Energy Resources and Their Use in Greece: Possible Paths to Future Economic Development and Sustainability

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1 Introduction

The present paper assesses the potential, over the next one to two decades, of several new technologies and renewable energy sources to increase sustainability, support long-term economic prosperity, promote energy security, and reduce adverse environmental impact in Greece. Energy has always played a critical role in a country's national security, economic prosperity, and environmental quality. Greece's present dependence on vulnerable sources of imported oil and, in the future, on natural gas is a major concern. The other major concerns are the volatility of energy markets, the increasing worldwide demand for energy, and the expected consequences of climate changes. All these necessitate immediate political actions for securing the country's energy future economic development and sustainability. In the face of the above concerns, Greece must consider how to guarantee sufficient, affordable, and sustainable supplies of energy.

Presently, fossil fuels dominate the country's energy landscape. Thus, necessary changes are urgently required so Greece can move towards a more sustainable energy supply and use that will drastically reduce the environmental cost of burning fossil fuels and the country's dependence on imported fuels. Decisions about future energy options require technology choices that involve a complex mix of scientific, technical, economic, social, and political considerations. This study ascertains that, with a sustained national commitment, Greece could achieve considerable energy-efficiency improvements, acquire new sources of energy supply, and effect substantial reductions in greenhouse gas emissions through the accelerated development and deployment of a portfolio of existing and emerging energy-supply and end-use technologies.

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2 Greece's Energy Challenges

In the beginning of the twenty-first century, the global annual growth in primary energy use has been on average almost 3 %. In 2006, the global demand in terms of primary energy was about 490 EJ. Today, over 80 % of the global energy supply is based on fossil energy sources, the most important being oil (35 % of global primary energy supply), coal (26 %) and natural gas (20 %) (IEA, 2008, 2009, 2011).

The ultimate origin of fossil fuels is solar energy that provided the energy needed for the historical accumulation of large amounts of biomass, followed by its transformation through a series of geological processes. Today, the most important renewable energy sources are indirectly (bio-energy, wind and hydro) or directly related to the availability of abundant solar energy. Solar energy has the theoretical potential to cover a large part of the increased energy needs of the entire Mankind. Of the renewable energy sources, geothermal energy has theoretically a great potential as well.

Since the adoption of the Energy 2020 objectives (European Commission, 2010) and Europe's adoption of a long-term strategy towards a low-carbon economy by 2050 (European Commission, 2011), a great deal of efforts have been made to encourage the development and use of energy in a more sustainable manner. Europe needs to be competitive and become less dependent on external energy suppliers. The comprehensive legislative and policy framework on sustainable energy set at the EU level aims at the following specific benefits for the European citizens: clean energy technologies, modern and smart infrastructures, safe and secure energy, hundreds of thousands of jobs, and a better quality of life in the cities. The entire EU is committed to reducing CO_2 emissions and making a radical move towards an almost fully decarbonised energy system by 2050. This means that the share of fossil fuels in the EU will decrease in the coming decades and, whatever are the choices made at the national level, sustainable energy, notably through new and renewable sources or improved energy efficiency, is the direction that we all have to follow.

Greece is highly dependent on imported energy. This is thought to expose the country to crises regarding energy availability and supply and oil and gas prices. Greece's high dependency on oil and gas has resulted in increasing discussions on the need for improvement of the country's energy security. This is considered to be one of the central drivers affecting future energy sector developments. Moreover, in Greece additional problems arise from the ageing energy systems and large greenhouse gas emissions. Thus, environmentally sound energy solutions are required. In fact, revolutionary changes are needed in the energy sector in order to cope with the country's future energy challenges. Principal measures related to meeting the challenges of mitigation and climate change, security of energy supply, as well as economic and environmental concerns, can be divided into two categories, namely, (1) measures enabled by new technology developments and (2) measures enabled by changes in efficient use of energy in industry, in heating/cooling systems of residential and commercial buildings and in transportation.

Renewable energy can supply the world's foreseen energy needs by orders of magnitude. However, with the exception of hydropower, geothermal, and wind, further developments are necessary to make renewable energies cost-competitive. The use of renewable energy is growing rapidly, but it accounts for only about 3 % of the world's primary energy consumption, with only about 1 % from geothermal, wind and solar. In particular, it produces 18 % of the world's electricity, 86 % of it by hydro (Lior, 2008). It should be pointed out that the successful implementation of the various renewable energy sources requires a realistic assessment of their positive and negative aspects. It is well known that renewable energy sources have many clear advantages (i.e. non-depleting and less polluting, limiting the excessive dominance of fossil fuels, etc.). Therefore, they have a strong socio-political appeal that unfortunately sometimes, tends to discount some of the disadvantages of large scale-use of renewable energy. Thus, we must look for renewable energy solutions that are sustainable by definition, i.e. economically, environmentally, and socially. It should be noted that some of the main challenges in massive sustainable implementation of renewable energies are their low energy flux. This necessitates the use of very large areas or/and quantities of materials, with consequence their negative environmental impact, and their time-dependent supply (e.g. with periods of no availability).

Despite all the above, renewable energy sources and new energy efficient technologies can provide distinct benefits to Greece in terms of competitiveness, growth and employment. They can offer an important contribution to security and diversity of energy supply and provide major opportunities in terms of industrial innovation and job creation, including the creation of new industrial sectors. Additionally, the transformation of our energy supply and conversion system will make Greece less dependent on external energy supplies and reduce our external fuels bill. The investments and technological innovation in renewable energy sources and new energy efficient technologies are not only pre-conditions for a low-carbon economy. They can also initiate a green and sustainable knowledge economy. To be successful, these investments must be combined with the development of more cost-competitive technologies that will allow the country to drive down the costs of renewable energy production.

3 Energy Resources and Conversion Technologies

The use of fossil fuels (oil, natural gas and coal) has provided the developed and developing countries with the means to become increasingly more prosperous. This historical model presently faces a number of challenges. The fossil fuels resources are limited and are rapidly being depleted. The present easily exploitable reserves of crude oil and natural gas are estimated to be exhausted in the next 40–100 years. The easily accessible reserves of coal are about twice as large, and probable additional resources would last for centuries at the current energy consumption level. Thus, the world energy supply is predominantly based on fossil fuel reserves and will be for several decades to come (VTT, 2009).

A system for providing energy in a useful form to the end-users primarily consists of an energy source, a transportation (or distribution) network and, in many cases, storage, energy conversion and end-use facilities. Currently, energy is stored in the form of the primary energy source, such as coal, oil, natural gas, etc., and energy production and supply are matched with market demands. Thus, we are mainly concerned with energy supply systems that have an established and widespread infrastructure, for example, electricity and district heat supply systems.

Electricity supply systems include, in addition to power plants, high-voltage power grids and distribution networks. Nowadays, the electrical power network is integrated with telecommunication and tele-control systems in order to ensure safe and reliable operation of the electrical power system. Electrical transmission systems are also expanding rapidly and to much longer distances, yet in most developed countries the core of these systems is antiquated and unreliable, leading not only to large transmission losses but also to severe insecurity of the distribution grid. Unfortunately, both governments and industry have not allotted sufficient funds for the modernisation and improvement of these distribution systems. In the future, the large penetration of distributed generation (i.e. producing energy from small local energy sources), renewable energy sources, demand-side management and energy storages will partially displace energy produced by large conventional plants. Distributed generation will have particular significance, especially in countries, where electricity supply systems are often limited.

Hydrogen is viewed as a possible alternative energy carrier because it is a clean fuel with its only emission being water. However, it has one drawback. In its gaseous form, it has a low density and, therefore, its storage and transportation create some challenges. Like electricity, hydrogen can be produced by a number of technologies using several primary energy sources, many of which are renewable. Carbon-lean technologies (e.g. the electrolysis of water using electricity and/or solar energy, gasification of biomass, etc.) are proposed as the technologies for hydrogen production. The hydrogen economy, including the entire necessary infrastructure, could provide a versatile new energy vector. At present, the use of hydrogen is mainly envisaged as a transport fuel and also as an energy storage medium to balance power production and demand (VTT, 2009).

3.1 Energy Conversion Technologies

The energy conversion technologies discussed in the present paper aim at the reduction of greenhouse gas emissions and the reduced use of depleting fossil resources via the utilisation of renewable energy, near-zero emission technologies, and the development of highly efficient energy conversion processes. For example, large-scale heating requirements, in municipalities and industry, can be accommodated by novel combined heat and power (CHP) conversion technologies. On the other hand, small-scale heating technologies are limited to solar heating, CHP systems based on fuel cells, etc.

The future development steps for carbon capture and storage (CCS) from fossil fuel plants are known as near-zero-emission technologies. The possibilities of CCS in connection with oxygen combustion in fluidised bed boilers, which provides an option for new large CHP and mid-scale (600–800 MW) coal and co-firing plants, as well as retrofits of existing plants, can be the focus of future developments in Greece. Moreover, integrated plant concepts based on fluidised bed pressurised gasification are especially feasible for CCS (VTT, 2009).

Centralised, large-scale bio-energy utilisation is dependent on an efficient procurement system to enable the harvesting, collection, transportation and storage of huge volumes of biomass from fields or forests to the plant. The most efficient and economic concepts of bio-energy utilisation are typically integrated into processes where biomass is primarily utilised as a raw material and its residues or waste are used for energy production. In the future, the production of liquid bio-fuels for transportation can be integrated with upstream industries (e.g. forest-based industry, food manufacturing, waste recycling, etc.) where biomass is used as a raw material.

In principle, carbon capture technologies could be applied to separating the CO_2 originating from biomass, provided the power plant is of sufficient size to justify the cost. Considering the whole life-cycle of biomass, the application of CCS to biomass energy conversion would generate negative atmospheric carbon emissions. Biomass bears certain similarities to fossil fuels, particularly to coal. Therefore, all technological routes for CCS could be applied to biomass energy systems. Biomass could also be co-fired in CCS-equipped coal-fired boilers, which would further reduce the CO_2 emissions from the power plant. The use of biomass is governed by local availability and the biomass cost. It is likely that biomass co-firing would be used predominantly as a means of reducing CO_2 emissions in boilers not equipped with CCS. One can see the potential for bio-CCS in the climate change mitigation scenarios. In the long-term, bio-CCS appears to be a notable option, significantly penetrating into the energy systems beyond 2050 (VTT, 2009).

3.2 Energy Use for Buildings and Transportation

Buildings (residential and commercial) consume about 30–40 % of the world's primary energy. Buildings account for about 45 % of the anthropogenic CO_2 emissions, and are thus an important target for reducing both energy use and CO_2 emissions. The two most important issues closely linked with the efficient use of energy in buildings are: the perennial difficulties of implementing massive improvements in this sector, and the challenging development of 'eco-efficient' or 'living' buildings. It is of fundamental importance to realise that the need for 'eco-efficient' buildings is absolute and not an optional energy conservation issue. Buildings provide comfortable, safe, healthy, and pleasant shelter, while their energy consumption (that also generates the associated CO_2 emissions) is often a major fraction of a building's life-cycle annual cost. It should be noted that technological improvements needed for reducing the energy consumption and

CO_2 emissions of the buildings, are in many cases available with an acceptable cost-benefit ratio based on life-cycle analysis (Lior, 2008).

Transportation accounts for 28 % of the global energy use and 23 % of the global CO_2 emissions. The amount of energy use is obviously affected directly by the fuel efficiency of the vehicle but also importantly by traffic conditions such as the number of vehicle moves (e.g. starting, acceleration, and idling, etc.). Furthermore, the time needed to travel between origin and destination, severely increases due to poor traffic design and control, resulting in significant energy losses and waste of precious time of travellers, but also raises threats to life and health. These consequences of poor traffic design and management can have serious negative economic, environmental and social impacts both individually and nationally. As obvious as all this is, a serious problem is that governments, and even individual vehicle owners, seem to pay much more attention to improving fuel efficiency of vehicles instead of dealing with air pollution and traffic congestion issues that cause enormous losses in terms of health, time, and ultimately economic growth (Lior, 2008).

Today, the transport sector relies on an unbroken and relatively cheap supply of oil for its survival. There is no other sector with such a high level of dependence on one single source of energy. The EU transport sector has an oil dependency of 98 %, the vast majority of which is imported. Transport patterns as well as road, rail, sea faring, and air travelling infrastructures were mainly developed during an era of relatively cheap fossil fuel prices. However, energy intensive pathways are no longer sustainable. In the EU, no other sector exhibits a similar growth rate of greenhouse gas (GHG) emissions as the transport sector. Note that, in the period 1990–2007, the total GHG emissions from transport (excluding international aviation and maritime transport) in the EU-27 increased by 26 % while, during the same period, emissions from non-transport sectors decreased (EREC, 2010).

To meet the Commission's ambition to 'end oil dependence in the transport sector', measures to improve efficiency, expand the use of bio-fuels as well as the promotion of new vehicle technologies (e.g. electric, renewable hydrogen and hybrid cars) are urgently needed. Bio-fuels can play a key role in making the transport sector sustainable. The EU is the world's leading region for both production and consumption of bio-diesel. In 2007, bio-diesel in the EU accounted for 63 % of the world's bio-fuel production. On the other hand, bio-ethanol is the most important bio-fuel at a global level, with the EU accounting for 10 % of its supply. It is estimated that bio-fuels production will increase from 34 Mtoe (million tonnes of oil equivalent) in 2020 to 102 Mtoe in 2050. The Renewable Energy Directive sets a binding target for the share of renewable energy in transport of at least 10 % by 2020, the majority of which will come from bio-fuels (EREC, 2010).

3.3 Energy Conservation

The energy use trends could, and should, of course be reduced by more judicious consumption. Rationally employed conservation is always the first step before other mitigation measures are taken, and is the easiest and cheapest to implement.

In the energy area in general, and in power generation in particular, one could safely say that 'a Joule saved is worth significantly more than a Joule earned' because it takes significantly more than 1 J of energy to generate 1 J of power. This is amplified several fold when one considers the resources and environmental impact associated with the construction and operation of a power plant or even a vehicular engine. It is clear therefore that the first priority in meeting the energy challenges of the twenty-first century is energy conservation. Energy conservation can be significantly improved by the development of highly efficient energy conversion processes, the reduction of blatant waste, the adoption of more modest lifestyles, etc. All these improvements can have a high impact on energy consumption, and importantly, on the associated undesirable emissions and environmental and social consequences (Lior, 2008).

3.4 Renewable Energy Sources

Nature offers a broad range of renewable energy sources, including solar thermal, photo-voltaics, bio-energy, wind, hydropower and geothermal. They all stem in some way or another from the constant flow of solar energy that hits the earth's surface. In fact, the solar energy arriving at the earth's surface in 1 h is about $4.3 \times 1{,}020$ J, which is almost equal to the total energy consumed on the planet in 1 year (U.S. Department of Energy, 2005).

For many centuries, industrialised societies have not been able to exploit this incredibly rich source of energy because of the lack of efficient energy conversion technologies. Today, we have the technologies to largely harvest the various direct or indirect solar energy sources and satisfy a planet hungry for energy. However, when outlining the availability of renewable energy sources, it is important to define their maximum energy utilisation potential (i.e. theoretical, technical and economical). The theoretical potential identifies the upper limit that can be produced from a certain energy resource based on current scientific knowledge. The technical potential takes into account the technical boundary conditions, i.e. the conversion efficiency of technologies, the overall technical limitations, including the land area available for energy generation and the availability of raw materials. The economical potential is the proportion of the technical potential that can be economically realised. Hence, the economic potential takes into account the cost levels which are considered to be competitive.

Thus, the questions to be answered by the renewable energy sector should not only be confined to the desirable centralised or decentralised energy system or to which renewable energy source will dominate in tomorrow's world. The two concepts and all types of energy harnessing technologies must be considered as interdependent if energy supply, climate mitigation and competitiveness are to be secured in a sustainable manner. In the following subsections, a brief outlook of the key renewable energy sources and technologies is presented (Brennan & Owende, 2010; Centi & Perathoner, 2010; Dosch & de Voorde, 2009; EREC, 2008, 2010; European Commission, 2007, 2009a; Martinot, Dienst, Weiliang, & Qimin, 2007;

OECD, 2011; Palz, 2005; The Danish Government, 2011; U.S. Department of Energy, 2008; WBCSD, 2005).

3.5 Hydropower Technology Outlook

The benefits and relevance of hydropower for the renewable energy sector are obvious. Hydropower, in particular, will play a key role in the future through

- The development of hybrid systems combining several technologies to guarantee the maximum energy production in the most efficient way.
- The development of multi-purpose hydro plants with applications in the fields of drinking water supply systems, irrigation channels, flood control and protection, the creation of adjoining environmental areas, waste water treatment plants and recreational purposes.
- The reduction of greenhouse gas emissions. According to a recent study (EREC, 2010), the operation of Small Hydropower Plants (SHP) could annually reduce greenhouse gas emissions such as CO_2 by 29 million tons and sulphur dioxide by 108,000 tons.
- Supporting the development of rural areas via the installation and co-operation of SHP.

3.6 Photo-Voltaics Technology Outlook

It can reasonably be assumed that photo-voltaic electricity will become a mainstream power source in Europe by 2020 and a major power source in 2050. The 'SET for 2020' study (www.SETFOR2020.eu), carried out by the European Photovoltaic Industry Association (EPIA), considered that PV could supply up to 12 % of the electricity demand in Europe by 2020, thus representing 390 GW of installed capacity and 460 TWh of electricity generation. The available land area and buildings in 'zero impact areas' (areas not in competition with food production, natural reserves, housing, industry or other purposes) represent a potential of more than 5,000 TWh of yearly PV electricity production.

All the above estimates are based on present knowledge and technological developments expected in the coming years. With the anticipated improvements in technologies such as concentrated PV and nanotechnologies, one can expect even a higher conversion efficiency and output performance (Dosch & de Voorde, 2009; Parida, Iniyan, & Goic, 2011; PWC, 2009).

3.7 Solar Thermal Electricity Outlook

The installed capacity in Europe is expected to reach 2 GW by 2012, 30 GW by 2020, 60 GW by 2030 and 125 GW by 2050. The technical potential in Europe is estimated at 20 times that figure within reasonable generation costs. For long-term renewable supply in the EU, regional approaches are of paramount importance. By focusing on Solar Thermal Electricity (STE), the EU and its member states should take advantage of the fact that the largest potential of the world is in Southern Europe and the Union's neighbour countries in the Mediterranean region (DESERTEC, 2009; EREC, 2010).

3.8 Solar Thermal Outlook

The importance of the heating and cooling sector in the EU has been clearly recognised, as it currently requires roughly half of the entire energy demand and will continue to be a major player in the total energy consumption. It is anticipated that he overall energy demand for heating and cooling will decline with the implementation of energy efficiency measures for buildings. Therefore, the deployment of renewable heating and cooling technologies must go hand in hand with major energy efficiency improvements in buildings to ensure a widespread take-up of renewable energy systems. Solar thermal has some unique and specific benefits, namely, the direct reduction of primary energy consumption. It is available nearly everywhere, its cost is highly predictable and the systems' lifecycle has a low environmental impact. Last but not least, the use of solar thermal contributes to the security of energy supply and creates local jobs (EREC, 2010; PEW, 2010).

The 2020 goal of the European solar thermal sector, in line with the 'full R&D and policy scenario' developed by the European Solar Thermal Industry Federation (ESTIF), is to have an installed solar thermal capacity of 272 GWh, equivalent to 388 Mio m2 of solar collectors. This corresponds to an estimated 6.3 % of the European Union's 20 % renewable energy target, representing an annual sectoral growth rate of 26 %. Moreover, it will result in an annual reduction of CO_2 emissions by 69 Mt.

3.9 Wind Technology Outlook

The medium term outlook for the wind industry looks strong. In 2009, the European Commission published its communication on 'Investing in the Development of Low Carbon Technologies (SET-Plan)'—COM2009/519, in which it is estimated that Europe needs €6 billion investment in wind energy research over the next 10 years (European Commission, 2009b). According to the European Commission's communication, the return would be fully competitive wind power generation capable of contributing up to 20 % of EU electricity by 2020 and as much as 33 % by 2030. More than 250,000 skilled jobs could be created. The European Wind Energy Association (EWEA) agrees with the European Commission's assessment, highlighting that additional research and significant progress in building grid infrastructure are key to the sector's success. Meeting the European Commission's ambitious plan for wind energy would require 265 GW of wind power capacity, including 55 GW of offshore wind by 2020. The 2030 target of 33 % of EU power from wind energy can be reached by meeting EWEA's 2030 installed capacity target of 400 GW from wind (EWEA, 2009).

3.10 Geothermal Technology Outlook

According to the European Geothermal Energy Consortium (EGEC), geothermal energy can substantially contribute to heating and electricity production, with ca. 20 % of the total EU consumption, or 70 Mtoe for electricity and ca. 30 % of the total EU consumption, or 150 Mtoe for heating and cooling. The availability of the resource, day and night, throughout the year, provides a back-up for the electricity grid anywhere. Thus, the 2020 target is the strengthening of the European geothermal industry by developing hydrothermal resources in Europe and expanding the Enhanced Geothermal System (EGS) concept, as well as by increasing the market penetration of geothermal heat pumps and ensuring a wider spread of geothermal district heating and cooling systems. The 2030 targets are: the decrease in EGS plant costs, the implementation of massive construction programmes, and the transfer of EGS technology outside Europe. Geothermal heat pumps and direct uses will be firmly established and further developed, notably in view of agricultural applications (e.g. heating greenhouses), new applications for pre-heating in industrial processes (high temperature), and new district heating systems for dense urban areas (EREC, 2010).

3.11 Bio-energy Technology Outlook

The leading principles for the further development of bio-energy in future energy systems are sustainability criteria, efficiency and competitiveness. The issues that will drive new developments in the coming years are the integration of bio-energy into supply structures with new conversion technologies, monitoring of bioprocesses, modelling of the whole bioprocess, the development of digestion technologies and training programmes. The technologies that have been already developed and that can have the biggest market potential are the biomass co-firing and combustion in Combined Heat and Power (CHP) plants. Currently, the weakest technology is the bio-hydrogen production, however, it is predicted to have a great market potential in the coming years. Moreover, it is expected that bio-fuels and 'high added' value chemical intermediates will attain a higher market potential with the introduction of second and third generation biomass conversion technologies.

The production of bio-fuels can improve the security of the transportation sector. The first generation of bio-fuels, mainly from Europe, will maintain a significant share of the total liquid fuels consumption. The second generation of bio-fuels from new bioprocesses coming on stream will increase the overall bio-fuels supply. Bio-refineries processing biomass into a spectrum of marketable products will be developed in the coming years and will have an important role in the 2050 strategy (EREC, 2010).

3.12 Renewable Electricity

In 2008, the installed renewable electricity capacity was more than any other conventional source of electricity. In particular, in 2008, the installed renewable electricity capacity made up 57 % of the total 23.8 GW, clearly led by wind, PV and biomass (EREC, 2010).

In order to meet Europe's 2020 climate and energy targets, the EU has to accelerate its ambitious plan of creating a single European power market, based on renewable energy sources electricity (RES-E), an EU Super Grid, and a Smart Grid in order to facilitate an intelligently and efficiently interconnected electricity system of both centralised and decentralised renewable energy installations. From now until 2020, Europe has to invest in new renewable energy production units to replace ageing plants while meeting future electricity demand. Approximately 330 GW of new power capacity needs to be built by 2020, which represents 42 % of the current EU capacity. With an average annual growth rate in renewable electricity capacity of 14 % between 2007 and 2020, the EU will have an installed renewable power capacity of about 520 GW in 2020, which means that an extra 336 GW will be installed in that time.

By 2020, the largest contribution to RES-E will come from wind, hydropower, and biomass. By 2030, this picture changes slightly and wind will be closely followed by PV (556 TWh) and hydropower (398 TWh). Wind and PV continue being the largest contributors up to 2050, but geothermal electricity will see the biggest increase in absolute terms between 2030 and 2050.

4 Greece's Sustainable Path to the Future

4.1 Energy Efficiency and Conservation

Increased adoption of energy efficient technologies is the nearest-term and lowest-cost option for moderating Greece's demand for energy, especially over the next decade. The potential energy savings available from the accelerated deployment of existing energy efficient technologies in buildings, industry, and in transportation sectors could more than offset projected increases in the country's energy consumption through 2030.

Buildings, which account for a high percentage of all energy consumed, have the greatest potential for improvements in energy efficiency. Thus, the use of currently available or emerging energy efficient technologies for buildings could lower energy consumption by 25–30 %, even with the anticipated new energy needs for buildings. These energy savings would eliminate the need of constructing new electric power generating plants except to address regional supply imbalances, replace obsolete generating assets, or substitute more environmentally benign electricity sources. Replacing incandescent lamps with compact fluorescent and new light emitting diode (LED) lamps alone could reduce the electricity use in buildings by 12 %.

Many energy efficient technologies for buildings represent attractive investment opportunities with a payback period of 2–3 years. While lack of information and capital discourages consumers and businesses from using these technologies, setting efficiency standards, incorporating efficiency into building codes, labelling product efficiency, and promoting consumer awareness could dramatically increase adoption of these measures.

The industrial and transportation sectors could also increase their energy efficiency significantly. The industrial sector could expand the use of available systems that both produce electricity and recover waste heat, along with other specific process technology improvements. Using rail for freight shipping could also reduce the transportation sector's fuel use, because it is ten times more efficient in terms of energy use than truck transportation.

4.2 New Supplies of Electricity

Although most electricity is produced conventionally, by burning fossil fuels, several non-traditional sources of electricity have the potential of significantly changing the supply mix during the next two to three decades. They can reduce greenhouse gas emissions substantially but is likely to cost consumers more than the current sources.

Figure 1 depicts the contribution of various energy sources to the total installed electric power in Greece. As can be seen the contribution of the fossil fuels (i.e. oil, gas and coal) is about 76 % of the total.

Coal-fired power plants currently generate most of the electricity consumed in Greece. Domestic coal reserves are sufficient for continued use of coal in power generation, taking into consideration future growth and demand in electricity. However, coal-fired plants produce a significant amount of CO_2, and future restrictions on greenhouse gas emissions may limit their use, unless the CO_2 is captured and stored. Carbon capture and storage (CCS) technology can capture and inject CO_2 into secure rock formations, such as deep saline aquifers, and deep coal beds. This technology has the potential of considerably reducing the amount of CO_2 emissions to the atmosphere from coal-fired plants. Refitting existing coal-fired power plants with CCS could reduce their CO_2 emissions by as much as 50 %, while new plants could eventually produce 90 % less CO_2. The potential exists to replace or refit all coal-fired power plants operating in the country with CCS plants in the future, albeit at considerably increased cost relative to existing plants. However, to demonstrate the reality of this potential at acceptable cost, public and/or private entities need to construct demonstration plants, new and retrofitted, with a variety of fuels (natural gas, biomass, and different types of coal), and carbon capture and storage technologies by 2020. These plants are needed to demonstrate that these technologies can be safely deployed.

Renewable energy sources, such as wind, solar, hydropower, geothermal, and bio-energy have a significant role to play in the future generation of the country's electricity. In 2008, conventional hydropower produced about 5 % (i.e. 3 TWh) of Greece's electricity, but its environmental impact might possibly limit its future

Fig. 1 Contribution of various energy sources to the total installed electric power in Greece. *Source*: Chatziargyriou (2009)

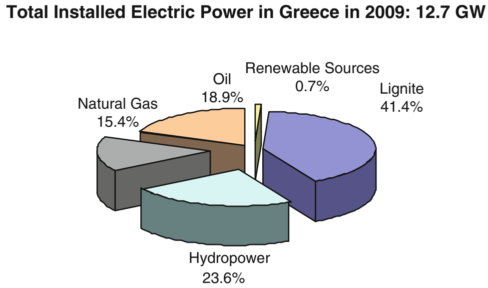

Table 1 Projected contribution of renewable energy resources to the total electric power production

Renewable energy source (RES)	2010 RES power-target (MW)	Percentage to total electric power production
Wind	3,648	10.7 %
Small hydropower plants	364	1.5 %
Biomass	103	1.1 %
Photo-voltaics	200	0.3 %
Geothermal	12	0.1 %
Large hydropower plants	3,325	6.4 %
Total	7,652	20.1 %

Source: Panagos (2009)

expansion. In 2008, non-hydropower renewable sources contributed less than 5 % of electricity. However, the use of both wind and solar power has grown dramatically in the last years. Table 1 shows the projected contribution of RES to the total installed electric power in Greece in 2010.

Overall, wind power has the highest potential in Greece, followed by solar. Apart from higher costs relative to traditional energy alternatives, neither has any technical constraints on expansion. According to the figures of Table 1, RES-E could realistically provide 20 % of the country's needs by 2020. To achieve this potential, however, Greece needs to help the price of renewable energy sources compare favourably with conventional ones. Moreover, because renewable energy sources are intermittent and geographically distributed, their large-scale use will require an expansion of and investment in the transmission and distribution of electric power. Fast-responding back-up electricity generation will be needed as well. If RES-E production increases over 20 % of the total generation, advanced electricity storage technologies will also be necessary.

4.3 The Electric Grid

The country's electric power transmission and distribution network urgently needs upgrading to improve reliability, increase security, and expand the use of energy efficient technologies. Much of the technologies to modernise the grid are available now and can help consumers to save energy, operators to be better informed, renewable energy to be incorporated, etc. The grid could be completely modernised and expanded in 20 years and the benefits, it is estimated, will significantly outweigh the costs. Carrying out modernisation and expansion simultaneously has the additional benefit of further lowering costs and implementing modifications at a faster pace.

4.4 Alternative Liquid Transportation Fuels

Petroleum is an indispensable transportation fuel today and will continue to be so for many decades. Improving vehicle efficiency is the best near-term option for reducing petroleum use. However, some fuel substitutes may become available after 2020. To reduce the country's dependence on imported petroleum, converting biomass into liquid fuels could provide, to an extent, domestic sources for transportation fuels. Cellulosic (non-food biomass) bio-fuel is another major non-petroleum option, although conversion of cellulosic energy crops has not been demonstrated on a commercial scale. Although biomass is renewable, limited availability of land and water resources would restrict its annual output. Conversion of cellulose to liquid fuels would require government incentives to farmers to sustainably grow cellulosic energy crops.

In principle, one can view all photosynthetic organisms as sunlight-driven cell factories that convert CO_2 into organic molecules with bio-fuel potential. It has been estimated that on an area basis, the productivity of photosynthetic microbes (PMs, i.e. microalgae comprising prokaryotic cyanobacteria and eukaryotic 'true' algae) is higher than that of terrestrial plants by at least one order of magnitude. However, there is huge variation among species regarding the lipid content they can attain under specific conditions. Oil contents between 20 % and 70 % of dry biomass weight have been reported and rather conservative calculations foresee yields starting at 60,000 litres/hectare. These figures illustrate the enormous potential of PMs. However, technologies that provide practical solutions, including cultivation and processing for the mass production of PMs on the scale required, are still insufficiently developed (Brennan & Owende, 2010).

The bio-refinery concept fully integrates chemicals and energy chains. The remaining biomass, after lipid extraction, can be utilised in different ways, such as in microbial conversion to methane, hydrogen, ethanol, lipids, or electricity. Additionally, chemical compounds can be extracted as valuable by-products, further benefiting the overall economics of the process. In addition to selecting suitable species as mentioned above, the genetic engineering of PMs could substantially help achieving the economical production of bio-fuel. Photosynthetic efficiency, growth, and yield are obvious traits for optimisation. At present, however, researchers have sequenced and annotated only a few algal genomes. Thus, only more research can generate a solid knowledge base on algae and lead to development of the molecular tools of genetic modification.

4.5 Future Obstacles and Policies

New emerging energy production and supply technologies have to overcome significant barriers before their widespread adoption. These barriers vary across technologies. These include the slow turnover of infrastructure, limited resources, potentially higher costs, concerns about performance, and uncertainty about restrictions on greenhouse gas emissions. As noted earlier, new energy-supply options will be more expensive than conventional fuels. In many cases, significant capital investments will be needed. Investor uncertainty about future energy prices may inhibit investments in new technologies. Policies, such as those that set efficiency standards, support renewable energy, and encourage demonstrations of CCS, solar, wind, and bio-fuels technologies, can help overcome these obstacles.

References

Brennan, L., & Owende, P. (2010). Biofuels from microalgae—A review of technologies for production, processing, and extractions of biofuels and co-products. *Renewable and Sustainable Energy Reviews, 14*(2), 557–577.

Centi, G., & Perathoner, S. (2010). Towards solar fuels form water and CO_2. *Chemistry & Sustainability, Energy & Materials, 3*(2), 195–208.

Chatziargyriou, N. (2009). *Future development of Greek electric production system*. In Workshop on green energy, International Hellenic University, Thessaloniki.

DESERTEC Foundation. (2009). *Red paper: An overview of the Desertec concept*. http://www.desertec.org/fileadmin/downloads/desertec-foundation_redpaper_3rd-edition_english.pdf. Accessed 20 Aug 2012.

Dosch, H., & de Voorde, M. H. V. (Eds.). (2009). *GENNESYS: White paper*. Stuttgart: Max-Planck-Institut für Metallforschung.

EREC. (2008, November). *Renewable energy technology roadmap: 20 % by 2020*. European Renewable Energy Council. http://www.erec.org/fileadmin/erec_docs/Documents/Publications/Renewable_Energy_Technology_Roadmap.pdf. Accessed 20 Aug 2012.

EREC. (2010, April). *RE-thinking 2050: A 100 % renewable energy vision for the European Union*. European Renewable Energy Council. http://www.rethinking2050.eu/fileadmin/documents/ReThinking2050_full_version_final.pdf. Accessed 20 Aug 2012.

European Commission. (2007, January 10). *Renewable energy roadmap. Renewable energies in the 21st century: Building a more sustainable future*. COM(2006) 848 final. Brussels.

European Commission. (2009a, April 24). *The renewable energy progress report*. COM(2009) 192 final. Brussels.

European Commission. (2009b, October 7). *Investing in the Development of Low Carbon Technologies (SET-Plan)*. COM(2009) 519. Brussels.

European Commission. (2010, November 10). *Energy 2020 – A strategy for competitive, sustainable and secure energy*. COM(2010) 639 final. Brussels.

European Commission. (2011, December 15). *Energy roadmap 2050*. COM(2011) 885 final. Brussels.

EWEA. (2009, November). *Pure power: Wind energy targets for 2020 and 2030*. European Wind Energy Association. http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Pure_Power_Full_Report.pdf. Accessed 20 Aug 2012.

IEA. (2008). *Energy technology perspectives: Scenarios and strategies to 2050*. Paris: International Energy Agency.

IEA. (2009). *World energy outlook*. Paris: International Energy Agency.

IEA. (2011). *World energy outlook*. Paris: International Energy Agency.
Lior, N. (2008). Energy resource and use: The present situation and possible paths to the future. *Energy, 33*(6), 842–857.
Martinot, E., Dienst, C., Weiliang, L., & Qimin, C. (2007). Renewable energy futures: Targets, scenarios and pathways. *Annual Review of Environment and Resources, 32*(1), 205–239.
OECD. (2011). *Towards green growth: A summary for policy makers*. Paris: Organisation for Economic Co-operation and Development.
Palz, W. (2005). *A PV roadmap for Europe*. Bonn: World Council for Renewable Energy. http://www.wcre.de/en/images/downloads/wrea_palz_pv_roadmap_europe.pdf. Accessed 20 Aug 2012.
Panagos, T. (2009). *Green energy perspectives*. In Workshop on green energy, International Hellenic University, Thessaloniki.
Parida, B., Iniyan, S., & Goic, R. (2011). A review of solar photovoltaic technologies. *Renewable and Sustainable Energy Reviews, 15*(3), 1625–1636.
PriceWaterHouseCoopers (PWC). (2009, September). *Delivering of earth's solar potential: Concentrating solar thermal power as a solution to the world's energy challenges*. http://www.pwc.com/gx/en/sustainability/assets/earths-solar-potential.pdf. Accessed 20 Aug 2012.
The Danish Government. (2011, February). *Energy strategy 2050 – From coal, oil and gas to green energy*. Copenhagen: The Danish Ministry of Climate and Energy. http://www.ens.dk/Documents/Netboghandel%20-%20publikationer/2011/Energy_Strategy_2050.pdf. Accessed 20 Aug 2012.
The PEW Charitable Trusts. (2010). *Who's winning the clean energy race: Growth, competition and opportunity in the world's largest economies*. Washington, DC. http://www.pewtrusts.org/uploadedFiles/wwwpewtrustsorg/Reports/Global_warming/G-20%20Report.pdf. Accessed 20 Aug 2012.
U.S. Department of Energy. (2005, April 18–21). *Basic research needs for solar energy utilization*. Report of the basic energy sciences workshop on solar energy utilization. Office of Science. http://science.energy.gov/~/media/bes/pdf/reports/files/seu_rpt.pdf. Accessed 20 Aug 2012.
U.S. Department of Energy. (2008, December). *New science for a secure and sustainable energy future*. A report from the basic energy sciences advisory committee. http://science.energy.gov/~/media/bes/pdf/reports/files/nsssef_rpt.pdf. Accessed 20 Aug 2012.
VTT. (2009). *Energy Visions 2050*. VTT technical research centre of Finland. http://www.vtt.fi/files/publications/EnergyVisions_2050.pdf. Accessed 20 Aug 2012.
WBCSD. (2005). *Pathways to 2050, energy and climate change*. Conches-Geneva, World business council for sustainable development, facts and trends series. http://www.wbcsd.org/web/publications/pathways.pdf. Accessed 20 Aug 2012.