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The introduction of Hydrogen Economy in Cyprus

Gregoris Panayiotou and Soteris Kalogirou

***Abstract*-- In this paper the introduction of hydrogen to the current energy system of Cyprus is examinepd. Drivers and barriers towards hydrogen economy are identified and possible solutions are proposed in terms of both policy planning and infrastructure. The introduction of hydrogen to the current energy system of Cyprus will have numerous advantages in all sectors with the main ones being the reduction of the dependency on imported oil, reduction of carbon dioxide emissions, improvement on the local air quality and the environment in general. The only sustainable and renewable path to produce hydrogen in Cyprus is by exploiting the solar potential of the island which is more than enough to cover its energy needs. This can be achieved by either water electrolysis or solar-thermolytic splitting of water.**

***Index Terms*--Hydrogen economy, Cyprus, drivers, barriers, sustainable**

I. Introduction

Energy has always been the dominant driving force for the socio-economic development of mankind. Nowadays the global energy system is highly depended on fossil fuels (i.e. petroleum, natural gas and coal) with all the consequent disadvantages such as energy dependency and environmental pollution posing great danger for our environment and eventually for the life on our planet. Many studies are confirming that fossil fuels reserves and especially oil reserves are depleting rapidly and the only system that is able to replace the current one is that of hydrogen economy or hydrogen energy system as it can be seen in Fig. 1 [1].

According to Veziroglu and Sahin [2] the hydrogen energy system is the best energy system to ascertain a sustainable future, and it should replace the fossil fuel system before the end of the 21st century.

This work presents the current energy situation in Cyprus in terms of energy consumption and renewable energy potential. The introduction of hydrogen economy is also examined while drivers and barriers towards hydrogen economy are identified and possible solutions are proposed in terms of both policy planning and infrastructure.

A. Climate of Cyprus

The island of Cyprus is located in the eastern Mediterranean Sea on an average north longitude of 35° and east latitude of 33°. The climate of Cyprus is characterized as a standard Mediterranean climate and it is mainly affected, as it is obvious, by the fact that that it is surrounded by the Mediterranean Sea. The main characteristics of this kind of climate is that it has hot and dry summers from the mid-May to mid-September, while winter is mild and lasts from the mid-November to mid-March. During the summer period Cyprus as an eastern Mediterranean territory is affected by the seasonal low barometric which has its centre to the northwest Asia and causes the high level of temperatures. More specifically during July and August the mean daily temperatures that appear are around 29°C at the centre of the island and 22°C at the higher tops of Troodos Mountain while the mean monthly temperatures during those months are 36°C and 27°C respectively.

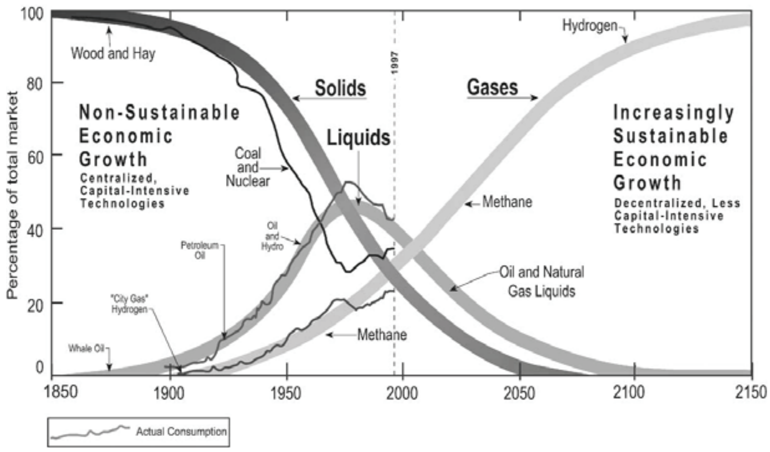

Fig. 1 Global energy system in transition, 1850–2150 [1]

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B. Population of Cyprus

The population of Cyprus, as the population of other countries, is increasing with an exponential trend. As can be seen in Fig. 2 there is an increase of 275,000 during the last 30 years. During the last report available in 2007 the population of Cyprus was equal to 873.900 people [3].

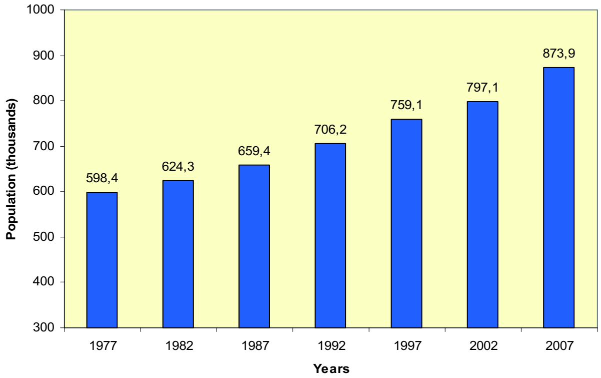

Fig. 2 Population of Cyprus over the last 30 years [3]

C. Current energy system of Cyprus

Cyprus does not have any indigenous energy sources while its power system is totally isolated and it is completely dependent on imported oil which has a share of 96.4% in total primary energy supply and 100% share in electricity production as can be seen from Fig. 3 [4]. The electricity consumption in Cyprus is 5746 kWh/capita which is rather high when compared with other European countries [4]. During the last years an attempt is being made to introduce both natural gas (NG) and Renewable Energy Sources (RES) into the current energy system, an action that faces several difficulties for various reasons. The goal to be reached is 28% share from NG by 2010 and the estimated share of RES is equal to 6% [5].

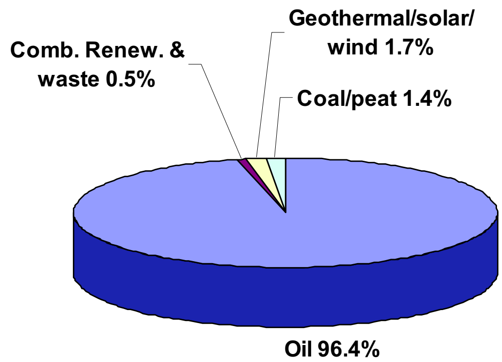

Fig. 3 Share of total primary energy supply for Cyprus in 2006 [4]

Power in Cyprus is produced by three thermal power stations with a total installed capacity of 1118 MWe which are located in Vasilikos, Dhekelia and Moni areas. Vasilikos Power Station has an installed capacity of 428 MW (3 x 130 MW steam units and 38 MW gas turbine unit), Dhekelia Power Station has an installed capacity of 360 MW (6 x 60 MW steam units) and Moni Power Station has an installed capacity of 330 MW (6 x 30 MW steam units and 4 x 37.5 MW gas turbine units). The fuels used for power generation are heavy fuel oil (HFO) for operating the steam plants and gasoil for the gas turbine plants. The load forecast for the period of 2000-2010 is presented in Fig. 4. During the late 70's the electricity generation was ~1000 GWh while the present one is ~5400 GWh and the forecast for 2010 is ~5700 GWh.

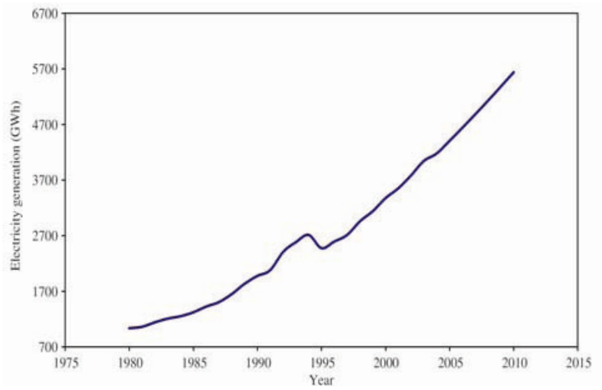

Fig. 4 Current and foreseen energy generation in Cyprus [5]

Another energy-consuming sector of the Cypriot energy system is that of transportation since the number of imported cars is increasing year by year, as it can be seen from Fig. 5. During the last two years has made an increase of 19,000 cars. As it is obvious this sector has a great share in the overall consumption of oil either in the form of petrol or diesel. Great potentials and prospects for energy saving can be achieved in this sector by introducing fuel cell vehicles (FCV's) that are using hydrogen as their 'fuel' and thus their only emission is just water vapour.

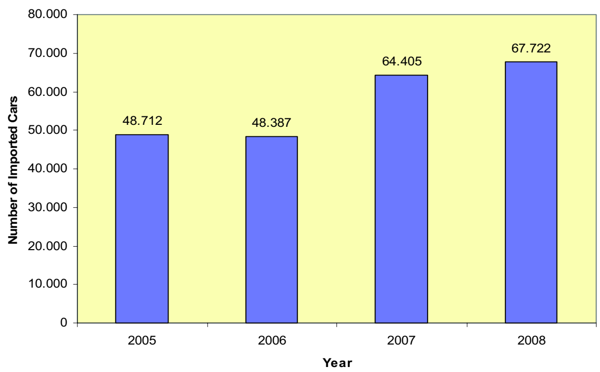

Fig. 5 Number of imported cars in Cyprus over the last 4 years [3]

D. Renewable energy potential in Cyprus

The available RES in Cyprus are that of solar and wind energy along with biomass. Due to the fact that Cyprus has a serious water shortage problem it is logical not to have any hydroelectric potential at all.

Solar potential

Cyprus lies in a sunny belt with an average annual solar potential on a flat surface to be around 1790 kWh/m^2 (Fig. 6). Mean daily global solar radiation varies from about 2.3 kWh/m^2 during the cloudiest months to about 7.2 kWh/m^2 in July [6]. The average number of hours of bright sunshine per day over the summer period is equal to 11.5 h whilst in winter period it is 5.5 h during the worst months (December and January).

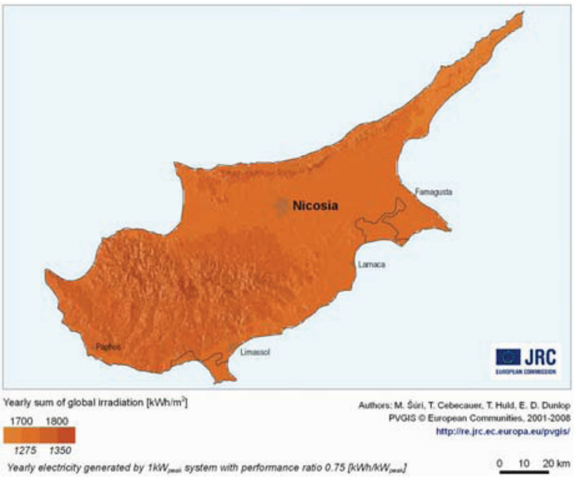

Fig. 6 Global radiation and solar electricity potential for horizontally mounted photovoltaic modules for Cyprus [7]

Wind potential

According to Pashardes et al. [8] the surface winds in the general area of eastern Mediterranean are mostly western or south-western in winter and north-western or northern in summer. Although high wind potential is not typical in Cyprus, several areas in the southern coastal zone of the island are identified as having annual wind speeds greater than 5m/s at 10m height as it can be observed from Fig. 7 [9].

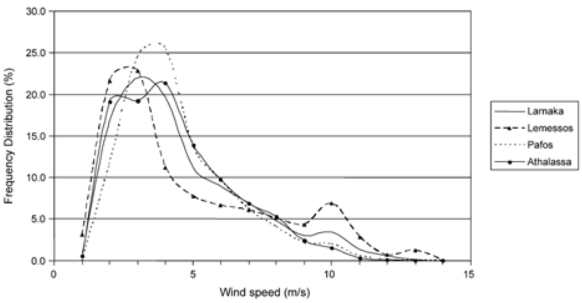

Fig. 7 Frequency distribution vs wind speed of various locations in Cyprus [9]

Biomass potential

Biomass by definition is anything that has organic origin and was grown or created into the time period of human lifetime and can be used to produce energy by a number of processes. So, it is very difficult to estimate the biomass potential of Cyprus since there is a great number of possible sources such as wood biomass and the residues of wood working industry, agricultural residues and agrofood effluents along with manures and the organic fraction of the municipal solid waste. The cultivation of special variety of plants called ‘energy crops’ is not viable due to the water shortage problem.

II. Hydrogen Economy

‘‘There is only one common thread running through these, and that is hydrogen…. That is why even the major oil companies are predicting that the energy future is hydrogen’’ [10].

Hydrogen, although the most basic and abundant element in the entire universe [11], on our planet it is bound up in compounds such as water, oil, coal and many others. Hydrogen is often identified and termed as a fuel which is a misunderstanding due to the fact that essentially it is an energy carrier [12].

Hydrogen has the great advantage that it can be produced by a great number of sources such as all kinds of fossil fuels and renewable energy sources (RES), this fact means that hydrogen can easily penetrate into any current energy system. Of course to be able to consider it as sustainable it should be produced by RES.

Theoretically the global hydrogen potential is inexhaustible and due to the fact that its production is not going to be limited to several areas, the energy dependence will fake out. In addition due to the variety of production methods one day every state could be able to produce hydrogen to cover its own energy needs.

After its production hydrogen can be stored and transported to where it is needed [10] and used either to feed fuel cells to produce electricity for both stationary and portable applications or to feed fuel cell vehicles (FCV’s).

The interest in hydrogen economy is of great importance for all countries especially the USA and the EU. The European Commission included both hydrogen and fuel cell applications in its Strategic Energy Technology Plan (SET-Plan) in November 2007 [13]. Additionally, a European public private partnership named Joint Technology Initiative (JTI) was set up which will spend almost 1 billion euros on hydrogen and fuel cells during 2008-2017.

Cyprus should consider the possibility of introducing hydrogen into its current energy system in order to limit the imports of oil along with the carbon dioxide emissions. Of course this will not be an easy path and it will need a lot of efforts and time from all the energy related agencies together with the government to achieve this target.

A. Drivers towards a Hydrogen Economy in Cyprus

Nowadays, several environmental and energy related aspects are strongly affecting the geopolitical conditions all around the world making the need of a more sustainable world based on a more sustainable energy system a necessity, with Cyprus not being an exception. The most important of these aspects are global warming along with climate change, air pollution and quality and energy security. These matters are often referred to as the drivers towards a hydrogen economy. All of them are also present in the Cypriot reality.

In general, *Climate Change* is of great importance for the environment in a worldwide level and the reduction of carbon dioxide emissions is imperative and this is a reason for a transition to a hydrogen economy.

Energy security is of very high importance for every country due to the fact that energy dependency is affecting their entire policy. By introducing hydrogen into their energy systems the degree of dependency decreases with all of the consequent positive impacts. This is of great importance especially for Cyprus since as aforementioned its energy system is both isolated and completely depended on imported oil.

Air pollution or *local air quality* is also another driver to a hydrogen economy due to the very low air quality observed around the wider areas where energy is produced by the conventional way of burning fossil fuels. The use of hydrogen can highly affect the local air quality since when it is used for energy production it doesn't emit any kind of air pollutants neither carbon dioxide.

B. Barriers to Hydrogen Economy

There are many barriers and difficulties to overcome on the path towards the development of a hydrogen economy. The main ones are:

- The high cost of this technology is the most important barrier for its further development and penetration to the current energy status; however as can be seen from Fig. 8 the cost of fuel cells has a slight decreasing trend which is a rather promising fact.
- The absence of hydrogen infrastructure is very important since aspects like hydrogen production stations, distribution network and refueling/delivery stations should be considered, planned and designed.
- The immaturity of this technology along with several consequent technological difficulties and concerns such as safety, limited life-time of fuel cells and limited current driving range of FCV's will play an important role for the future of the oncoming hydrogen economy.
- Safety issues occurring both from the transportation/distribution and the storage of hydrogen.
- Absence of codes and standards concerning all aspects of hydrogen economy.
- Public acceptance and understanding of these technologies and of their positive socio-economic effects.

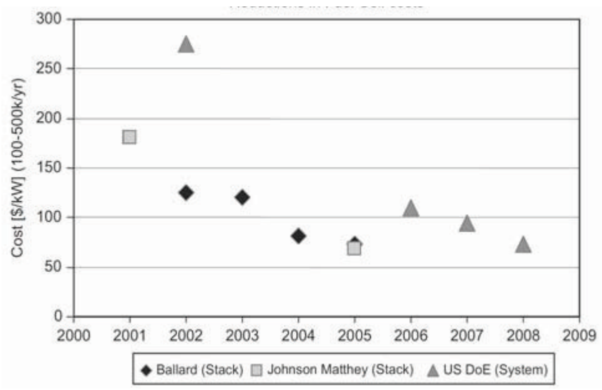

Fig. 8 Reduction in fuel cells costs [14]

C. Hydrogen Production

As aforementioned, hydrogen can be produced by various methods which are divided into two main categories according to the source of energy used namely, fossil fuels and RES.

Currently, the annual production of hydrogen on a global basis is about 600 million m^3 which are mainly used as chemical raw material and in metallurgy with 60% of it being directly produced by steam reforming of fossil fuels and around 40% as a by-product of the petrochemical industry and the electrolysis for chlorine production [15].

Hydrogen can be 'extracted' either from fossil fuels such as natural gas and coal by a process named steam reforming or by a number of different paths from RES.

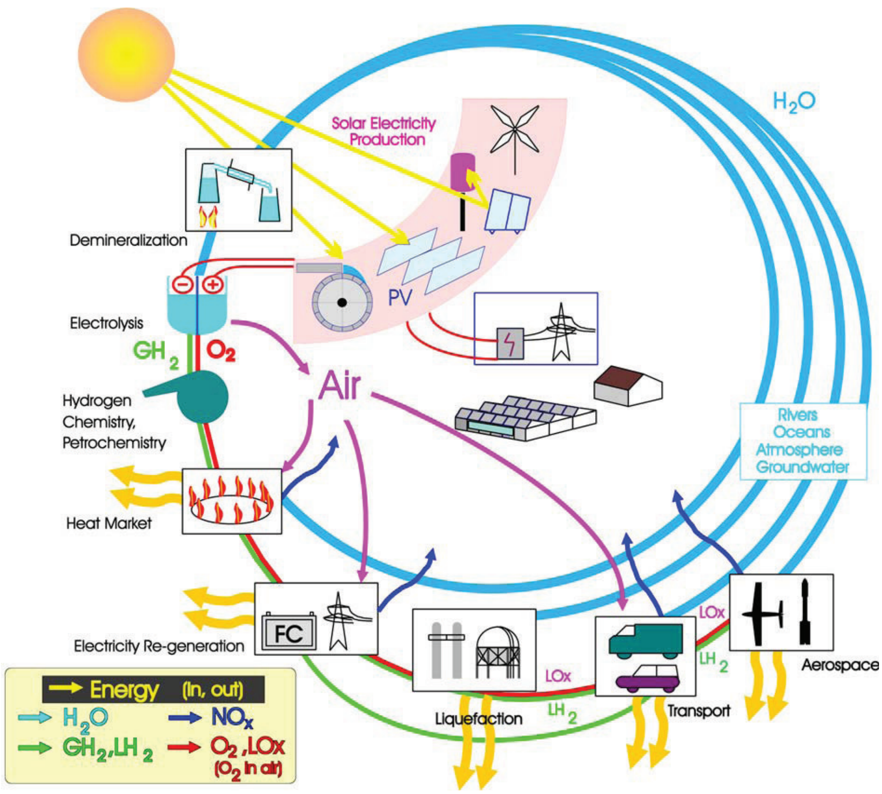

Fig. 9 Materially closed hydrogen energy systems [16]

The paths to produce hydrogen from RES are:

- Water electrolysis using the current produced by RES (solar, wind, geothermal, hydro and wave).
- Pyrolysis or gasification of biomass.
- Biological hydrogen production (biophotolysis and photo-fermentation).
- Photoelectrolysis of water.
- Reforming of biofuels.
- Solar-thermolytic splitting of water.

The main advantage when producing hydrogen from fossil fuels is that this technology is well established and has been used for many years along with the fact that the cost of producing hydrogen from fossil fuels is significantly lower than producing it from RES (Fig. 9). However, the main drawback of this technology is that it still uses fossil fuels with all the environmental concerns and geopolitical problems such as carbon dioxide emissions, pollution and energy security still present.

When hydrogen is produced from RES, then the main and most important advantage is that it is both sustainable and renewable. This means that environmental concerns such as pollution, carbon dioxide emissions and geopolitical aspects such as energy security and fossil fuels dependency no longer exist. Additionally, another important element is that RES are more evenly distributed around the globe which means that energy dependency in some specific areas with all the consequent geopolitical aspects is not present.

Hydrogen production via electrolysis of water and reforming of biofuels are well-established technologies and commercially available. Water electrolysis is a very clean process capable of producing high purity hydrogen (99.999%) that can be used in fuel cells and FCV's. The basic requirement and cost of this process is DC electricity which can be derived from many types of RES directly. The cost of hydrogen when produced by water electrolysis is also depended on the scale of the electrolysis plant (Fig. 10).

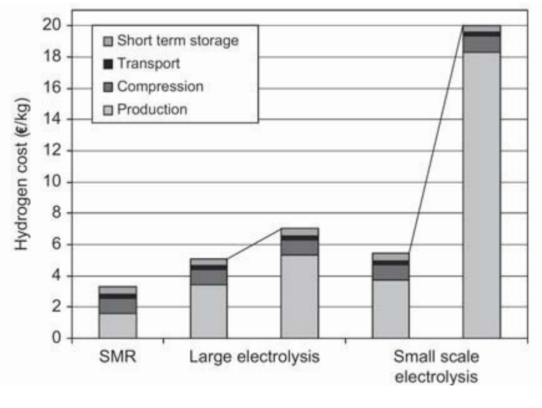

Fig. 10 Hydrogen cost production for three industrial production pathways [14]

D. Topologies of hydrogen based systems

There are many scenarios for the topology of the oncoming hydrogen economy system with the main ones being the decentralized, the centralized and the mix systems. Their main difference is on the scale of the hydrogen producing stations and the distribution system used.

Centralized

A centralized hydrogen system is producing hydrogen on large-scale stations from a variety of energy sources but it is depended on the development of a dedicated hydrogen distribution infrastructure [17]. Also, another concern for this kind of system is that since the hydrogen producing stations are of large-scale then public acceptance is again present while environmental problems might also exist.

Decentralized

This system is based on the local production of hydrogen mostly from electrolysis and biomass processes. Because of this fact, this kind of system is overcoming most of the infrastructural barriers the transition to hydrogen economy faces. In other words this system is of great importance and is allowing the benefits of distributed generation, home refueling and even giving people the ability of 'controlling' energy [18].

Centralized and Decentralized mix system

In this system the advantages of both systems are used depending on the energy needs of each specific area. For example areas with high energy demand are going to use pipelines for the distribution of hydrogen while both kinds of systems are going to supply hydrogen to the market. The degree to which each system will contribute to the final system will depend on the specific profile of each country concerning many parameters such as available energy sources and their distribution together with energy demand. This maybe is the most suitable topology for Cyprus.

III. Conclusions

Cyprus should find ways of decreasing the dependency on fossil fuels, diversify its energy mix and stop paying penalties for excess carbon dioxide emissions. Hydrogen along with RES is the only solutions to these problems. The possibility of introducing hydrogen economy to Cyprus should be initiated in order to create the appropriate conditions to accept and adapt hydrogen economy when the time comes. However, some basic things have to be done such as to inform and educate people about hydrogen and its technologies in order to eliminate any inaccurate prejudices, make a correct and in depth time planning for the introduction of hydrogen into the current energy system of Cyprus and last but not least plan and design the hydrogen infrastructure which will be necessary to support the oncoming hydrogen economy. Of course, from the policy point of view regulations, codes and standards concerning all aspects of hydrogen economy, especially safety, should be formed into a cautiously planned and expressed policy scheme. Additionally, subsidization schemes should be considered by the governmental agencies in order to give people a 'push' towards the start of using hydrogen technologies.

Finally, the only sustainable, renewable and with a great potential way to produce hydrogen in Cyprus is by using solar energy either by water electrolysis or by solar thermolytical process. In this way the only inexhaustible source of energy abundantly available on the island, i.e., solar energy, will be used efficiently. A good start is to introduce hydrogen power buses as part of the reforming of the public transportation system of Cyprus.

IV. References:

[1] R.A. Hefner, The age of energy gases. Int J Hydrogen Energy 2002;27:1–9.
[2] T.N. Veziroglu, S. Sahin, '21st Century's energy: Hydrogen energy system', Energy Conversion and Management 49 (2008) 1820–1831
[3] Statistical Service of the Republic of Cyprus
[4] International Energy Agency (IEA), http://www.iea.org/
[5] A. Poullikkas, Implementation of distributed generation technologies in isolated power systems, Renewable and Sustainable Energy Reviews 11 (2007) 30–56
[6] Meteorological Service of the Republic of Cyprus, 1985
[7] PVGIS, European Communities, 2001-2008, http://re.jrc.ec.europa.eu /pvgis/
[8] S. Pashardes S, C. Christofides, Statistical analysis of wind speed and direction in Cyprus, Solar Energy 1995;55:405–14.
[9] C. Koroneos, P. Fokaidis, N. Moussioupoulos, Cyprus energy system and the use of renewable energy sources, Energy 30 (2005) 1889-1901
[10] P. Hoffmann, 2002. Tomorrow's Energy: Hydrogen, Fuel Cells, and the Prospect for a Cleaner Planet. MIT Press, Cambridge, MA 301pp.
[11] P. Roberts, The End of Oil: On the Edge of a Perilous New World, Houghton Mifflin Company, Boston, 2004
[12] D.K. Garman, 2004. Renewable energy and new technologies. Economic Perspectives: An Electronic Journal of the US Department of State 9 (2), 23–26 /http://usinfo.state.gov/journals/ites/0504/ijee/ ijee0504.pdfS.
[13] Commission of the European Communities, 2007
[14] Roads2HyCom, Fuel Cells and Hydrogen in a Sustainable Energy Economy, Final Report of the Roads2HyCom Project, 2009
[15] A. Ajanovic, On the economics of hydrogen from renewable energy sources as an alternative fuel in transport sector in Austria, Int. J. of Hydrogen Energy 33 (2008) 4223-4234
[16] C.J. Winter, Hydrogen energy – Abundant, exfficient, clean: A debate over the energy-system-of-change, Int. J. of Hydrogen Energy (2009) 1-52 (Article in press)
[17] W. McDowall, M. Eames, Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature, Energy Policy 34 (2006) 1236–1250
[18] J. Rifkin, The Hydrogen Economy: The Creation of the Worldwide Energy Web and the Redistribution of Power on Earth. Polity Press, Cambridge, 2002.

V. Biographies

Gregoris Panayiotou was born in Limassol, Cyprus on February 18, 1983. He graduated from the Technological Educational Institute of Athens as an Energy Technology Engineer and had his Masters in Heriot-Watt University, Edinburgh entitled MSc in Energy.

He is currently employed at the Cyprus University of Technology as a Research Assistant in a project concerning the categorization of buildings in Cyprus according to their energy performance.

He has 3 journal publications and 4 conference publications on aspects like Wind energy potential analysis and evaluation of Fuel Cells' performance. His special fields of interest include Renewable Energy Sources and especially hydrogen technologies.

Soteris Kalogirou was born in Trachonas, Nicosia, Cyprus on November 11, 1959. He graduated from the Higher Technical Institute, and studied at the Polytechnic of Wales and the University of Glamorgan in UK.

For more than 25 years, he is actively involved in research in the area of solar energy and particularly in flat plate and concentrating collectors, solar water heating, solar steam generating systems, desalination and absorption cooling. Additionally, since 1995 he is involved in a pioneering research dealing with the use of artificial intelligence methods, like artificial neural networks, genetic algorithms and fuzzy logic, for the modelling and performance prediction of energy and solar energy systems.

He has 22 books and book contributions and published 185 papers; 79 in international scientific journals and 106 in refereed conference proceedings. Until now, he received more than 1450 citations on this work. He is Associate Editor of Renewable Energy and Energy, Section Editor of Journal of Engineering and Technology Research and Editorial Board Member of another eleven journals. He is the editor of the book Artificial Intelligence in Energy and Renewable Energy Systems, published by Nova Science Inc. and author of the book Solar Energy Engineering: Processes and Systems, published by Academic Press of Elsevier.

He has been a member of WREN since 1992 and is a member of the Chartered Institution of Building Services Engineers (CIBSE), American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE), Institute of Refrigeration (IoR) and International Solar Energy Society (ISES)..