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Towards an inventory of the archimedean small hydropower potential of Greece

Alkistis Stergiopoulou[1], Vassilios Stergiopoulos[2]

[1] Institut für Wasserwirtschaft, Hydrologie und Konstruktiven Wasserbau, B.O.K.U. University, Muthgasse 18, 1190 Vienna, (actually Senior Process Engineer at the VTU Engineering in Vienna, Zieglergasse 53/1/24, 1070 Vienna, Austria).
[2] ASPETE, School of Pedagogical and Technological Education, Department of Civil Engineering Educators, ASPETE Campus, Eirini Station, 15122 Amarousio, Athens, Greece.

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Abstract
The present paper describes the evaluation of the Greek Archimedean Small Hydro Resources, considering the basic data for the 14 water regions of the country, adopting a holistic assessment methodology of the total theoretical hydro potential of Greece, which could be exploited by using Archimedean Screw Turbines (ASTs). The total evaluation of the theoretical Archimedean hydropower potential of Greece, which may be produced with ASTs, is of the order of several TWh / year, with a theoretical installed capacity of screw turbines in the range of thousands MW, with important values of special capacity and special capacity density, demonstrating the major existing unexploited hydropower potential for a future true sustainable development with small hydro plants in Greece based on environmentally friendly screw turbines.

Keywords: Archimedean screw Turbines; Renewable Energy; Small Hydro; Greek Hydro-potential.

1. Introduction
During Archimedean hydro technology had a very long history in the world and in Greece. Archimedean Screws Turbines (ASTs) are a new form of small hydroelectric power plant that can be applied in various watercourses even in low head sites. The renaissance taking place actually throughout the world in the promotion and construction of renewable energy low-head small hydro plants valorises ASTs [1-5]. ASTs offer a clean and renewable source of energy and are safer for wildlife and especially fish than other hydro generation options. Archimedean hydropower has attracted recently the attention of many researchers and several European industrial companies are installing such screw plants [4-8]. The following Figure 1 presents a photorealistic view of such an inclined axis Archimedean hydro plant [9].
The rebirth in Greece of nowadays of the Archimedean screw philosophy, as a modern hydropower tool, could cover various hydropower requirements of hundreds of sites. The installation of a series of such small ASTs in the Greek natural and technical watercourses could be relatively simple, with a good efficiency, similar or higher than that of other small water power stations, and costs can tend to be lower on low head sites [3-11]. Such ASTs could be used for small heads, in the range of 1 to 5 m, with various

flow rates between 0.1 to 50 m^3/s and should be inclined at an angle, between 22°and 33° from the horizontal [4, 6, 7]. For greater heads, a cascade of two or more similar ASTs could give an efficient hydropower solution. For the case of important water discharges the Archimedean technology imposes two or more ASTs in parallel. Two photorealistic views of Archimedean plants, with three rotors in series and in parallel, is given in the next Figure 2 [9].

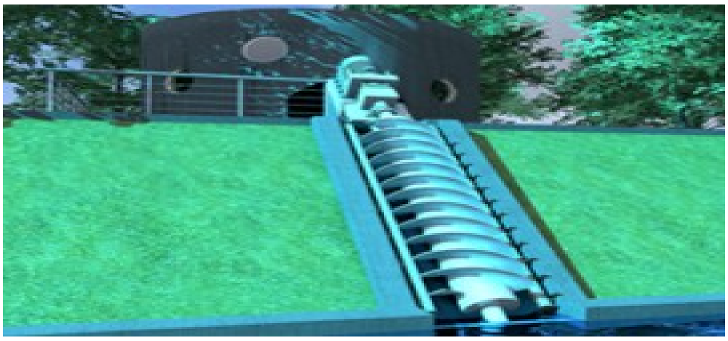

Figure 1. Photorealistic view of one AST (photo A. Stergiopoulou).

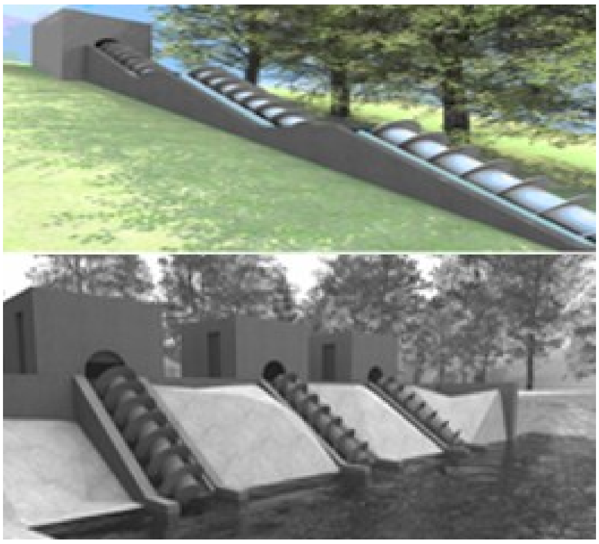

Figure 2. Photorealistic views of ASTs having three screw rotors in series and in parallel (photos A. Stergiopoulou).

Many watercourses in Greece could be used as source of small hydro power plants using ASTs. The total availability of small-scale potential water resources is enormous in Greece and have different characteristics. Taking into account that the new ASTs could cover the significant, but so far mostly untouched renewable and green energy of small hydropower, with very low head differences it is necessary to study the inventory of the Archimedean Small Hydropower Potential of Greece [9].

2. Some Basic Greek Hydraulic Data

Greece with a surface 131.913 km^2, is rich in small and large watercourses, having various catchment areas, with rough terrain, steep slopes and non-uniform precipitation distribution [4, 9]. The country is divided in the following 14 Water Districts presented in Figure 3 (01) W. Peloponnese, (02) N. Peloponnese, (03) E. Peloponnese, (04) W.C. Greece, (05) Epirus, (06) Attica, (07) E.C. Greece, (08) Thessaly, (09) W. Macedonia, (10) C. Macedonia, (11) E. Macedonia, (12) Thrace, (13) Crete and (14) Aegean Islands.

The values used for the catchment areas, lengths and available heads of watercourses were estimated in the basis of maps from the National Military Geographical Service in scales 1:50,000 and 1:400,000.

The Archimedean hydropower inventory estimations of the present paper concern only natural watercourses excluding all the existing hydraulic open channels and the kinetic hydraulic energy of small and larger rivers of Greece. Greek water resource spatiotemporal behaviour is in general irregular with considerable seasonal and yearly fluctuations. The flow discharges were estimated on the basis a) of the collected measurement data, which are sometimes, systematic and other times, sporadic and incomplete, b) of theoretical calculations c) of comparisons and interpolations between neighbouring basins with certain geological and hydrological similarities.

Figure 3. Greek Water Districts.

In the present work the analysis of the Archimedean small hydropower possibilities of the Greek space has been based to studies of the available flow time series, to use of a representative value of water discharge Q, obtained from Flow Duration Curves, and many times to quite simple linear simulations between two catchment areas, based on the catchment area ratios A1/A2 and or to the precipitation ratios P_1/P_2

$$Q_1/Q_2=(A_1/A_2).P_1/P_2 \quad (1)$$

If the precipitation distribution is the same in two basins, then the transposition of rain-runoff data could be made according to the ratio of their areas.

$$Q_1/Q_2=(A_1/A_2) \quad (2)$$

An area of about 45.915 km^2, corresponding to 35% of total Greek surface, was investigated. Figure 4 describes the percentage of the investigated areas of the 14 Greek Water Districts [7].
The number of the examined watercourses per Water District 01, 02, 03,…014 is presented in the Figure 5 [9].
A general idea concerning the map of the annual isoyetial curves of Greece in mm is given in Figure 6 [4, 9].

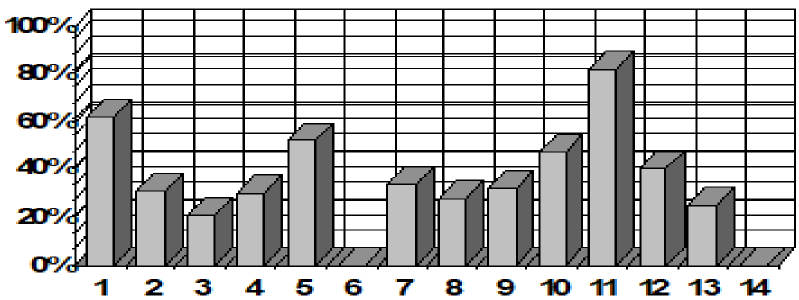

Figure 4. Percentage of the 14 Water Districts investigated areas.

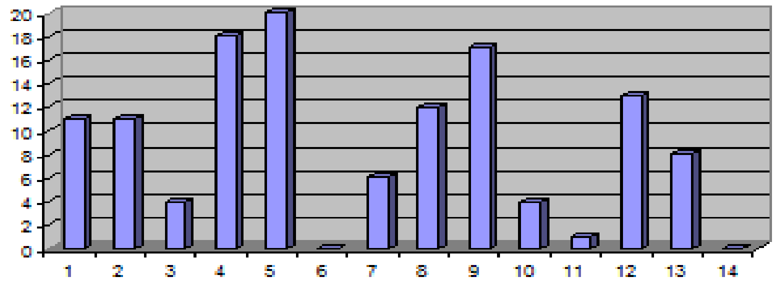

Figure 5. Number of the examined watercourses per Water District.

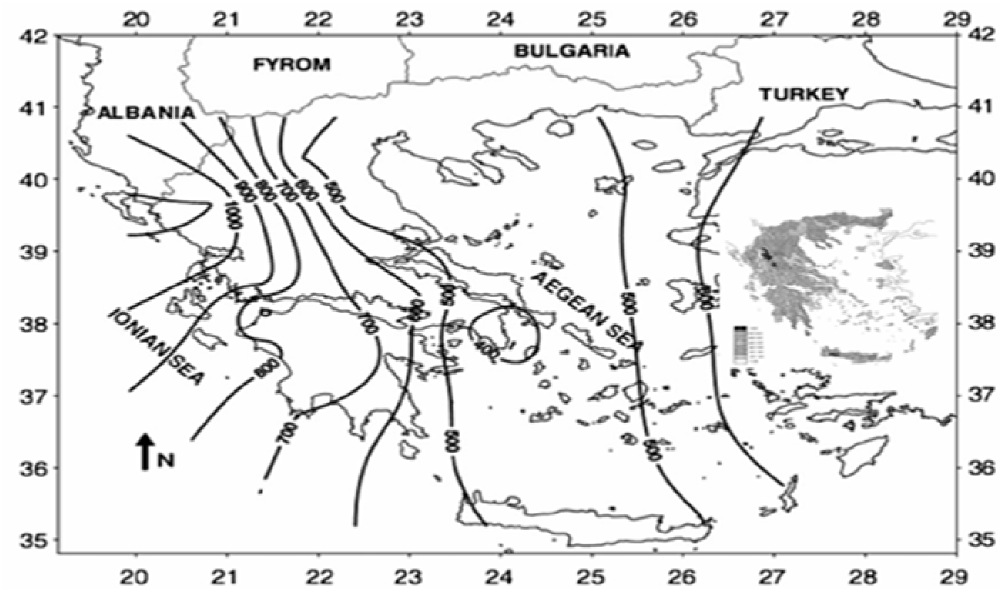

Figure 6. Map of the isoyetial curves of Greece, in mm (1950-2000).

3. Looking for the Greek Archimedean Small Hydropower Inventory

The examined area of about 45.915 km^2 was investigated by adopting a holistic assessment methodology and using simple quasi-linear formulas, water discharge values and data determined by precipitation and evapotranspiration in order to obtain a first theoretical Archimedean hydropower potential estimation of each Greek watershed, each water basin and district, as a function of mean flow and gross head $(Q.\Delta H)_{mi}$ for the 14 Greek Water Districts. The theoretical hydropotential E_i(kWh) and the hydropower P_i(kW) are mainly functions of the available water discharge Q and the topographical height ΔH [4-7]. The catchment area A, the length L of the watercourse, the time t and efficiency of the hydro screw installations play one important role in the determination of E_i and P_i:

$$E_i=f_1(Q,H,A,L,t,\eta) \quad (3)$$

$$P_i=f_2(Q,H,A,L,t,\eta) \quad (4)$$

Ideally, ASTs could make hydropower generation possible almost everywhere flowing rivers are available. In areas of low flow but the higher head, this idea could be expanded to a theoretical chain of Archimedean plants in series such as what is proposed in Figure 9. In cases of bigger flow and the higher head, the same idea could be applied to theoretical chains of Archimedean plants cascades in parallel and in series such as what is proposed in the same Figure. Schematic cascade representations of several ASTs in series to take advantage of available water head alongside a relatively long pathway and in parallel, for bigger flows, to be applied in the watercourses of the water districts of Greece, are given in the following Figure 7 [9].
We used for each catchment area a quasi linear variability of the flow Q_i, alongside a watercourse i, as illustrated in Figure 8, with a mean value flow discharge-height $(Q.\Delta H)_{mi}$ obtained.

$$(Q.\Delta H)_{mi}=(Q_i.H_i)/2 \quad (5)$$

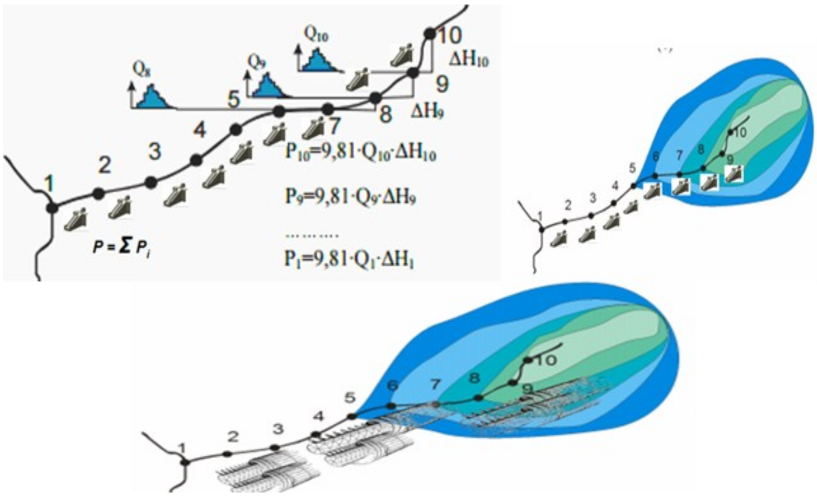

Figure 7. Schematic representations of several ASTs in series and in parallel.

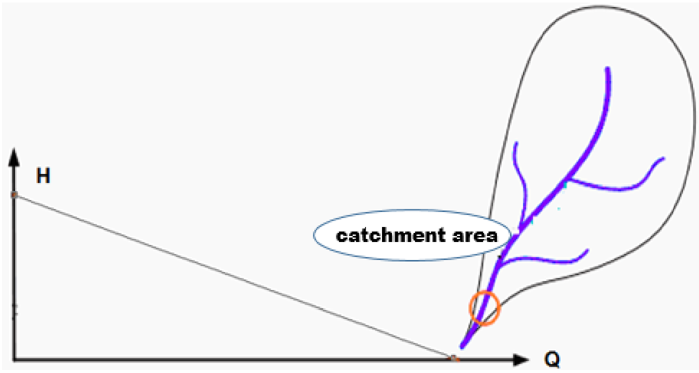

Figure 8. Schematic representation of linear flow discharge variation of each watercourse.

For a typical watercourse *i* the theoretical Archimedean hydropower potential is calculated by using the linear formula

$$E_i(kWh)=9.81.(Q.\Delta H)_{mi}.8760 \quad (6)$$

with Qi(m3/s), as the representative value from the flow duration curve water discharge and ΔHi (m), as the available constant over the year head in watercourse. Figure 9 gives the estimated theoretical Archimedean hydropotential, E_{th} in in GWh, per Water District.

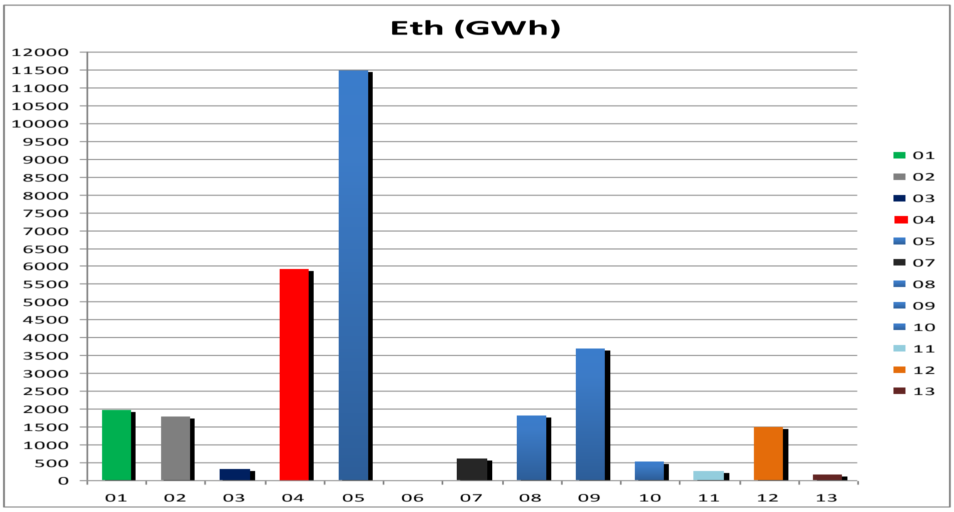

Figure 9. Theoretical Archimedean hydropotential per Water District in GWh.

The total theoretical Archimedean hydropower potential of the natural watercourses obtained for the estimated Greek area is around Eth= 30 TWh. The present calculations correspond to an overall theoretical Archimedean small hydrocapacity of about 3,500 MW. In this inventory is not included the important small hydropower kinetic energy potential of natural watercourses, water supply and irrigation systems neither the very promising coastal and tidal currents potential. Following the present inventory the corresponding total Greek energy conservation, in terms of T.O.E. and T.C.E., is estimated more than $2.57.10^6$ T.O.E. and $5.14.10^6$ T.C.E. respectively. The theoretical specific Archimedean small hydrocapacity (KW/Km^2) had been calculated easily in the basis of the obtained energy output. A mean value of 74.7 (KW/Km^2) corresponds to the total investigated area. The small hydropower density or rather the specific theoretical small hydropotential of the entire country, is approximately calculated 0.651 GWh/Km^2. We present bellow some results obtained from the Archimedean inventory for the Peloponnesian Water Districts 01, 02 and 03 as well for the Water Districts W.C. Greece (04) and Epirus (05). The calculated theoretical hydropotential, in GWh, of the main watercourses of the Peloponnesian water districts 01, 02 and 03, is presented in the schemes of Figure 10.
Figures 11 and 12 present the calculated hydropotential, in GWh, of the Water Districts of W.C. Greece (04) and Epirus (05).

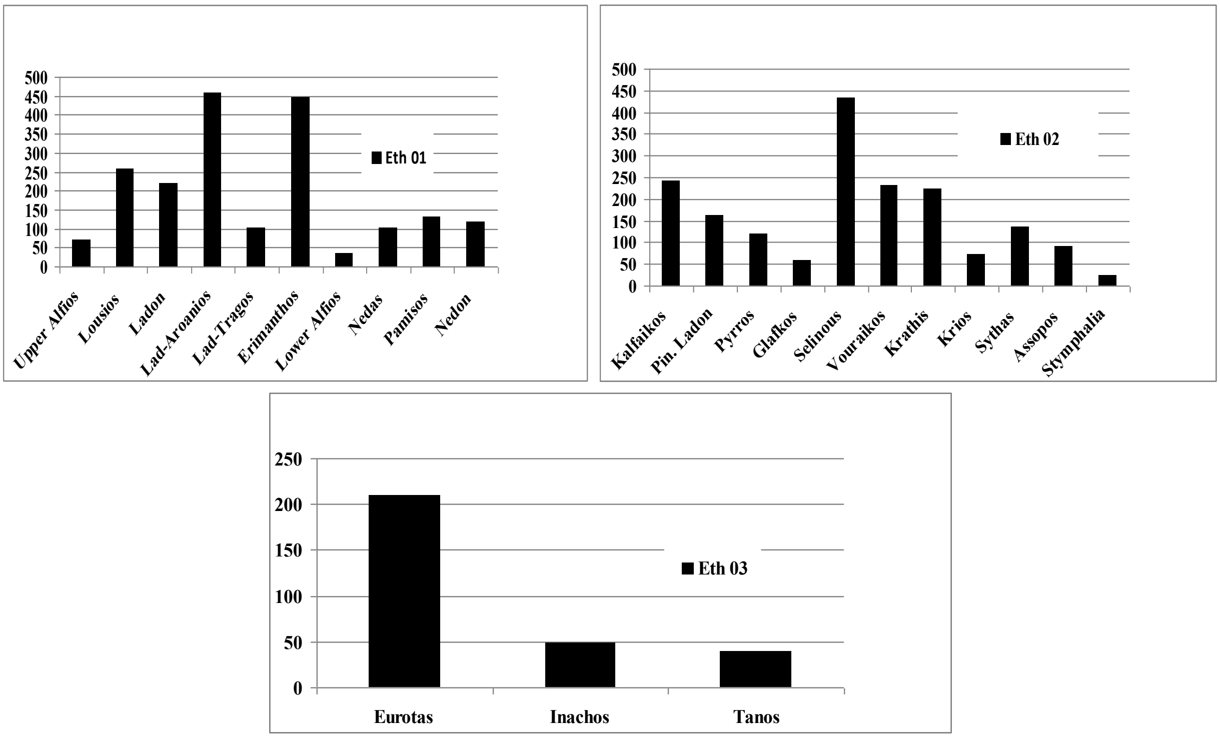

Figure 10. Theoretical hydropotential, in GWh, of the Peloponnesian Water Districts (01, 02, 03).

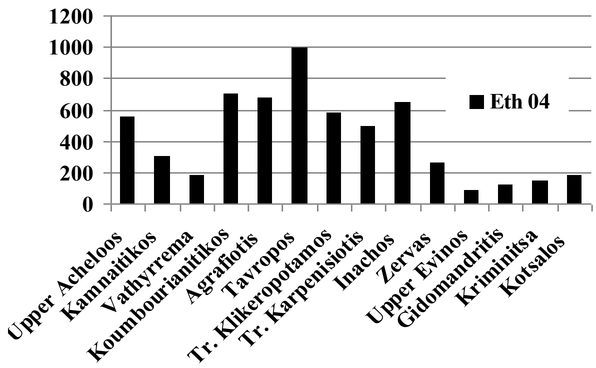

Figure 11. Theoretical hydropotential, in GWh, of the Water District of W.C. Greece (04).

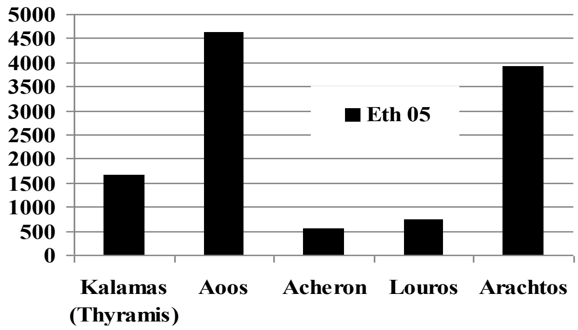

Figure 12. Theoretical hydropotential, in GWh of Epirus (05) main rivers.

The preliminary Archimedean small hydropotential results demonstrate the predominance of the water districts of Epirus and of Macedonia, having together the most important theoretical hydropotential of the whole country. The same could be said for their theoretical small hydropotential (20TWh, 1500MW) and the corresponding specific theoretical hydropotential (2 GWh/Km², 250 KW/Km²). The important role, mainly of the Pindos Mountain Range, controlling the annual rainfall difference between the North-Western Greece (1.000 to 2.000mm) and the Eastern Greece (400 to 500 mm/year) seems to be obvious. It is important to note, for the Epirus water district that, even though its total area is only 7.55% of the total Greek area, the corresponding Archimedean hydropotential is greater than 38% of the total calculated small Greek hydropotential. The corresponding theoretical Archimedean small hydropotential is 11.48TWh, 1310.6MW. The specific theoretical hydropotential is 2.25GWh/Km² and 257KW/Km². Besides the obvious role of Pindos mountain range it is important to note the important small hydroelectric potential role of a series of other mounts (e.g. the Vermion, Olympos, Athos, Taygetos etc.). The calculated mean Epirus-Macedonia specific theoretical hydropotential values are 2 GWh/Km² and 250 KW/Km².

4. Conclusions

By considering the basic data for the 14 water regions of the Greece and by adopting a holistic assessment methodology of the total theoretical hydro potential of Greece we had obtained in the present paper the inventory of the Greek Archimedean Small Hydro Resources, which could be exploited by using Archimedean Screw Turbines (ASTs). The total evaluation of the theoretical Archimedean hydropower potential of the country, which may be produced with ASTs is of the order of 30 TWh / year, with a theoretical installed capacity of screw turbines in the range of 3,412 MW, with special capacity and special capacity density equal to 74.30 kW / km^2 and 0.65 GWh / km^2 respectively. These inventory values demonstrate the major existing potential for a true sustainable development with small hydro plants in Greece based on environmentally friendly ASTs. According to the presented inventory, it seems that Greece has, in the Era of Transition and in the economic crisis of nowadays, an important unexploited Archimedean hydropower potential of several TWh and an important Archimedean hydrocapacity of thousands of MW.

Despite the fact that there are thousands of very promising potential sites at small waterfalls and many river weirs of Greece, low head hydropower is developing very slowly across the country. The climatic and topographic conditions in Greece favor the development of many small Archimedean screw hydropower stations, harnessing the potential of a large number of small and big watercourses crossing mainland of the country. Pleiades of promising small hydro sites in Greece for ASTs installation are presented in Figure 13, in which is also given a “2 Archimedean Hydro Spears (AHS)” representation, with the important small hydroelectric role of Pindos mountain range, along the first AHS, from Epirus, Thessaly, Central Greece, Peloponnesus, and the role of the mounts of Vermion, Voras, Paikon, Rodope of Northern Greece, Macedonia and Thrace, along the second AHS.

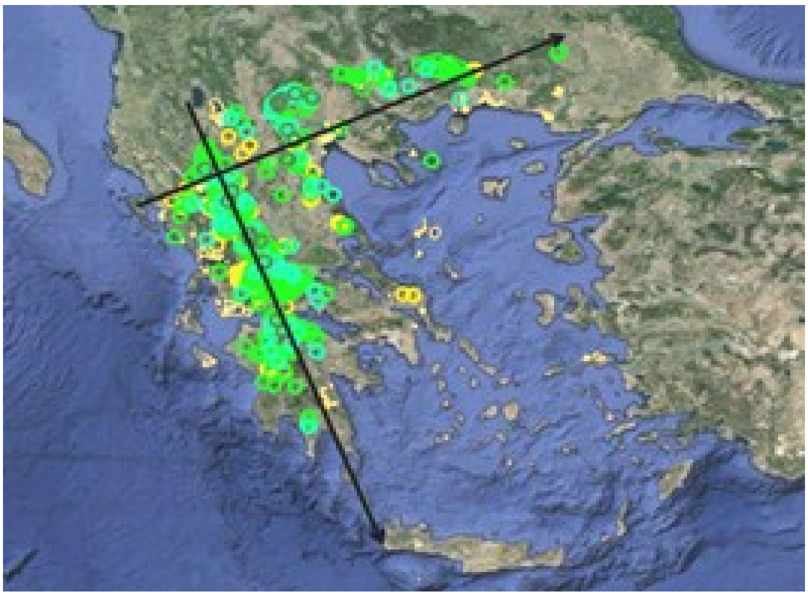

Figure 13. The two Archimedean Hydro Spears of Greece.

Dedication
The present paper is dedicated to the memory of our wonderful son and brother George Stergiopoulos, Biosystem Engineer and M.Sc. in Waste Treatment, who recently passed away.

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Alkistis Stergiopoulou is Doctor of Philosophy (Ph.D.) of the National Technical University of Athens, Master of Science in Water Resourses & Technology (Civil Engineering School, National Technical University of Athens, 2008), Master in Total Quality Management (Open University of Greece, 2012), BSc in Natural Resources Management & Engineering (Agricultural University of Athens, 2007). She was Researcher of the BOKU University of Natural Resources and Life Sciences (Vienna, Austria, 2014-2017) and Basic Scientific Member of the National Research Project ARCHIMEDES III. Her main research interests are, Archimedean Screw Turbines, Small Hydropower, Renewable Energy Sources, C.F.D., Applied Hydraulics, Fluid Mechanics, Optimization and Special Water Processes. She is the co-founder of the FISCHCOM Company. She was Process Engineer in the M+W Group. Actually she is Senior Process Engineer at VTU Engineering in Vienna, Austria.
E-mail adress: alkisti_ster@yahoo.gr

Vassilios Stergiopoulos is Professor of Hydraulics and Hydropower at the Civil Engineering Educators Department of the School of Pedagogical and Technological Education (ASPETE, Athens, Greece), Docteur d'Etat ès Sciences Mathématiques (University of Aix-Marseille II, France) Docteur-Ingenieur and D.E.A. in Fluid Mechanics (University of Aix-Marseille). His main research interest are Archimedean Screw Turbines and Plants, Small Hydropower and Hydraulic Turbomachines, Renewable Energy Sources, Environmental Hydraulics and Fluid Mechanics, C.F.D.
E-mail adress: bstergiopoulos@aspete.gr