded that the more beneficial one, is the GR scenario, since the total final profit for Greece reaches 6.4 billion euros in 2020, compared to the BAU one that results profit of about 5.2 billion euros. This difference is due to the greater amount of lignite that is traded in case of implementing the GR scenario, as well as the higher revenues that the Hellenic government would have from selling electricity produced by Renewable Energy Sources to the consumers.

Environmental Assessment

Compared to other renewable technologies, PV and WT make more moderate impacts on the environment. Both solar and wind energy constitute renewable energy resources. Therefore, solar and wind power technologies emit negligible amount of greenhouse gases during their lifecycle compared to combustion of fossil fuels. However, they have some negative impacts on the environment like any other energy technologies, a massive environmental impact is expected.

The impacts should be evaluated for construction, operational and decommissioning stages; some impacts may be permanent, others temporary or occurring from time to time. All possible threats to the environment, people, fauna and flora, especially birds, air, water, land have to be estimated carefully. A lot of information about site geology, archaeology, architectural heritage, proximity to other infrastructures has to be studied and analysed for site selection.

The importance about the environmental assessment of the proposed project is the reductions of the CO_2 for both scenarios. Regarding the GR scenario, after replacing 19,509 GWh lignite and oil based electricity generation with electricity production from solar and wind, estimated CO_2 emissions in 2020 are 18,869,440 tons less than in 2010. As for the BAU scenario, it gives 4,757,096 tons less of CO_2 after replacing 4,411 GWh of electricity production with PV and wind technologies. The emission factors for lignite and oil are 1.1 and 0.72 ton/MWh, respectively [16].

Table 2. CO_2 emission from electricity production for GR scenario

	2010	2015	2020
Electricity production from lignite [GWh]	29,021	21,364	16,329
Electricity production from oil [GWh]	8,362	3,641	1,545
CO_2 emission factor for oil electricity production [ton/MWh_e]	0.72	0.72	0.72
CO_2 emission factor for lignite electricity production [ton/MWh_e]	1.10	1.10	1.10
CO_2 emissions from lignite electricity production [Mton]	31.92	23.50	17.96
CO_2 emissions from oil electricity production [Mton]	6.021	2.622	1.112

Table 3. CO_2 emissions from electricity production for BAU scenario

	2010	2015	2020
Electricity production from lignite [GWh]	29,021	26,861	24,862
Electricity production from oil [GWh]	8,362	8,235	8,110
CO_2 emission factor for oil electricity production [ton/MWh_e]	0.72	0.72	0.72
CO_2 emission factor for lignite electricity production [ton/MWh_e]	1.10	1.10	1.10
CO_2 emissions from lignite electricity production [Mton]	31.92	29.55	27.35
CO_2 emissions from oil electricity production [Mton]	6.021	5.929	5.839

The importance of the sustainable development concept in Greece is a crucial part in its trial to confront with the current status of the fossil resources depletion in regards with the economic crisis. What makes the above mentioned CO_2 reductions important are the avoided taxes that the country will eventually avoid.

As the project has to be implemented until 2020, it should be divided into several phases, but having one massive overall arrangement. Each phase should be arranged with strategic assessment consisting of several parts, involving stakeholders, different organizations and public acceptance. All the parties have to agree on the basis of environmental impact assessment (EIA) (if needed), environmental conservation plans and programs. As all the procedures take a considerable amount of time the project should be divided between governmental and industrial sectors creating competition resulting in higher work quality.

Conclusions

Summarizing the highlights of this paper the following results are of high importance.

- The project has been carried out for two different scenarios. Integrally, a new infrastructure was simulated to ensure energy security as it reduces dependence on fossil fuels,

while minimizing the electricity imports during peak electricity demand; boosts the economy while inaugurating a new labour sector with the creation of thousands eco-industry jobs.

- By implementing the proposed scenario (GR), 28.8% of total electricity production is projected to come from wind and solar power in 2020, as corresponding share in 2010 was only 5.5%. Taking into consideration a number of aspects, the realization of the project leads to 1.15 billion euros higher profit for the Hellenic State at the end of 2020. As calculated, IRR and PBP for the Green scenario are 11.7% and 8.16 years respectively, hence regarding the investors it is considered much more viable than the usual one. Furthermore it can bring additional income from the sale of unconsumed lignite by the Public Power Corporation (PPC).
- As the Environmental Assessment is a very long and responsible work, only the main issues were overviewed and CO_2 emissions calculated. The Green scenario lowers CO_2 emissions four times more than the business as usual one.

In reality, such a project requires a huge amount of investments. Being a member of the EU community Greece is simultaneously facing a sharp economic crisis. However, Greece has to reconsider its energy policy especially for the electricity production. The triple targets of the 20-20-20 package are considered by the Greek Government as both obligations and opportunities. Despite the free-of-charge mining of lignite, its proven reserves will sustain no more than 40 years. The question is how this forthcoming lignite shortage can be outweighed from the proposed penetration of wind and solar PV systems.

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Paper submitted: December 28, 2013
Paper revised: February 17, 2014
Paper accepted: May 5, 2014