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Critical evaluation of the hydropower applications in Greece

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Abstract

Hydropower is a proven technology for electricity generation, contributing with almost 20% to the fulfilment of the planet electricity demand. Hydropower is also renewable because it draws its essential energy from the sun and particularly from the hydrological cycle. Greece and more precisely the west and north part of the mainland possesses significant hydropower potential that is up to now partially exploited. In the present survey, one investigates the existing situation concerning the applications of hydropower plants in Greece, while the results obtained are compared with the corresponding international and European situation. Subsequently, emphasis is laid on estimating the electricity-generation utilization degree of the existing large hydropower stations, using 25-year long official data. The results obtained underline the fact that the electricity generation is not a priority for the national water management policy and most Greek hydropower stations are used mainly to meet the corresponding peak load demand. On the other hand, increased interest to create numerous new small hydropower plants throughout Greece has been expressed during the last 5 years. According to the information gathered and analyzed, one may state that the available local hydropower potential is quite promising and can substantially contribute to the accomplishment of the national-EU target to cover the 21% of the corresponding electricity consumption from renewable resources. For this purpose one should first define an approved and rational water resources management plan and secondly support the increased utilization of large and small hydropower plants for electricity generation. In this case, properly designed hydropower plants

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should lead to considerable profits, contributing also in the country's independency from imported oil and accomplishing the Kyoto protocol obligations.

Keywords: Hydropower; Electricity generation; Large hydropower plants; Small hydropower plants; Water potential; Capacity factor

Contents

1. Introduction

As we move into the 21st century, global economic prosperity is driving the consumption of energy to record levels, with electricity consumption anticipated to increase [1–3] at rates faster than overall energy supply, see also Fig. 1. The vast majority of energy today is provided from carbon-containing fuels, like coal, gas and oil (see for example Fig. 2). However, taking into account the growing global concern regarding the lack of sustainability of these forms of energy several analysts bring into question the use of fossil fuels in a long-term time horizon. Concern over disruptive fossil fuel markets and

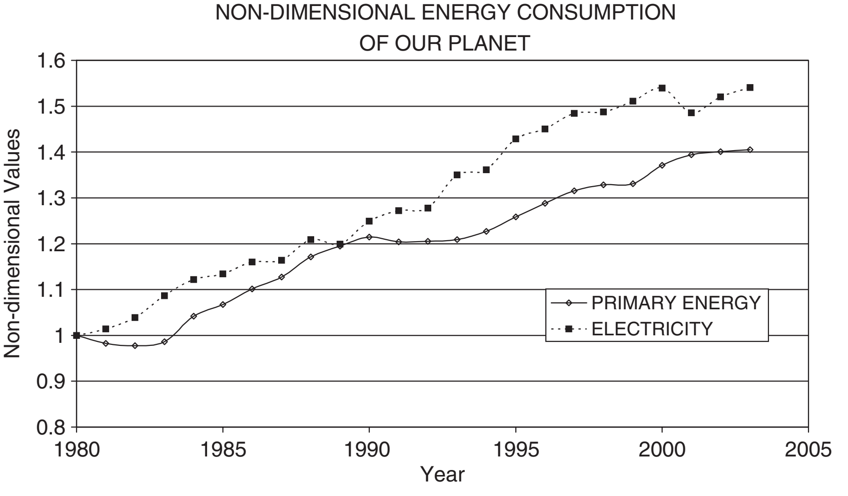

Fig. 1. Worldwide primary energy and electricity consumption time-evolution.

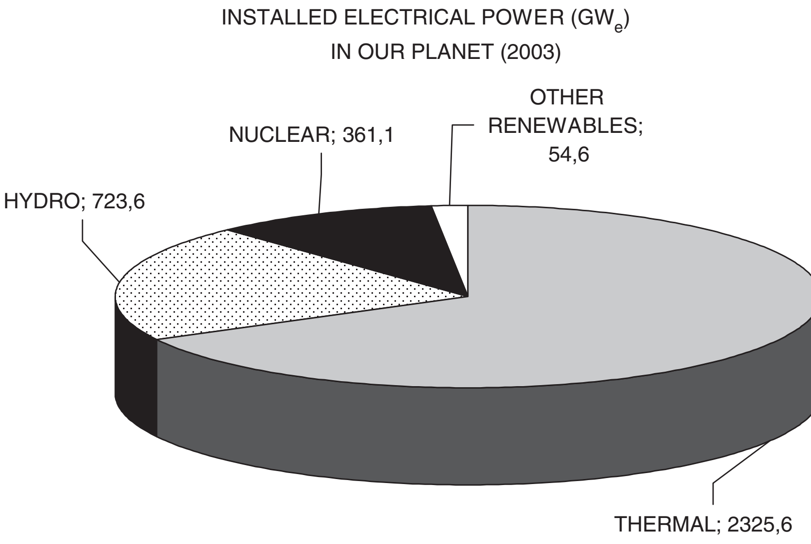

Fig. 2. Hydropower contribution at the planet electrical demand.

uncertain pricing as well as the significant environmental consequences of thermal energy sources have enabled sustainable energy policies that include the significant development of renewable energy supplies [4,5].

Renewable energy technology exists in many forms. From the recent point of view renewable energy is often related to the electricity from wind energy [6], solar energy [7] or geothermal energy [8]. Yet the largest source of renewable energy for electricity production comes from a proven technology [9–11], that of hydropower. Hydropower is renewable because it draws its essential energy from the sun and particularly from the hydrological cycle, which in its turn provides a continuous renewable supply of water. Currently, hydropower represents more than nine-tenth (9/10) of all renewable energy generated, and continues to stand as one of the most viable sources of the new generation into the future. It also provides an option to store energy and to optimize electricity generation [12,13]. Due to the above described characteristics and the fact that the forecasts for the energy future of our planet are not optimistic, hydropower is expected to play a very important role in the future energy balance [14].

Summarizing, some of the main beneficial characteristics of hydropower are the following [15,16]:

- Its resources are widely spread around the world. Potential exists in about 150 countries and about 70% of the economically feasible potential remains to be developed.
- It is a proven and well advanced technology, with more than a century of experience, with modern power plants providing the most efficient energy conversion process (>90%) that the mankind has developed up to now.
- The production of peak load energy from hydropower allows the best use of base load power available from other less flexible electricity sources.

- It has the lowest operating costs and the longest plant life, compared with other large scale generating options.
- The fuel (water) is renewable and it is not subjected to market fluctuations up to now.

In addition to the above mentioned advantages, if one considers the fact that most of the world electric energy comes from thermal resources, which cause significant environmental impacts, hydropower can definitely contribute to a cleaner environment. For instance, almost 2800 TWh of hydro-based electricity worldwide replace either 1200 Mt of coal or 4.5 billion barrels of crude oil. In fact, more than 1300 Mt of CO_2 emissions are avoided due to the hydropower electrical generation (2004 data).

2. Time evolution of hydropower applications in Europe

The world's total technical feasible hydro potential is estimated at 14,000 TWh/yr, which is slightly lower than the entire planet electricity production for the year 2005 ($\approx$15,000 TWh). According to various estimations about 8000 TWh/yr is currently considered economically feasible for development. Moreover, there is now more than 105 GW [14] of new hydrocapacity under construction in comparison with the existing 720 GW, worldwide. Most hydropower projects are very often part of multipurpose developments, providing also benefits such as irrigation water, industrial and drinking water supply, flood control, improved navigation etc. By far the greatest amount of current development is in Asia (84 GW) and South America (14.8 GW), while in Africa and Europe the corresponding new power is 2.4 and 2.2 GW, respectively.

More precisely, in Fig. 3 one may find the "in operation" hydropower time-series since 1980 for both the Western Europe and the entire planet. According to the data available there is a constant increase of new hydropower installations worldwide, since every year approximately 10.5 GW of new hydroplants come into operation. This is not the case for West Europe, since the corresponding new hydrocapacity remains practically constant during the period examined, slightly exceeding the 153 GW.

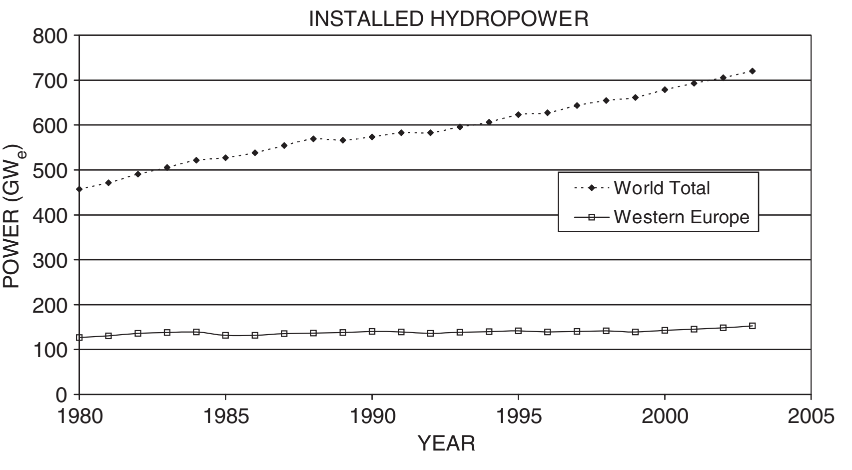

Fig. 3. Time-evolution of installed hydropower.

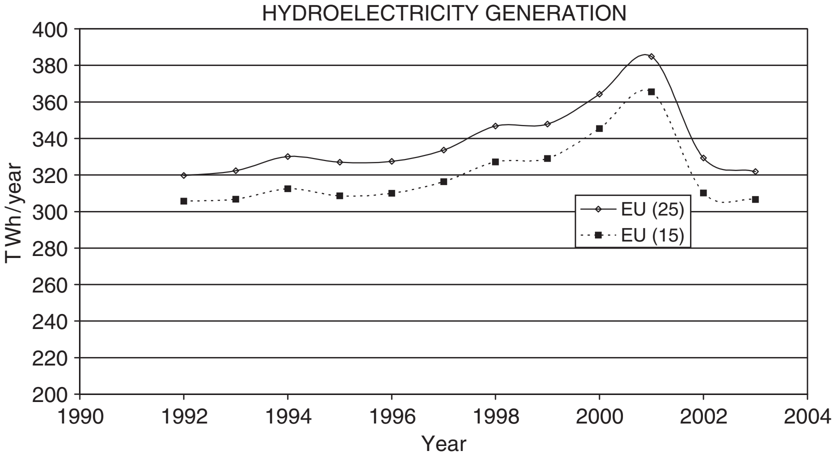

Fig. 4. Energy yield of EU hydropower stations in the course of time.

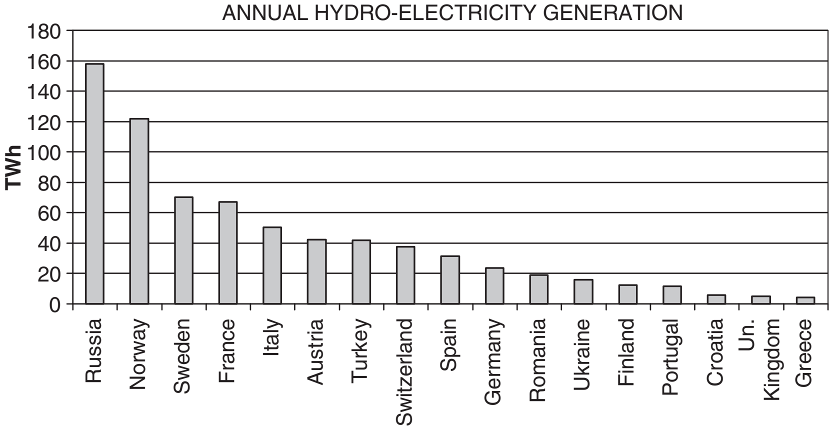

Fig. 5. Hydropower contribution to national energy consumption in Europe.

This situation is also supported by the annual electricity production of the existing hydropower stations in EU-15 as well as in EU-25. In fact, the corresponding electricity production in EU-15 (Fig. 4) varies between 310 and 365 TWh since 1992, while another 15 TWh is the hydroelectricity generation of the 10 new EU members during the same period.

More specifically, hydropower contribution to the total electricity production in Europe varies considerably between countries, ranging from 0% to 99%, see Fig. 5. In fact, a closer inspection of the European hydropower stations map makes clear that most hydroplants are located in Western Europe (France, Italy, Spain) and in Scandinavian Peninsula. Although in many parts of Europe hydropower development has already passed its peak time, there is still considerable activity both in up rating and refurbishment projects. A total of 2210 MW of new capacity is under implementation in at least 23

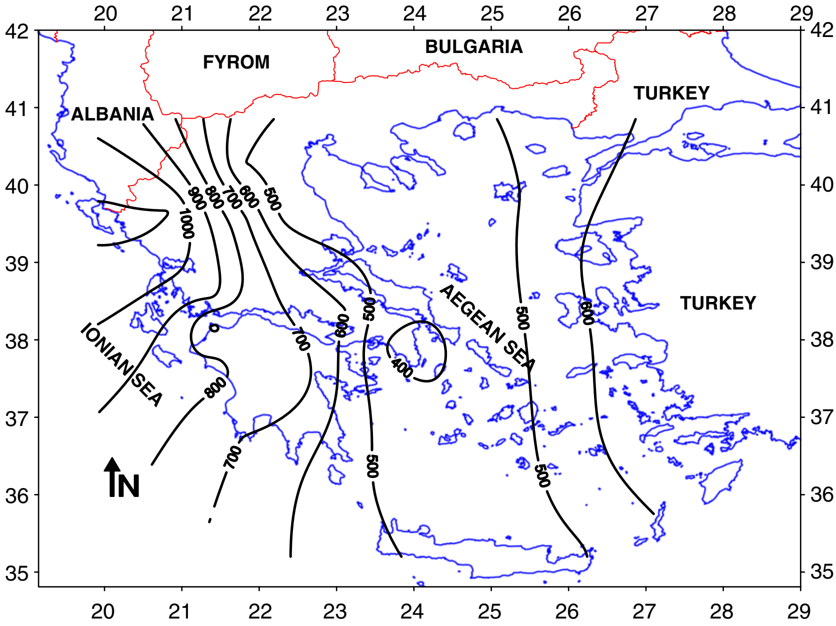

Fig. 6. Annual mean precipitation values (in mm H_2O) for the 1950–2001 period.

countries and more than 8000 MW could be implemented in the near future. The most significant new projects are under way in Bosnia, Bulgaria, Germany, Greece, Iceland, Italy, Norway, Portugal, Romania, Slovenia, Spain and Ukraine.

3. "In operation" hydropower installations in Greece

Greece is, since 1980, a country member of EU and is located in the southeast end of Europe. Greek mainland and more precisely its west part possesses significant hydropower potential that is up to now partially exploited. It is important to mention that the ground configuration (topography) in combination with the relative high precipitation [17], Fig. 6, facilitates the applications of similar power stations. In this context, one may demonstrate in Fig. 7 the "hydraulicity" of the major regions of the country. According to the available data, only a minor part of the local water potential is up to now exploited.

It is also important to note that several rivers go through Greece in Aegean Archipelago. The most important of them are: Evros, Nestos, Strimon, Axios, Aliakmon, Penios, Arachtos, Acheloos, Sperchios and Alfios. From the above mentioned rivers, Acheloos has a considerable water flow of approximately 300 m^3/sec during December (see also Fig. 8), while the flow rate of Axios is almost 230 m^3/sec in March. Finally, the flow rate of Evros varies between 200 and 220 m^3/sec from January to March [18]. Taking into consideration the remarkable water flow rate of all these rivers, it is quite rational that several hydropower installations have been erected in order to exploit their considerable hydropotential.

In Greece, up today, exist fifteen (15) large hydropower (LHP) stations of total capacity of 2950 MW and almost fifty (50) small hydropower (SHP) stations, total rated power

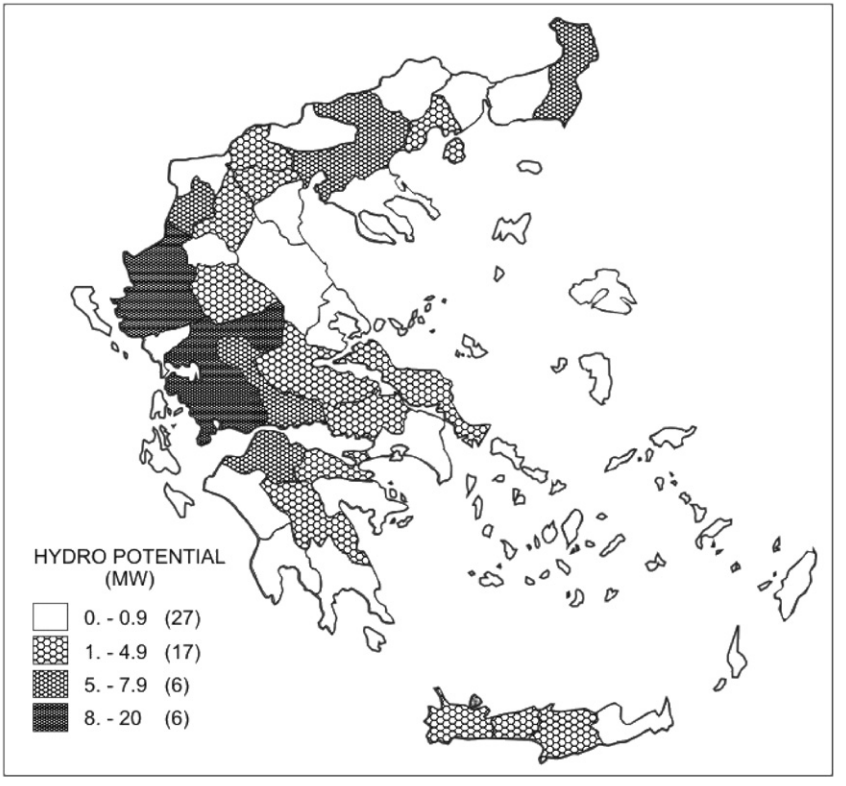

Fig. 7. Greek hydropotential values.

70 MW. The first two power stations being in operation since 1954 are the hydropower stations of Agras (I, II) and the SHP plant of Louros, see also Table 1. Since that period, several much bigger hydropower stations have been erected, like the ones of Kremasta (440 MW), and Kastraki (320 MW) in west Central Greece as well as Polifito (375 MW) in central Macedonia. Unfortunately, during the last 10 years no other new large hydroplant has started operation. In fact, although the hydropower station of Messochora in Thessaly (rated power 170 MW) is ready for operation, this is not allowed due to significant reactions of local communities, which do not accept to be removed in new locations in order to facilitate the operation of the new hydropower station.

It is also important to note that two of the existing LHP stations (i.e. Sfikia and Thissavros) are operating in reversible mode, i.e. as water pumping stations during the low demand periods storing water at high elevation using cheap base load from lignite fired power stations and as hydroturbines during peak load demand periods covering the increased power demand.

The rated power of the hydroturbines used [19] present large variety, i.e. from 15.5 MW up to 125 MW. In most cases, Francis type turbines are used, excluding Plastiras (Tavropos) 3×43.3 MW and Piges Aoou (2×105 MW) installation, where the high hydrodynamic head available imposes the utilization of Pelton type turbines, Table 1.

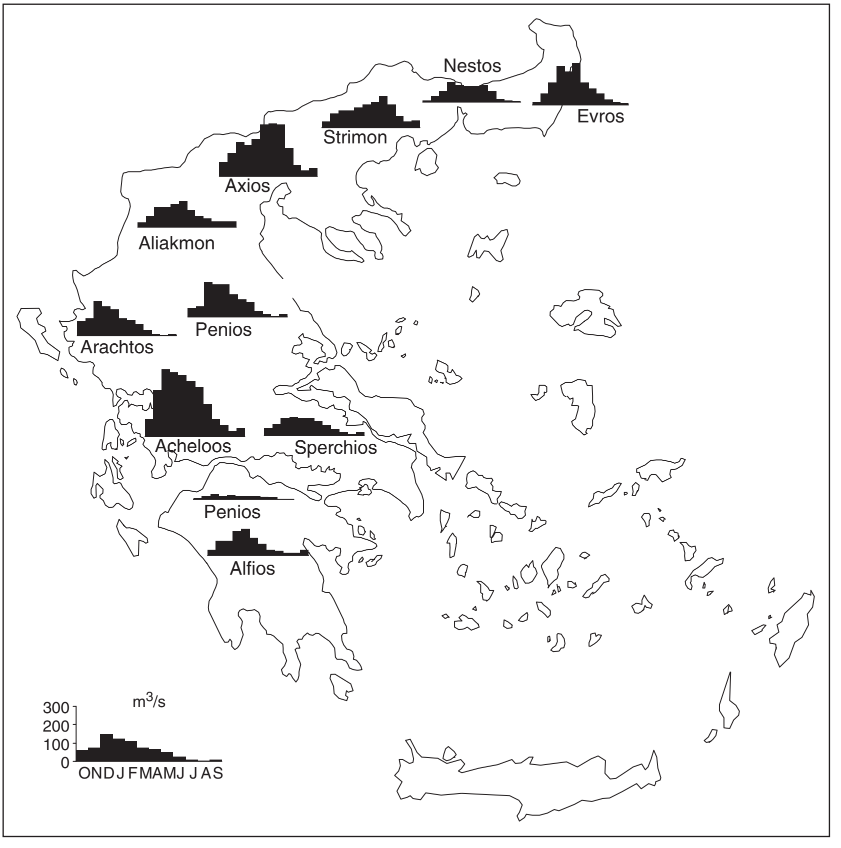

Fig. 8. Mean annual flow rate of the major Greek rivers.

Table 1
Main characteristics of existing large hydroplants

	Location	Start-up time	Power (MW)	Turbine number	Head mH_2O
1	Agras	1954	50	2	158
2	Asomata	1985	108	2	38.7
3	Piges Aoou	1990	210	2	652
4	Edeseos	1969	19	1	120
5	Thissavros	1997	300 (rev)	3	160
6	Kastraki	1969	320	4	76
7	Kremasta	1966	437.2	4	124
8	Ladonas	1955	70	2	239
9	Plastiras	1960	129.9	3	577
10	Platanovrisi	1999	100	2	—
11	Polifito	1974	375	3	146.5
12	Pournari I	1981	300	6	68
13	Pournari II	1985	36.5	2	—
14	Stratos I	1989	150	2	36
15	Sfikia	1985	315 (rev)	3	58.5

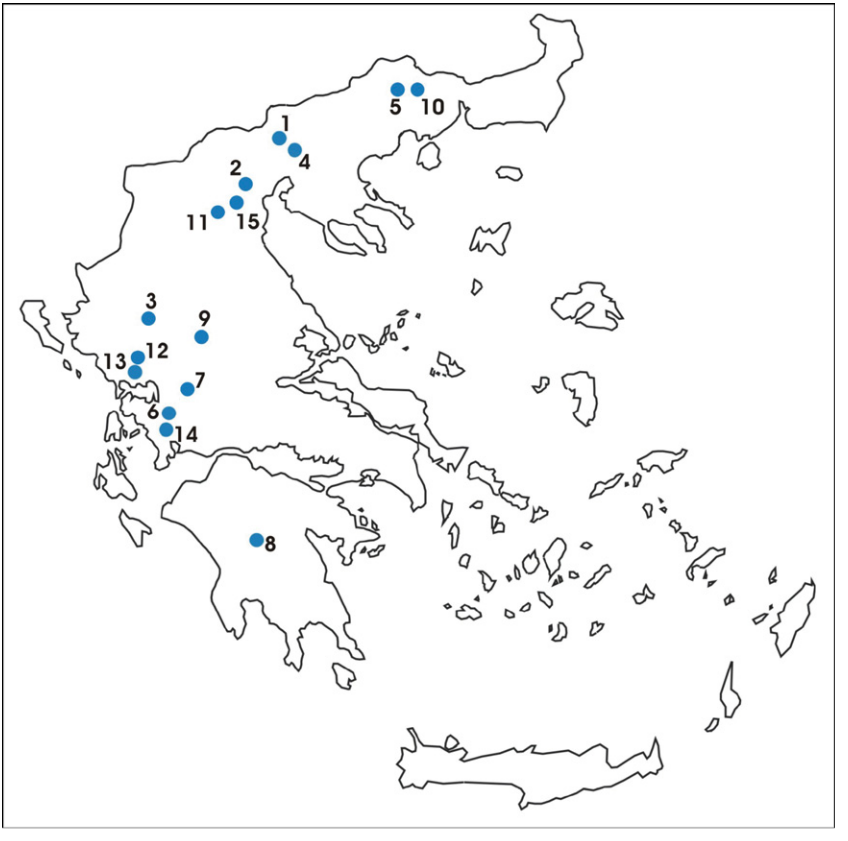

Fig. 9. Geographical distribution of large hydroplants in Greece, see also Table 1.

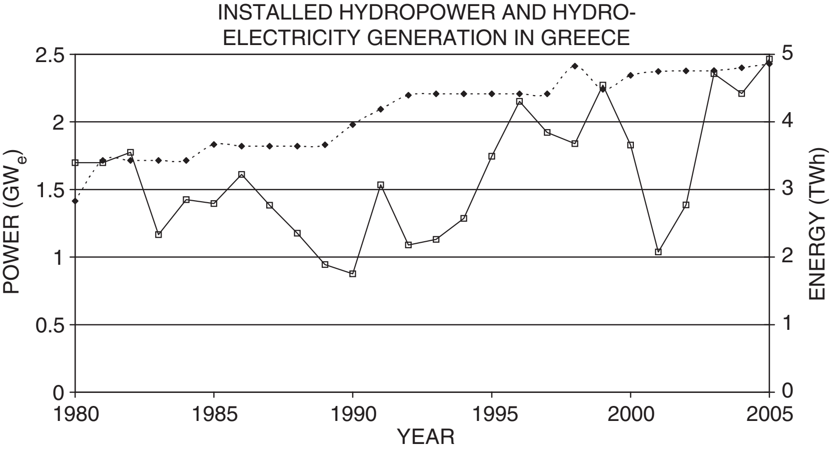

Fig. 10. Installed hydropower (excluding reversible plants) and annual energy yield.

In Fig. 9 one may find the geographical distribution of existing Greek LHP stations. In fact, the major hydropower stations are located in west Greece (Kremasta, Kastraki, Stratos, Pournari, Piges Aoou and Plastiras) as well as in central Macedonia (Polifito, Sfikia, Asomata). The two younger stations of Thissavros and Platanovrisi are located in North Greece, while only the early station of Ladonas exists in South Greece, i.e. in Peloponnesus.

Subsequently, one may investigate, Fig. 10, the time-evolution of the installed hydrocapacity in Greece during the last 20 years, see also Table 1. As it is obvious from the data provided, there is a remarkable hydropower addition between 1980 and 1992, hence the installed capacity was 2200 MW by the end of 1992. In the data presented we do not include the two reversible hydropower stations of Sfikia (315 MW) and Thissavros (300 MW) which started their operation in 1985 and 1997, respectively. The last LHP station which entered the Greek electricity generation system is the one of Platanovrisi in 1999. Bear in mind that during 1998 the new-erected hydropower station of Messochora was ready for operation. However, the strong and dynamic opposition of the local citizens prevents this station to come into operation.

In the same Fig. 10 one may also find the time-variation of the annual electricity generation by the existing LHP stations. According to the official data considerable energy yield variation is encountered, since in 1990 the hydroelectricity was 1.9 TWh and in 2005 approached the 5 TWh. Unfortunately, the hydroelectricity contribution to the local electricity consumption, Fig. 11, is quite limited, since the 25-year average value is only 9.5%. In fact, the hydroelectricity contribution after 1990 has been always less than 11%, taking into consideration the almost constant hydropower stations capacity and the continuously increasing network electricity demand.

Finally, it is worthwhile to investigate the energy-generation utilization degree of the Greek LHP stations during the last twenty-five (25) years. More specifically, the corresponding utilization degree is expressed by the appropriate annual capacity factor "CF" of the installation [20], defined as

$$CF = \frac{\mathrm{E}_y}{8760 \cdot \mathrm{N}_0}, \tag{1}$$

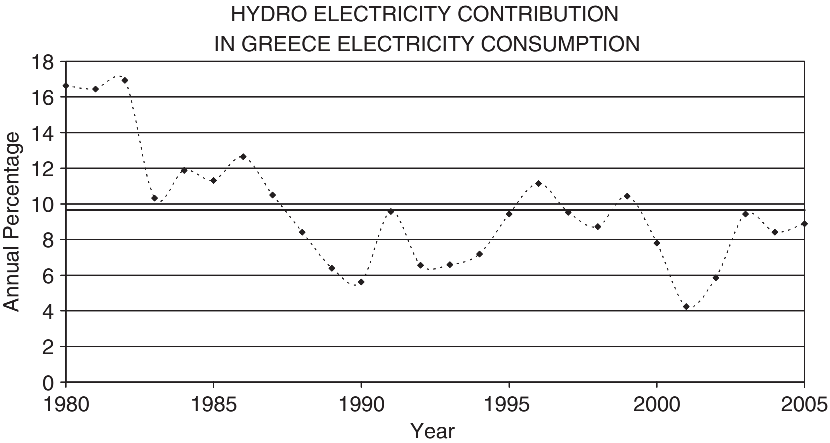

Fig. 11. Hydroelectricity contribution in Greece electricity consumption.

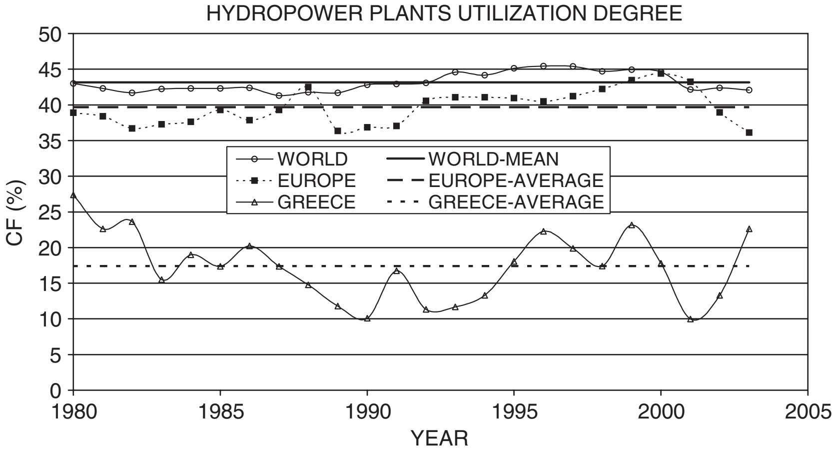

Fig. 12. Existing hydropower stations utilization degree.

where "E_y" is the annual hydroelectricity generation and "N_0" is the corresponding rated power of the installation under discussion. Comparing the calculation results for Greece, Europe and the entire planet (Fig. 12) one should state the following:

- There is a significant "CF" time variation in Greece, which is much more intense than the one in Europe and the entire planet.
- The calculated "CF" values for Greece are considerably lower than the corresponding European and world-wide values (i.e. 17% versus 40–44%).
- The exploitation strategy of the available hydropotential in Greece is entirely different from the one applied in the international electricity generation market. One sound explanation for this difference is the utilization of Greek LHP stations to meet primarily the corresponding peak load demand.

In the next section one is going to provide more details concerning the annual yield of each one of the existing LHP stations during the last decade (1995–2005).

4. Detailed energy production analysis of LHP stations in Greece

The four biggest LHP stations in Greece (Table 1) include the power stations of Kremasta (440 MW), Polifito (375 MW), Kastraki (320 MW) and Pournari-I (300 MW). All these stations were erected 25 yr ago and represent more than 50% of the installed national hydrocapacity. In this group one may also include the reversible power stations of Sfikia (315 MW) and Thissavros (300 MW). Using the long-term energy yield of all these LHP plants, Fig. 13, one may state that Kastraki and Kremasta power stations present considerable utilization degree (CF ≈ 25%), producing together almost 1.5 TWh/yr.

On the other hand, Polifito and Pournari-I LHP stations have a considerable lower utilization degree (CF ≈ 11%), since the available water potential is also used for several parallel activities (mainly agriculture irrigation). Finally, the two reversible LHP stations of Sfikia and Thissavros present fair CF values (CF ≈ 15%), taking also into consideration their remarkable contribution to the local network load management.

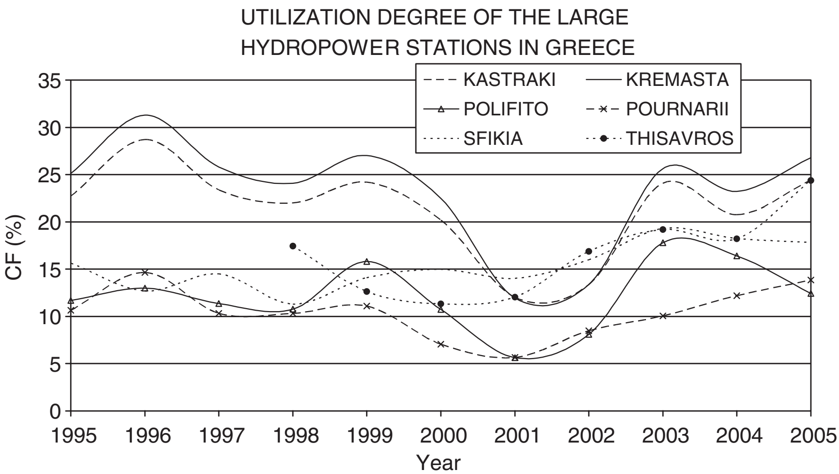

Fig. 13. Existing Greek LHP stations utilization degree.

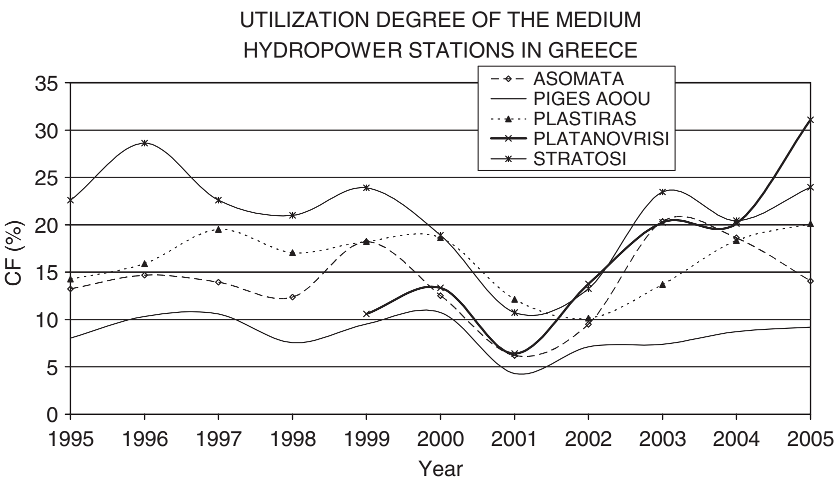

Fig. 14. Existing Greek medium size hydropower stations utilization degree.

The second group contains the medium-sized hydropower stations of Asomata (108 MW), Piges Aoou (210 MW), Plastiras (130 MW), Stratos-I (150 MW) and the most recent one of Platanovrisi (100 MW). According to the existing official data (Fig. 14) Stratos-I (being in the same region with Kremasta and Kastraki, Fig. 9) present the highest CF (CF$\approx$21%) of the group. Acceptable may be also characterized the utilization degree of Plastiras (CF$\approx$16.5%) and Pratanovrisi (CF$\approx$16.5%) hydropower stations. On the contrary, the CF of the biggest power station of this group (i.e. Piges Aoou) is very low (CF$\approx$8.5%) strongly questioning the financial viability [21] of the corresponding investment. Finally, the time-average CF of Asomata hydropower station approaches 14%.

The last subgroup of the existing medium-small hydropower plants include the power stations of Agras (50 MW) and Edesseos (17 MW), the quite recent one of Pournari-II

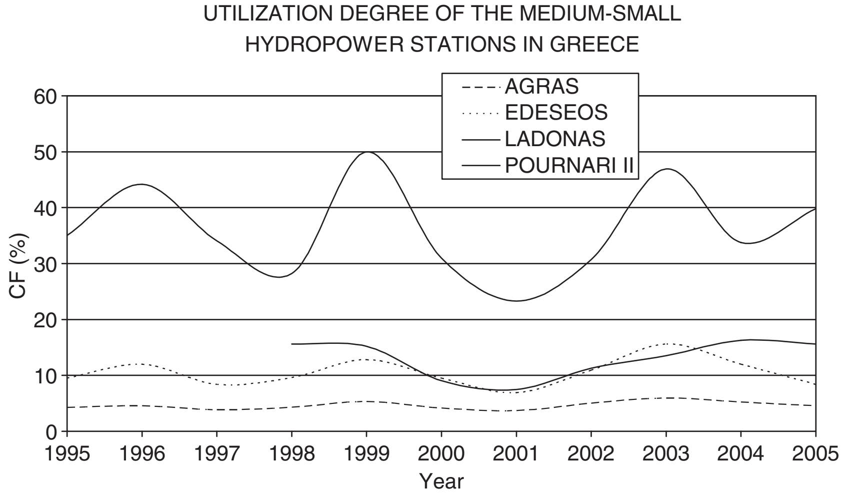

Fig. 15. Existing Greek medium-small size hydropower stations utilization degree.

(36.5 MW) and one of the oldest Greek hydropower stations of Ladonas (70 MW), being the only one located in South Greece, Fig. 9. Using the long-term official energy generation values, Fig. 15, the utilization degree of Agras is extremely low (CF ≈ 4.5%). Similarly, the CF of Edesseos (located nearby Agras) is also very low (CF ≈ 10.5%), proving that both stations are not used by priority for energy production. On the other hand, Ladonas power station presents the best energy utilization degree of all LHP stations in Greece, presenting long-term average CF value higher than 36%. Finally, the relatively new power station of Pournari-II presents similar CF value (CF ≈ 13%) with the biggest Pournari-I power station, which is also rather low.

Recapitulating and using the long-term time-series of electricity generation of existing LHP stations in Greece one may state the following:

- There is not a common energy-generation utilization degree of the existing Greek LHP stations, which present considerably variable CF values, i.e. from 4.5% up to 36%.
- Only the power stations of Ladonas, Kremasta, Kastraki and Stratos-I present an acceptable energy production utilization degree, comparable with the corresponding values throughout Europe.
- The long-term annual utilization degree of Agras, Piges Aoou, Pournari-I and Edesseos is very low, strongly questioning the economic behavior of these power stations.
- All the other hydropower plants present CF values between 10% and 20%, which is also quite low for the international standards.

5. SHP stations in Greece

According to the existing nomenclature a hydropower plant is characterized as small if its rated power is less than 10 MW. The first SHP station which has been operating in Greece since 1927 is the one of Glafkos (1.6 MW) located in N. Peloponnesus [22], while

Table 2
Small hydropower stations in Greece

	Location/name	Property	Power (MW)
1	Vermio I	PPC	1.8
2	Giona, Fokida	PPC	8.5
3	Patra, Glafkos	PPC	4.8
4	Stratos II	PPC	6
5	Tsivlos, Akrata	Private	2.82
6	AG. Marina, Lakonia	Private	1.0
7	Klitoria, Achaia	Private	1.0
8	Platanaki, Ilia	Private	1.3
9	Platanaki Ilia	Private	1.3
10	Makroxori, Veria	PPC	10.8
11	Louros	PPC	10.3

during almost at the same period of time (1929) the SHP station of Vermio (1.8 MW) has been also erected in central Macedonia. Up to 1994, only eight SHP stations, belonging to the State controlled Greek Public Power Corporation (PPC), had been operating with total rated power equal to 42.8 MW. After the application of the law 2244/94 permitting the installation of power stations based on renewable energy sources by private investors [23], an increased interest to create new SHP plants throughout Greece has been expressed.

In fact, on the basis of the available information, currently in Greece operate 32 SHP plants with rated power equal to 60 MW. Eleven SHP stations (Table 2) have rated power between 1 and 10 MW representing the 82% of the entire installed power. On top of this, there are additional very small (mini) hydropower stations (rated power less than 1 MW) with total capacity of 10.7 MW [24]. Out of the eleven SHP plants six (42.2 MW) belong to PPC, while the other five were created by private investors.

It is also interesting to note that all the private SHP plants, along with the Glafkos power station, are located in Peloponnesus, see Fig. 16. Finally, one should also bear in mind that although LHP stations represent the vast majority of the installed hydropower, SHP stations constitute remarkable energy production facilities with considerable higher utilization degree of the available water potential than the LHP plants [25]. This is obvious if we compare in Fig. 17 the time-evolution of the corresponding CF of large to the SHP stations of PPC, for which we have extended operational data. In fact, the average CF of SHP stations is more than two-fold the corresponding value of LHP plants for the last decade examined.

6. Conclusions and proposals

As already mentioned, Greece mainland possesses a remarkable hydropotential, which can significantly contribute to covering the continuously increasing national electricity demand. However, during the last years the installed hydropower capacity stagnates, while the utilization degree of the existing LHP stations is very low. Keep in mind that all the LHP plants in Greece belong to the State controlled PPC, which after the application of the law 2244/94 lost the monopoly of the local electricity market.

Fig. 16. Geographical distribution of small hydroplants in Greece, see also Table 2.

More specifically, in view of the electricity market liberalization procedure PPC is no more interested in creating new LHP plants, taking also into consideration the high initial capital required and the negative attitude of the local people towards new hydropower installations in their region. This discouraging situation becomes even worst due to the entire absence of a rational national water management plant. In fact, in most cases local municipalities and agricultural cooperatives control, via their political influence, the utilization of the available water potential. Hence, the electricity production is not a priority, thus several LHP stations present, during more than a decade, extremely low CF values.

On the other hand, SHP plants are characterized more attractive mainly due to their size and their negligible environmental impacts. More specifically, most SHP stations present quite higher utilization degree of the available hydropotential, while the financial opportunities offered for further exploitation of the local hydropotential in view of the existing techno-economic conditions are quite attractive. However, even for the SHP stations the proprietary problems of water resources should be solved.

Summarizing, according to the information presented and analyzed, one may state that the available local hydropower potential is quite promising and can substantially

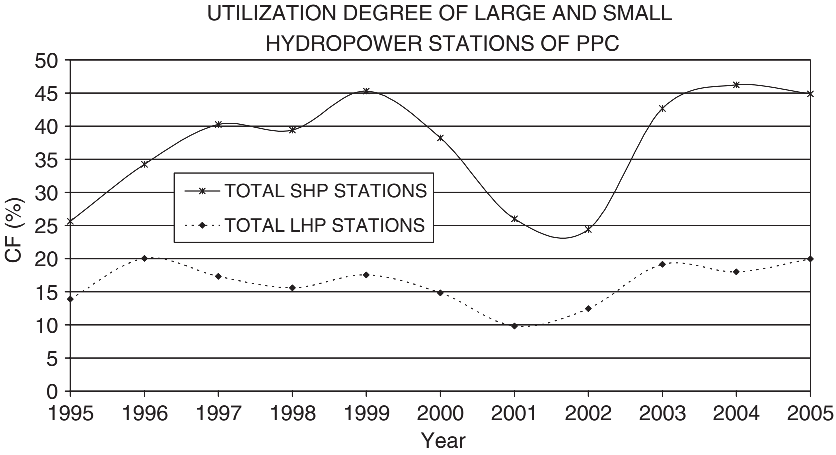

Fig. 17. Comparison of the utilization degree of Greek PPC hydropower stations.

contribute to the accomplishment of the national-EU target to cover the 21% of the corresponding electricity consumption from renewable resources. For this purpose one should first define an approved and rational water resources management plan and support the increased utilization of large and SHP plants for electricity generation. In this case, properly designed hydropower plants should lead to considerable profits, contributing also in the country's independency from imported oil accomplishing as well the Kyoto protocol obligations.

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