QUANTIFYING THE WATER-ENERGY NEXUS IN GREECE

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ABSTRACT

Water and energy are two of the most valuable elements of modern societies' lifestyle and needs. Therefore, the need for determining, analysing and improving the interconnection of water and energy has recently become an important field of research. On the one hand, water is an essential element for the extraction, refining, processing and conveying energy and for the operation of hydroelectric and thermal power plants. On the other hand, provision of water for any kind of human activities requires huge quantities of energy.

In many regions of the world, availability of renewable water is under constant stress. The exploitable resources can differ significantly from one area to the other. Population and economic development along with climate change add to the stress on water quantity and quality. International organizations, such as the United Nations and the International Energy Agency, are therefore examining the energy-water nexus and analyzing ways of turning the relationship from competitive into cooperative.

In this paper we provide a first assessment of this nexus for Greece, i.e. we explore the required amount of water used per amount of energy produced and vice versa, in the Greek territory. More specifically, the amount of freshwater consumed per unit of energy produced in m^3/MWh is determined: a) for both conventional (lignite, diesel and fuel oil-fired) and advanced (CCGT) thermal power plants in the electricity generation sector; b) for extraction and refining activities in the primary energy production sector; and c) for the production of biodiesel that is used as a blend in the ultimately delivered automotive diesel fuel. Hydropower and Renewable Energy Sources are not taken under consideration, as the corresponding amount of freshwater consumed is considered negligible. In addition, the amount of electricity consumed for the purposes of water supply and sewerage in kWh/m^3 is presented. The necessary processed data have been gathered through: a) on-spot analytical recordings; b) interpersonal or telephone communication with multiple technical departments across Greece; and c) detailed examination of provided financial, technical and sustainability reports. Finally, in view of the expected challenges to the energy and water sectors of Greece as a result of anticipated future socio-economic conditions and climate change, suggestions for the improvement of water-energy use efficiency are made, based on information from national projects, such as NSRF 2014-2020 and on personal estimations of the authors.

Keywords: sewerage, biodiesel, power generation, primary energy, water supply, water-energy nexus, Greek territory

1. Introduction

It is widely accepted that Greece is an advantaged country, if we consider the available water resources and the important potential of exploiting the renewable energy potential such as solar power, wind power, geothermal fields and more. Especially, with the recent discussion and research for fossil fuels that can be technically extracted and financially exploited, this energy-water interconnection becomes crucial for the economical, political and social development of this country.

2. Water for energy

Water is consumed at thermal power plants, for primary fuels (oil and natural gas) and for biofuels production. Hydropower is considered as a renewable energy source and, since the vast majority of water used, returns to its source (i.e. a river or a dam), the quantity of water actually consumed is very small and therefore not considered in our calculations. In addition, water consumption for power generation from renewable energy sources is negligible.

2.1. Thermal power plants

The majority of the installed capacity serves the interconnected system (**mainland** as well as Andros, Corfu, Lefkada, Cephalonia and Zakynthos). Independent power production is conducted in **Crete** and the remaining islands.

In **W. Macedonia**, lignite power plants utilize steam's power in order to produce electricity. Based on information provided by the technical department of the unit located in Agios Dimitrios, water is extracted from ground or surface sources and then it is lead to the plants via pumping stations and/or gravitation pipeline networks. Water is treated in the form of unprocessed liquid in special facilities in order to be softened (removal of salts) at the beginning of the production cycle and in the form of wastewater at the end. In order to reject the unnecessary heat, special towers are used to cool the circulating water. There are three kinds of losses in the cooling tower: a) blowdown losses, b*)* evaporation losses and c*)* drift losses.

Because the quantity of water that is reused (mainly for irrigation of the fields in the broader area) cannot be subtracted from the quantity of unprocessed water that is extracted initially, the final average consumption rate is 2.45 m^3/MWh. During the summer peak demand, this figure can reach the level of *2.70 m^3/MWh.* The main source of water is Aliakmon's lake, but the demand is, also, covered with drillings near thermal power stations.

In **W. Peloponnese** (lignite fired) the average water use is 3.00 m^3/MWh, in **Crete** (diesel fired) the respective value is in the order of 0.10 m^3/MWh and, finally in **Attica-Euboea** (fuel-oil fired) the consumption is 0.0015 m^3/MWh (Zafirakis *et al*., 2014).

Table 1 shows water consumption data for conventional thermal power plants and the share in conventional power production.

Table 1: Water consumption for conventional thermal power stations in Greece

Amount of freshwater consumed for electricity production in m^3/MWh			
W. Macedonia (56%)	W. Peloponnese (11%)	Crete (8%)	Attica-Euboea (25%)
2.45-2.70 m^3/MWh	3.00 m^3/MWh	0.10 m^3/MWh	0.0015 m^3/MWh

According to Hellenic Association of Independent Power Producers (HAIPP), the companies that are engaged in the sector of energy production via **natural gas power plants** are *Protergia*, *Elpedison* and *Heron*, either directly or through their subsidiaries. Public Power Corporation S.A.-Hellas, also, owns natural gas units.

Combined Cycle Thermal Power Plants rely on the combined operation of gas turbines and steam turbines and include heat recovery boilers, three phase modern generators and other accompanying facilities. They are one of the most reliable options for power generation using natural gas as a combustion fuel, especially for application in liberalized energy markets.
Based on data from the international literature and telephone contacts with technical departments of the above mentioned companies, the estimated water consumption, mainly, for the needs of cooling in natural gas power plants is 1.20 m^3/MWh.

2.2. Primary fuels production

The companies operating in this economic sector are Kavala Oil S.A., Hellenic petroleum and Motor Oil (Hellas)/Corinth Refineries S.A. The first one is responsible for the extraction of hydrocarbons and the other two for the refining. For the extraction of lignite, water is used only for drenching and avoidance of dust spreading and is considered negligible.

According to data from the **Kavala Oil S.A.** technical department, 2700 barrels/day of sea water are injected into the deposit in order to support the pressure. In addition, 100 m^3/day of fresh water are consumed for the creation of steam used for the operation of heat exchangers, pumps and other mechanical equipment. The estimated production of crude oil is of the order of 1,200-1,400 barrels/day. Hence the demand of crude oil for water is, approximately, 0.077 m^3 of water per 1 barrel produced or 0.56 m^3/toe.

Regarding **Hellenic Petroleum**, based on the daily production of the refinery in Elefsina, which is around 3500 barrels/h and with an estimated freshwater consumption around 600 m^3/h, the resulting value for the water consumption per unit of crude oil processed is 0.17 m^3/barrel or 1.24 m^3/toe.

In **Motor Oil**, the water demand is covered by seawater treatment desalination units. Multi-Stage Flashing and Reverse Osmosis technologies are used, with the latter to be the most environmentally and economically efficient. With these units, full satisfaction of the refinery's needs in water is accomplished and the subsequent need for purchase of additional fresh-water is eliminated. After the water is used, a part of it is recycled in the desalinators of crude oil; the rest of it is specially treated and led back to the sea. Therefore, the consumption of freshwater is negligible.

The consumed amounts of freshwater for the primary fuels production and the respective share in total national production are summarized in Table 2.

Table 2: Freshwater consumption in Greek refineries

Amounts of freshwater consumed for primary fuels production in m^3/MWh		
Kavala Oil (100%)	Helpe (65%)	Motor Oil (35%)
0.05 m^3/MWh	0.11 m^3/MWh	-

2.3. Biofuels production

The only biofuel that is currently produced at national level is biodiesel and is used in the transport sector. Biodiesel is premixed at a small percentage in all available quantities of diesel. The annually required amounts come from Greek energy crops and raw materials, which are totally absorbed and converted into biodiesel, in the manufacturing plants operating in the country. These additional quantities are produced either from imported raw materials in domestic units or are directly imported as a complete product from other Member States.

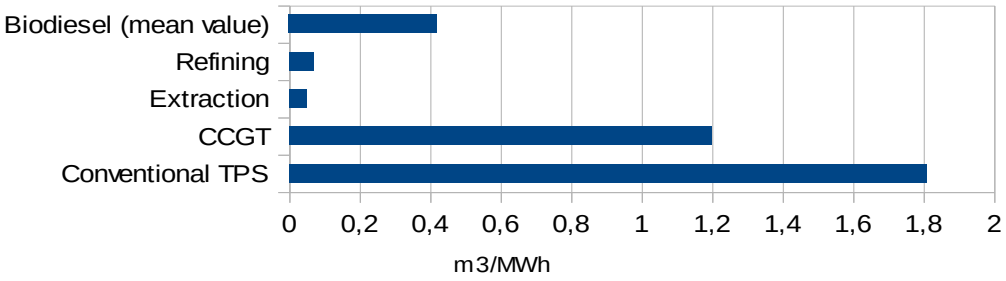
The mixing rate is steadily improving through years. Mixing started by the end of 2005 with a rate of 2.5%. After seven years, in early 2013, fuel B7 is available, a type of diesel consisting of unaltered biodiesel in a percentage close to 7%. B7 is provided at any service station within the Greek territory. The mixing is done either at refineries or companies importing diesel, before delivering it to the wholesale domestic market. The main crops that are cultivated for biodiesel production are sunflower and rapeseed. According to IEA, the water consumption varies approximately from 1.00 to 10.00 m^3/toe.

2.4. Final results

Cumulatively, water consumed in each of the prementioned energy sectors is shown in Table 3.

Table 3: Water for energy in Greece

Amount of *freshwater* consumed per unit of energy produced in m^3/MWh				
Power generation		Crude oil production		Biodiesel production
Conventional*[1]	CCGT	Extraction	Refining*[2]	Rapeseed/Sunflower
1.81 m^3/MWh	1.20 m^3/MWh	0.05 m^3/MWh	0.07 m^3/MWh	0.09-0.86 m^3/MWh



*[1] This value is the weighted average from the values of Table 1.
*[2] This value is the weighted average from the values of Table 2.

3. Energy for water

In many cases, almost 1/3 of a municipality's yearly budget is absorbed by water supply and sewerage systems. The basic reason for this financial status is energy intensive mechanical equipment used for the provision of the prementioned services.

Table 4: Energy for water in 37 municipalities of Greece

Annual amount of water abstracted (from drillings and springs) and bought in m^3		Annual amount of sewage and waste water treated in m^3	
245,695,017		171,986,511	
Annual electricity cost for water supply services in €		Annual electricity cost for sewage and wastewater treatment	
19,997,471.59		8,157,778.36	
Annual amount of electricity for water supply services in MWh		Annual amount of electricity for sewage and wastewater treatment in MWh	
131,562.31		53,669.59	
Energy for water supply in KWh/m^3		Energy for wastewater treatment and sewerage in KWh/m^3	
Calculated	*Possible Value Range*	Calculated	*Possible Value Range*
0.53	*0.35-0.55*	0.31	*0.25-0.45*

During the 25th General Assembly of EDEYA (Hellenic Union of Municipal Enterprises for Water Supply and Sewerage) members, data were gathered concerning the number of serviced residents, water quantities, cost of electricity for water supply and sanitation in 2012. 37 municipalities were involved. The estimation that for the total annual production of water the respective annual percentage of managed wastewater and sewage is 70%, is necessary for conducting further calculations. In addition, the overall price of electricity is considered equal to

0.152 €/kWh. The number of serviced inhabitants based on actual data is approximately 2,000,000. Analysis of the data leads to Table 4.

The calculated amount of electricity for water supply and sewerage can be shown in Figure 1.

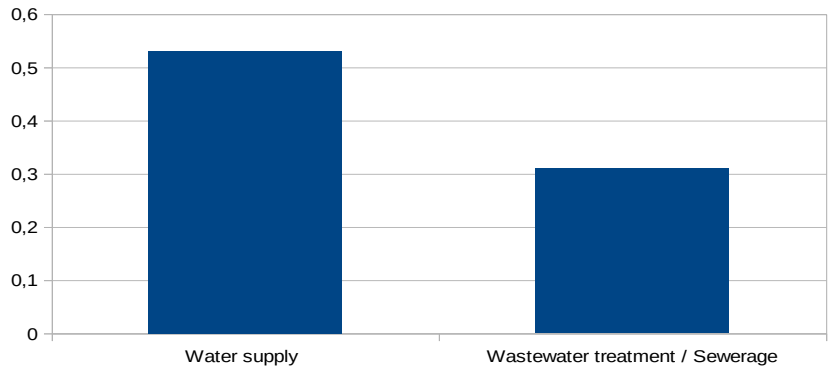


Figure 1: Electricity for water supply and sewerage in Kwh/m^3, in Greece

Regarding desalination in Greece, reverse osmosis units are mainly in operation. For salty water, the corresponding energy consumption varies from 3.00 to 15.00 KWh/m3 and for bracklish, it varies from 0.50 to 3.00 KWh/m3 (Loukas Georgalas, 2010).

4. Conclusion

This paper has presented the first results of an analysis of the water-energy nexus in Greece. The calculated values for both parts of the nexus are, approximately, at the same levels with the ones presented in the United Nations World Water Development Report of 2014, concerning water and energy. As regards the water requirements of the energy sector, a major conclusion is that gradually eliminating conventional power generation units, which are the most water intensive, can significantly reduce water needs. Modern technologies such as CCGTs should be expanded, when it comes to fossil fuel fired power plants. Of course, the major bet is to increase the share of renewable energy sources, with wind power as a leader, followed by photovoltaic systems. The continuous pressure on the aquatic environment sets as a high priority the implementation of sustainable development patterns, through the appropriate design, application and effective operation of methods and projects, which improve not only the supply but, also, the demand for water.

Among the targets of the National Strategic Reference Framework (NSRF) of Greece for the new Programming Period of 2014-2020, water resources play an important role. Ineffective water use both for household needs and irrigation purposes is the major problem. The actions that are promoted are: a) tackling problems in specific protected areas, with sensitive aquatic systems, that are intended for water abstraction and human consumption, b) implementation of water supply and network leakage control projects in order to improve the usage efficiency and quality of drinking water, such as replacement of water supply networks, construction of modern aqueducts, drillings, pumping stations, reservoirs and supplies of remote monitoring and remote control systems, c) implementation of many sewerage network projects and construction of sewage treatment plants, especially in settlements of third priority.

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