Management of Solar Electricity Production: Opportunities for Sunray Mediterranean Areas

Štefan BOJNEC

Drago PAPLER

Abstract:

This paper investigates natural factor endowments and managament opportunities in develoment of solar electricity production in sunray Mediterranean areas. The focus is on the investigation of the natural factor endowment supply-side factors as potentials for determing and management of solar electricity production. With the regression analysis we have confirmed the crucial role of natural sunray weather conditions as potentials for solar electricity production. We derive conclusions with managerial and policy implications for development of solar photovoltaic electricity production.

Key words:

Solar energy, natural factor endowment, sustainable energy development, Mediterranean Use

Introduction

One of the global challenging issues is global warming and climate change with seasonal changing, but increasing patterns in energy consumption (Nordhaus 1994, Stern 2007, Wagner et al. 2007). In Europe, the European Union (EU) (EU-Commission 2001) aims to promote production and use of renewable sources of energy. We focus on solar electricity production, which is similar as water and wind energy natural renewable source of energy (e.g. Strong and Scheller 1993, Hegedus and Luque 2006).

During the recent years the manufacture of solar cells and photovoltaic arrays has been one of the fastest-growing energy technology and business. Due to the growing demand for renewable energy sources, photovoltaic production has been increasing rapidly, particularly of grid-tied electrical systems built into the roofs or walls of different buildings and installations. Among the main world producers of the solar cells are Japan, Germany, China, other Europe, the United States of America, Taiwan, other Asia, and Australia. Advances in technology, increases in global competition, and manufacturing scale have caused the declining patterns in the cost of photovoltaic, while some countries have also provided different incentives and subsidies for promotion of solar-generated electricity production and/or consumption from renewable sources of energy. Opportunities for purchases of better technologies at relatively declining prices are increasing, which reduces investment costs for the solar energy production.

Among strategic energy objectives of most of developed and several developing countries are to improve efficiency in energy supply and energy consumption and to increase the importance of different renewable sources of energy (e.g. Makipelto 2009). Production and consumption of solar energy has increased rapidly during the last few years, which has been caused by the rapid growth in investments into the solar technology, production and consumption of solar energy.

In this paper we investigate opportunities for solar electricity production in Mediterranean areas focusing on the Northern African countries with geographical proximity towards the European countries. First, we present methodology and data used. Second, we present the empirical results of potential solar photovoltaic electricity production. The case study results confirm natural climatic comparative advantages in solar photovoltaic electricity production in African Mediterranean areas. Third, we derive main policy and business implications. Final section provides main conclusions and implications for future research.

Methodology and data

As the method of analysis we apply descriptive statistics and the regressions analysis (Norušis 2002). We aim to explain natural potentials for solar photovoltaic electricity production, which is determined by sunray at potential locations for solar photovoltaic electricity plants. We focus on a case study of a potential solar electricity plant for city of Tunis. We estimate function of solar photovoltaic electricity production for a potential solar photovoltaic electricity plant Q_{SE} (in kWh), which is explained by natural factor endowment expressed by the sunray per area at the neighbouring meteorological station (Sunray in Wh/m^2) and the steepness of the solar photovoltaic modules on roofs of buildings or other possible constructions (Steepness):

$$Q_{SE} = f(Sunray, Steepness).$$

Moreover, we estimate function of solar photovoltaic electricity production for a potential solar electricity plant in city of Tunis by using monthly meteorological and climatic data. Monthly solar photovoltaic electricity production is explained by the sunray per area, the average monthly temperature °C (Tn) at the neighbouring meteorological data station and the average length of the lighting day (Day):

$$Q_{SE} = f(Sunray, Tn, Day).$$

The regression functions in the logarithm forms are estimated by using the ordinary least square (OLS) method.

The data used are collected from the following websites:
http://valentin.de/calculation/pvonline/pv_system/,
http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php?map=africa&lang=en,
http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php?map=africa,
http://www2.arnes.si/~gljsentvid10/ast_kalk.html or
http://www.xylem.f2s.com/kepler/js_sunrise_moonrise.html.

Empirical results

Impact of location in development and management of photovoltaic systems

With merging of more photovoltaic modules and with use of some other elements such as accumulators, regulators of filling and trafficators, we can construct different possible powerful systems for supply of electrical energy to any possible location, if we have available enough strong sunray radiation. As can be seen from Table 1, which compares the Central European village, Strahinj in Slovenia in Central Europe with the Northern African cities, in the Northern Africa with geographical latitude north from the northern tropic, the most suitable position for photovoltaic modules is the southerly direction with incline of 30 degrees. The similar holds for the geographic latitude south from the southern tropic, but that the most suitable position is the northerly direction with incline of 30 degrees. Along the equator, the most suitable location is a flat area (0 degrees). For 5-20 degrees of geographical latitude northern or southern, the most suitable is 15 degrees incline for photovoltaic modules.

Tab. 1 Effects of solar photovoltaic cells made from polycrystalline siliceous for the Northern African towns by geographical position and inclination in comparison with Slovenia

State, town	**Geographical latitude**	**Geographical longitude**	**0 °**	**15 °**	**30 °**	**45 °**	**60 °**	**75 °**
SLOVENIA, Strahinj	46°17'03" North	14°18'0" East	920	1.001	**1.033**	1.015	948	835
TUNISIA, Tunis	36°49'07" North	10°9'57" East	1.312	1.416	**1.447**	1.403	1.284	1.098
ALGERIA, Alger	36°45'10" North	3°2'31" East	1.299	1.400	**1.430**	1.388	1.270	1.088
MOROCCO, Agadir	30°25'05" North	9°36'40" West	1.547	1.679	**1.714**	1.659	1.515	1.292
EGYPT, Aswan	24°04'54" North	32°54'38" East	1.721	1.829	**1.834**	1.736	1.547	1.278

Source: http://valentin.de/calculation/pvonline/pv_system/ and own calculations.

Sunray conditions and solar photovoltaic electricity production

Production of solar photovoltaic electrical energy is closely associated with the conditions of the sunray radiation on a module, which is changing with the steepness of the photovoltaic module location. As can be seen from Figure 1, the effects of the solar photovoltaic electricity production from the solar photovoltaic cells from polycrystalline siliceous in the case of Tunis as well as in general, is biased significantly to the location and steepness of the photovoltaic module, where the solar fotovoltaige electricity plant is built. By considering the coordinates for Tunis with the northern geographic latitude an optimal orientation of the photovoltaic systems is the southerly direction. In addition, important is the situation of the fixed construction of the photovoltaic modules on roofs of buildings or other open constructions, which is defined with the slope of 31 degrees of the photovoltaic modules. The situation and the slope are calculated with the use of a calculator, which is on the website http:// www.valentin.de for different towns in the world, including for the Northern African countries and for our case study in Tunis.

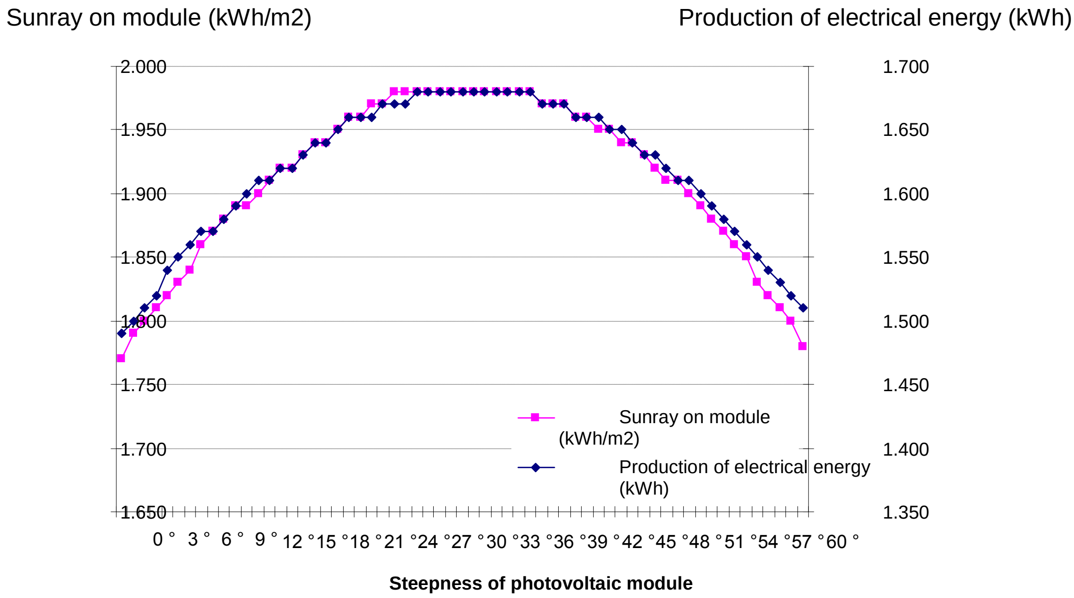

Fig. 1 Association between sunray radiation on a module and production of solar photovoltaic electrical energy, a case study for a solar photovoltaic system in the city of Tunis

Source: http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php?map=africa&lang=en and authors' calculations.

Length of the lighting day

The length of the lighting day depends on the geographical situation and is changing by the location of the towns. We compare the length of the lighting day in selected Northern African towns, Slovenia, and the equator situation using the calculator of the length of the lighting days at the websites: http://www2.arnes.si/~gljsentvid10/ast_kalk.html or http://www.xylem.f2s.com/kepler/js_sunrise_moonrise.html. If the length of the lighting day in Ljubljana in Slovenia is taken as the benchmark of comparisons, then in Aswan is the lighting day shorter for 0.33 %, in Tripoli for 0.23 %, in Tunis for 0.14 %, while in Alger is longer for 0.22 %. Along the equator in Africa (Sao Tome), the annual length of the lighting days in comparison with Ljubljana is longer for 4.95 %.

The number of the lighting days by months in different seasons varies. For example, in January in Ljubljana is the average length of the lighting day 9.01 hours, in Alger and Tunis 9.98 hours, in Tripoli 10.26 hours, and in Aswan 10.83 hours. Along the equator in Africa

(Sao Tome), the length of the lighting day in January is 12.85 hours and has a similar duration time in each month of a year. For example, in June the average length of the lighting day is 13.61 hours in Aswan, 14.29 hours in Tripoli, 14.39 hours in Alger, 14.40 hours in Tunis and 15.71 hours in Ljubljana. There are also some differentials in the average annual length of the lighting days, which among the analyzed cities is the highest near the equator in Africa (Sao Tome) with 12.81 hours, then in Alger 12.22 hours, in Ljubljana 12.19 hours, in Tunis 12.18 hours, in Tripoli 12.17 hours, and in Aswan 12.16 hours.

As can be seen from Figure 2, the average duration of the lighting hours per a month for African Mediterranean and other African cities is more stable than for example for Ljubljana, which is situated in Central Europe. This gives potential operational advantages to solar photovoltaic electricity plants in Mediterranean, particularly North African areas as well as in the deserts Sahara and in the Middle East.

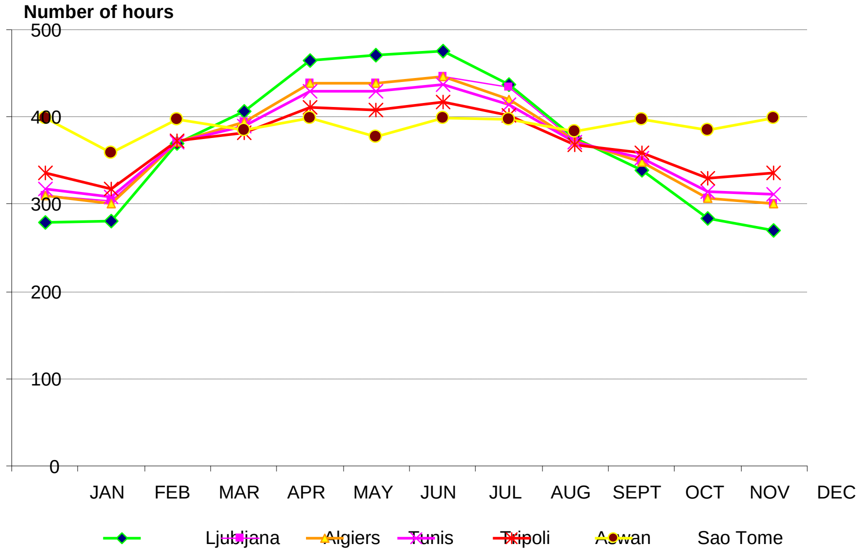

Fig. 2 The number of the lighting hours by months for selected Mediterranean African cities and in Ljubljana

Source: http://www.xylem.f2s.com/kepler/js_sunrise_moonrise.html and authors' calculations.

Sunray radiation per area and solar photovoltaic electricity production

The natural and climatic conditions are important technical determinants of solar photovoltaic electricity production. We illustrate this in the case of Tunisia, which has the Mediterranean climate conditions along the seaside and costal areas, and inside the country is a dry steppe climate, which towards the south switches into desert climate. In the northern parts there is around 600 mm of rains, in the middle parts 400-600 mm of rains, and in the southern parts, where is the desert Sahara less than 100 mm of rains. The city of Tunis has the geographical situation 36° 48′ 0″ N of the northern geographic latitude and 10° 11′ 0″ E of eastern geographical longitude. The average annual temperature is 23 °C, while the average monthly temperature in January is 9 °C and in July 26 °C. On average there is annually 400 mm of rains (Figure 3).

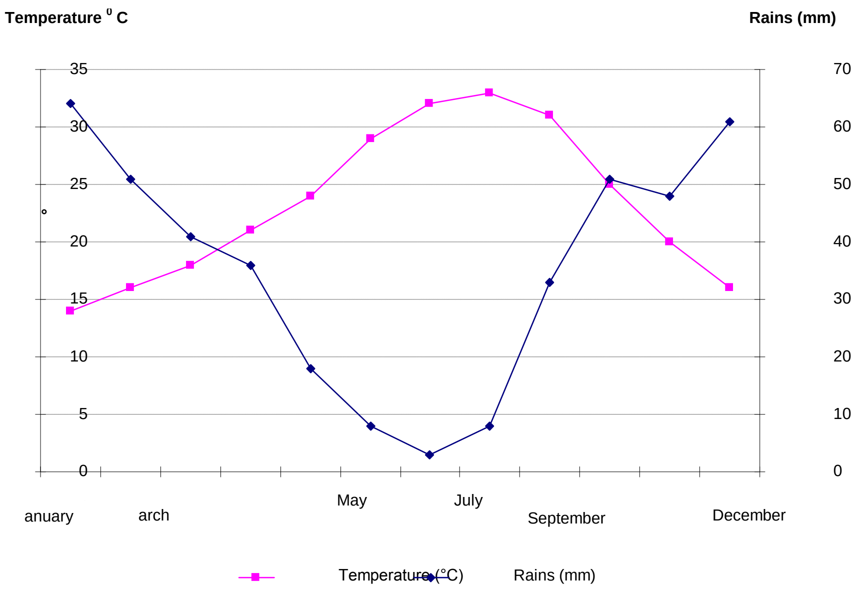

Fig. 3 Monthly meteorological data for the city of Tunis

Source: http://en.wikipedia.org/wiki/Tunis

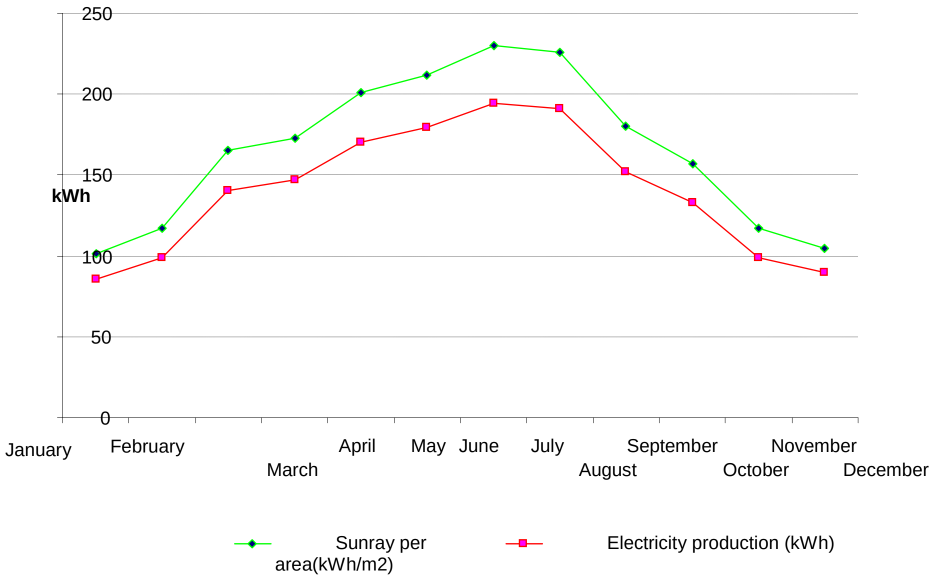

Fig. 4 Sunray radiation per area and potential electricity production from a solar photovoltaic system by months for the city of Tunis (steepness of modules is set at 31 degrees)

Source: http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php?map=africa and authors' calculations.

Figure 4 presents patterns in monthly sunray radiation per area and potential patterns in production of solar electrical energy from solar photovoltaic system in the city of Tunis in a case of the southern-side plant location and steepness of photovoltaic modules of 31 degrees. The estimated optimal sunray radiation per area for the city of Tunis is 1,740 kWh/m^2 annually. This is about one third more than for example for the areas around Ljubljana in Slovenia, which is also the member of the European Union (EU). By considering the Performance of Grid-connected PV at the website http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php?map=africa and by considering estimated possible losses of temperatures due to estimated damages which are caused by extreme temperatures and the slope effect of reflection with changing weather conditions, the estimated potential of annual production of solar photovoltaic electrical energy for the city of

Tunis is 1,340 kWh/m^2. This clearly confirms natural and climatic advantages of the northern African areas in solar electricity production vis-à-vis Slovenia, which has natural and climatic conditions, which are rather similar to the EU average.

Regression analysis

The regression results of solar electricity production for the city of Tunis indicate that the crucial potential determinant for solar photovoltaic electricity production is a favourable natural endowment by the sunray radiation per area. The association between potential solar photovoltaic electricity production and the sunray radiation per area seems to be close to a linear: an increase in the sunray radiation per area by one percent increases potential solar photovoltaic electricity production from 0.91% to 1.05% (Table 1). The impact of the changing steepness of the photovoltaic modules for solar photovoltaic electricity production is significant. This confirms the sensitivity of the solar electricity production on the changing sunray position on the photovoltaic modules.

Tab. 1 Solar photovoltaic electricity production from solar photovoltaic electricity plant in the city of Tunis, annual data

		ln(Constant)	ln(Sunray) (kWh/m^2)	ln(Steepness(°)	AdjR^2	F
1	ln(Q_{SE})	-0.557	1.052		0.993	8605.0
		(-6.506)	(92.763)			
2	ln(Q_{SE})	0.289	0.913	0.045	0.994	4904.5
		(0.995)	(19.455)	(3.032)		

ln – natural logarithm. In the brackets are t-statistics.

Source: Authors' calculations.

Tab. 2 Solar photovoltaic electricity production from solar photovoltaic electricity plant in the city of Tunis, steepness of modules from 15 degrees to 45 degrees, monthly data

		ln(Constant)	ln(Sunray) (in kWh/m^2)	ln(Tn) (°C)	ln(Day) (in hours)	AdjR^2	F
	ln(Q_{SE})	0.075	0.953			0.857	2221.5
		(0.733)	(47.132)				
	ln(Q_{SE})	0.122	0.917	0.045		0.857	1111.3
		(1.084)	(22.106)	(1.013)			
	ln(Q_{SE})	-0.847	0.763	0.070	0.283	0.858	747.5
		(-1.642)	(8.461)	(1.528)	(1.923)		

ln – natural logarithm. In the brackets are t-statistics. Dependent variable: Q_{SE} = monthly solar photovoltaic electricity production. Explanatory variables: Sunray = monthly sunray radiation per area at the meteorological station in Tunis (Wh/m^2), Tn = average monthly temperature in a neighbourhood of solar fotovoltaic electricity plant, and Day = Number of lighting hours by months.

Source: Authors' calculations.

Moreover, we estimate the regression for solar photovoltaic electricity production for a potential solar electricity plant in the city of Tunis by using monthly meteorological and climatic data. Monthly solar photovoltaic electricity production is explained by the sunray radiation per area, the average monthly temperature, and length of lighting hours per a month. The regression results in Table 2 reinforce the significant positive association between solar photovoltaic electricity production and the sunray radiation per m^2. The changing monthly temperatures only modified a slightly the strong positive association between solar photovoltaic electricity production and the sunray variable. The included variable for the lighting day a bit decreases the significance of the regression coefficient and the size of the partial elasticity coefficient between solar photovoltaic electricity production and the sunray variable. The impact of the length of lighting day on solar photovoltaic electricity production is found to be significantly positive.

Policy and business implications

The great availability of free solar energy in the nature and absence of negative environmental emission and externalities from solar electricity production for ecosystem and environment is an advantage in long-term sustainable energy and economic development. Considering the northern African Mediterranean natural and climatic conditions with high intensity of sunray radiation and relatively long sunray period in a year, and the distance proximities to Europe, the development of solar electricity plants in the Northern Africa and Sahara can become an important source of electricity supply not only for the local needs, but also for electricity export to Europe. However, this needs investments both in the solar electricity plants developments and in the electricity supply networks for transfer of surplus of electrical energy from the solar electricity production areas in Africa to Southern Mediterranean European countries.

A great potential for solar electricity production in Sahara, the Northern Africa and in deserts of Middle East gives opportunities for development of solar plantations for electricity production by use of different solar electricity production technologies, which are development or are emerging from solar cells or with water heating for drive of turbine or by columns types or some other possible types of solar electricity plants. This solar electricity production could substitute production of electricity from nuclear electricity power stations and thermoelectricity plants in several parts of Europe, particularly in a case of more intensive investments into solar electricity production in Africa and in high voltage electricity supply networks construction between Africa and Europe. In addition to investments, the expectations are also in new solar electricity production technologies developments with greater abilities of transfer of solar energy into electrical energy adapted for African natural and climatic conditions, and with expected declines in investment costs. This is important for business implementation at micro-enterprise investment level and for broader regional energy and economic cooperation and networking between African Mediterranean, Middle East, and European continents.

Among possible threats, but at the same time additional opportunities for renewable electrical energy production development are wind electricity plants, which have particularly been developed in some European countries. It is expected that both micro-investment efficiency appraisals and social cost-benefit analysis in regional development will play an important role in further development and implementation of different possible strategies in renewable energy production development. However, on long-term it is more likely that different renewable sources of energy such as solar and wind electricity production will become increasingly more important to match with the increasing demands for electricity consumption by growth of population and particularly by growth of real incomes.

Development of solar electricity production in developing African countries could have also import spill over effects on the rest of the economy by providing electrification for rural African villages and in rural areas, for new job creation and reduction of unemployment, thus also contributing to reduction of poverty and mitigating migration pressures from several poor African regions to more developed parts of Africa and particularly to Europe. Therefore, potential development of solar electricity production in developing African countries is a challenging issue for access to electricity and for local employment and incomes in time of global climatic changes in a search for micro-economic private and social cost-benefit efficient ways in development of energy supply and economic development. However, African developing countries also lack knowledge and investment means to efficiently use sunray radiation for energy production and for local economic development to improve living standard of local population. At the same time electrification of African rural areas is a necessary precondition for development of primary processing industry to use local factor endowments towards higher value-added activities and a possible way to use advanced information, communication and other technologies. As this is at the same time associated with aims to reduce global environmental pollution, production of solar energy in sunray African areas is also a global energy policy and business challenge.

Conclusion

In spite of favourable natural climatic conditions, production of solar electrical energy in Mediterranean Northern African and Middle East areas is in an early stage of development. The sunray radiation conditions are identified as a crucial potential for solar electricity production as one of main potentially important renewable sources of energy. Production of the solar electrical energy is biased on sunray radiation, air temperature, wind, and some other weather conditions at the location of the solar electricity plants. The investment appraisal for individual solar electricity projects should consider both the changing economic conditions at the solar electricity energy market and the changing climatic conditions to utilize the solar renewable natural potential for electricity production from this renewable source of energy.

The competitive priorities of investment strategy into the solar energy production should consider market energy and electricity opportunities, which have arisen from the increasing demands for the energy and electrical energy. Although this paper has focused on the supply-side factors, which are determing solar electricity production, three management, business and policy issues are particularly important for the future research. First, this are the market analyses for the solar energy, which consider supply-side factors, demand-side factors, and the critical evaluation of the opportunities for intercontinental energy and electricity cooperation and networking between the Medeterranian African, the Saharian African and in Middle East desert areas, and European countries. Second, the investment appraisal efficiency and investment policy into the solar electricity plants considering technical, economic, and ecological factors in the long-term energy development with considering different sources of energy and particularly different renewable sources of energy, their prices and possible substitution effects. Third, education, research and promotion activities to rise the awaranes on the importance of the investments' economic, technological and ecological efficiency into the solar electricity plants for solar energy production, and on the improved public opinion on the competitive abilitities for the renewble solar energy production in the long-term sustainable energy and economic developments in the sunray Mediterranean areas.

Literature:

EU-Commission (2001). Directive 2001/77/EC of the European Parliament of the Council of 27 September 2001 on the Promotion of electricity produced from renewable energy sources in the internal electricity market. Brussels: European Commission.

Hegedus, S., and Luque, A. 2006. Handbook of photovoltaic science and engineering. Chichester: John Wiley & Sons.

Makipelto, T. (2009) Competitive Priorities of Investment Strategy: Case Wind Power, International Journal of Sustainable Economy, 1(4), 388-402.

Nordhaus, W.D. (1994) Managing the Global Commons: The Economics of Climate Change. Cambridge, MA: The MIT Press.

Norušis, M.J. (2002) SPSS 12.0: Guide to Data Analysis, Upper Saddle River (N.J.), Prentice Hall.

Strong, S. J., and Scheller, W. G. 1993. The solar electric house: Energy for the environmentally-responsive, energy-independent home. Still River: Sustainability Press.

Stern, N. (2007) The Economics of Climate Change. Cambridge: Cambridge University Press.

Wagner, W.R., Beal, C.N., and White, J.C. (2007) Global Climate Change: Linking Energy, Environment, Economy and Equity. London: Springer.