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Greece beyond the horizon of the era of transition: Archimedean screw hydropower development terra incognita

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Abstract
The main aim of this paper is to prove, according to our inventory that, beyond the horizon of the era of transition and economic crisis of nowadays, Greece is a real "Archimedean Screw Hydropower Development Terra Incognita", a country generously blessed with water, having an important hydropower potential. This inventory shows that the unexploited small hydropower capacity of Greece, including Archimedean possibilities, is approximately 3.500MW. The significant untapped small hydrodynamic potential demonstrates the important role of Pindos Mountain Range, controlling the annual rainfall difference between the North-Western and the Eastern Greece. 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 very promising Archimedean small hydro screw plants, having inclined and horizontal axis hydrodynamic rotors, could be installed following two hydro development axis (spears).

Keywords: Renewable energy; Small hydro; Archimedean screw turbines; Energy systems.

1. Introduction

During the last years of the strong economic crisis, the recession has been damaging the long-term productivity of whole Greek economy, leading to lower investments including white gold and creating strong discussions with controversies and different views concerning small hydro. Although the small hydro perspective is of considerable interest and the hydropower fuel is the largest, the most viable and reliable future indigenous renewable source of energy, the current status of many Greek decision makers' attitudes are characterized by erroneous opinions and obsessions. Despite the existing very promising potential, the installed capacity of small hydro power plants is only a few hundreds MW representing about 10% of the currently installed capacity from renewable energy sources and producing approximately 18% of the Renewable Energy Source (R.E.S.) produced energy. The present paper proves that the climatic and topographic conditions in Greece favor the development of many small hydropower stations, harnessing the potential of a large number of rivers crossing mainland of the country and ending up in the Aegean Archipelago**.** A recent inventory will show that the existing unexploited theoretical small hydropower capacity of Greece, including Archimedean possibilities, is very important about some thousands of MW, with an important total theoretical hydropotential in TWh. These preliminary hydropotential results demonstrate the important role of Pindos Mountain Range and the predominance of the water districts of Epirus and of Macedonia, having together the most important theoretical hydropotential of the whole country. Despite the fact that there are thousands of very promising potential sites at small waterfalls and many river weirs across the country, low head hydropower is developing very slowly in Greece. Archimedean screws are a new type of turbines, not only in Greece but also in all countries throughout the world, giving nowadays very promising perspectives for a real green screw small hydropower development [1-4].

2. A short view of recent a.s.t. research for A.I.A.H.T. & A.W.C.T.

Various innovative small-scale models of new Archimedean Screw Turbines (A.S.T.'s) were designed, and developed in the framework of the research program of ARCHIMEDES III. During the last years a series of extensive ARCHIMEDES III research experiences had been made in an open flume hydraulic experimental channel, concerning initially various, small-scale AIAHT's (Archimedean Inclined Axis Hydropower Turbines) configurations. Two representative Archimedean experiences in an open flume channel for two inclined axis AST are schematically illustrated in Figure 1, together with the first experimental results (efficiency η in function of flow ratio Q/Qo, with Qo the design flow) relative to a third AIAHT closed circuit integrated hydropower plant [4-8].

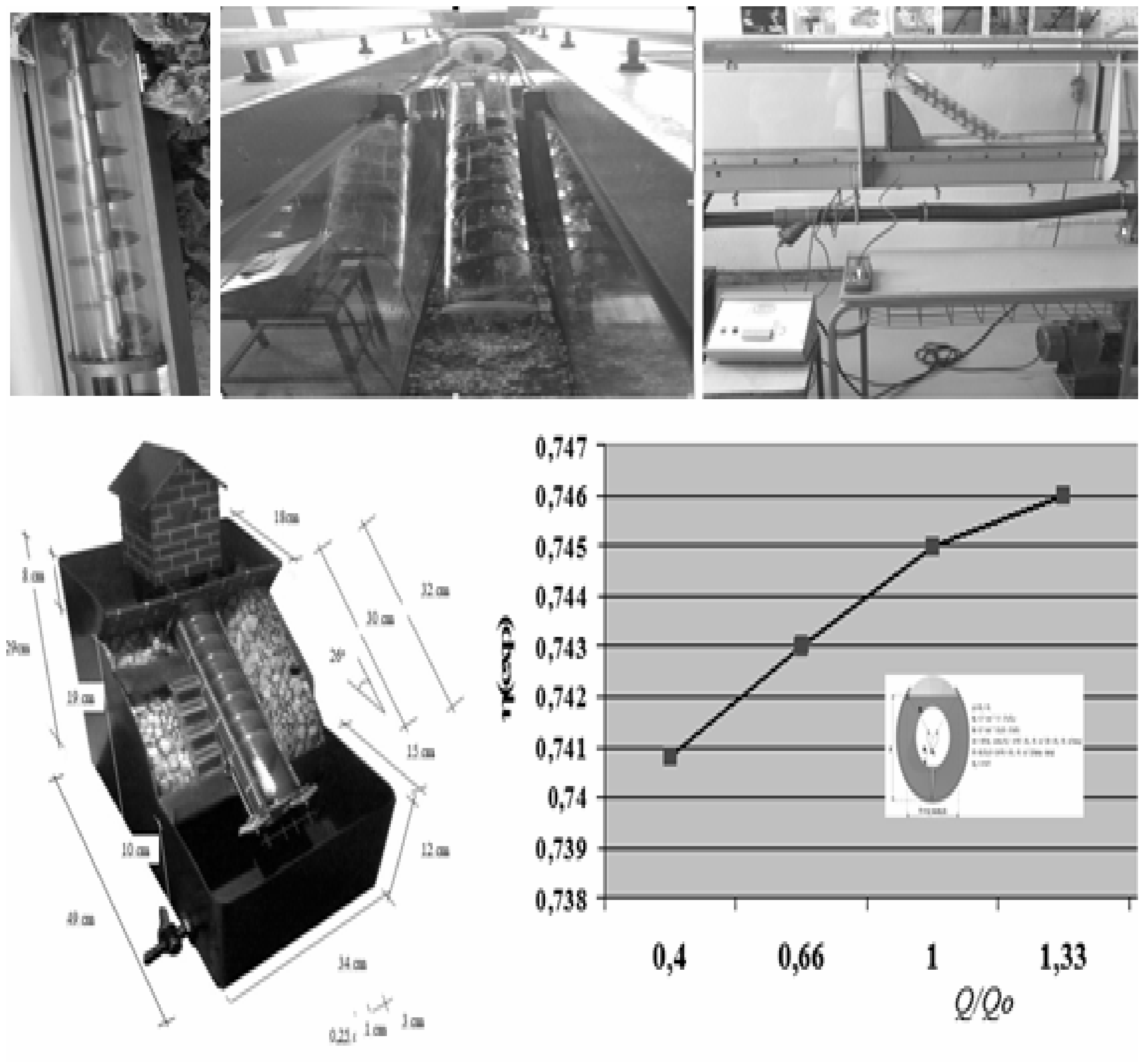

Figure 1. Three innovative small-scale models Archimedean spiral rotors developed in the framework of the research program ARCHIMEDES III (photos A. Stergiopoulou)

Recently three other new 2-bladed AIAHT, of the same length 30.5cm, the same input diameter 5cm, with an output diameter 9.4cm and three step ratio S/D=1, 0.8 and 1.2, were developed and are under experimental exloitation in the framework of the same research program (Figure 2) [4-8].

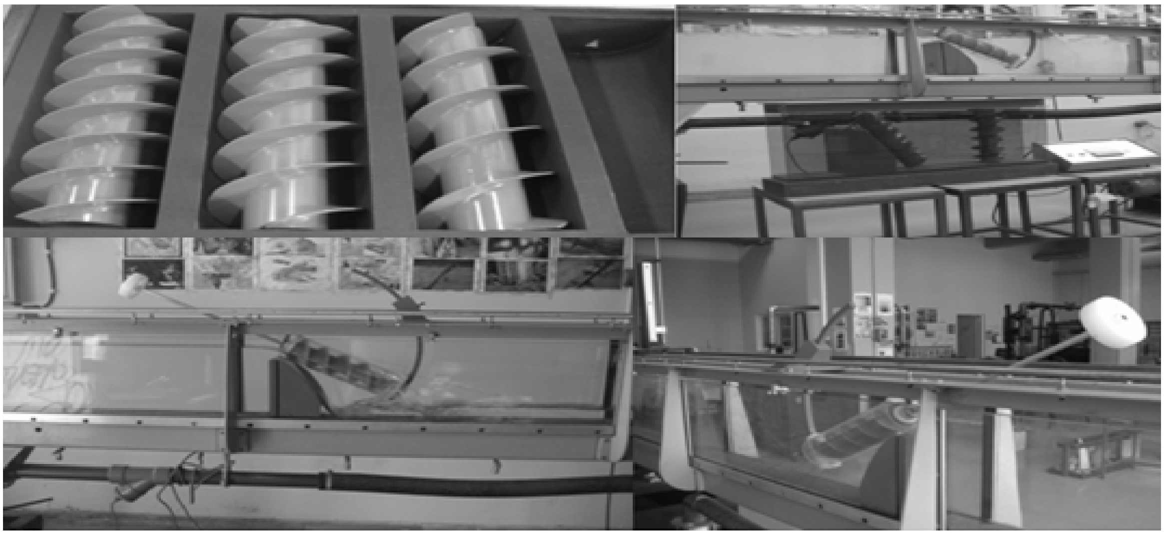

Figure 2. New AIAHT's representative ARCHIMEDES III experiences (photos A. Stergiopoulou)

The possibility of exploiting kinetic hydraulic energy of irrigation and drainage hydraulic networks, and currents of technical and natural watercourses, for power generation, have both been given little attention, although such currents represent a large renewable energy resource which could be exploited by "modern Archimedean screw technologies". A series of Archimedean Water Current Turbines (AWCT) photorealistic views, with horizontal axis floating screws for the Greek natural and irrigation man-made networks are presented in Figure 3. In this figure are given the geometrical characteristics of the new horizontal Archimedean Screw Turbine recently installed and experimented in the hydraulic channel of the Laboratory of the Institute for Water Management, Hydrology and Hydraulic Engineering, in Vienna with the dimensions $L_{channel}$=10m, $b_{channel}$=1.4m, $h_{channel}$(depth)=1m. Some photorealistic views of floating AWCT's are given in the same figure [9].

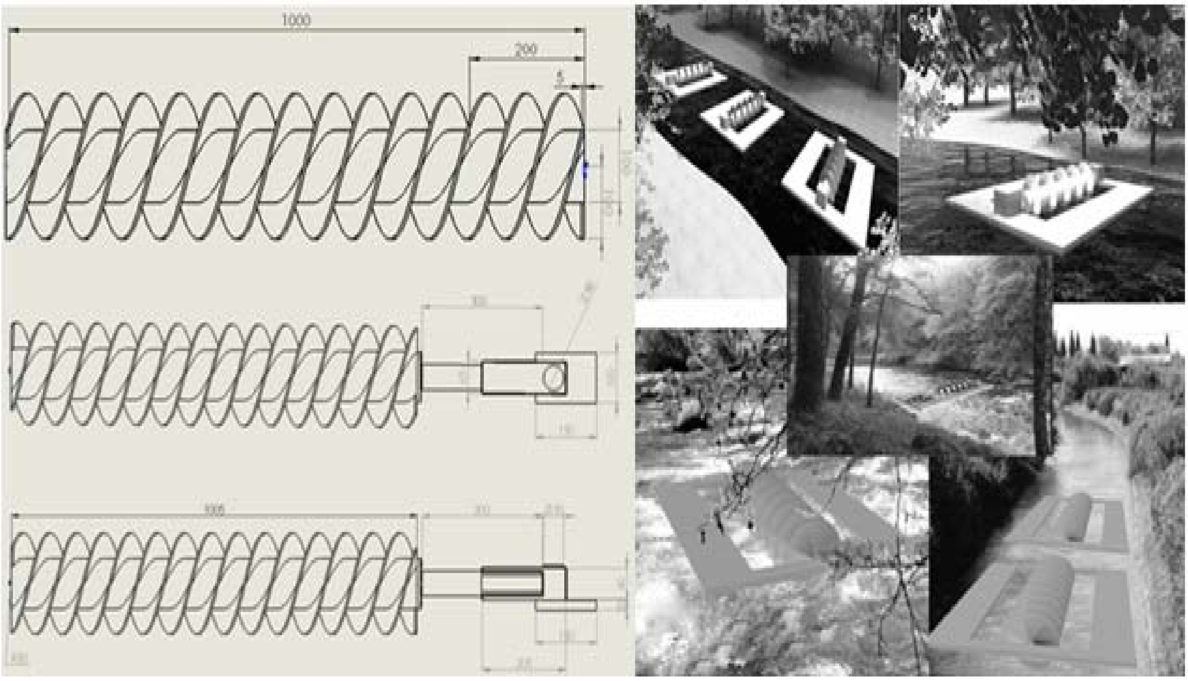

Figure 3. Design of a new developed horizontal screw rotor with photorealistic views of floating screws (photos A. Stergiopoulou)

3. Towards a Greek Archimedean small hydropotential inventory

The important role, mainly of Pindos Mountain Range, controlling the annual rainfall difference between the North-Western and the Eastern Greece seems to become obvious in Figure 4.
A general idea concerning the map of the annual isoyetial curves of Greece in mm is given in Figure 5.

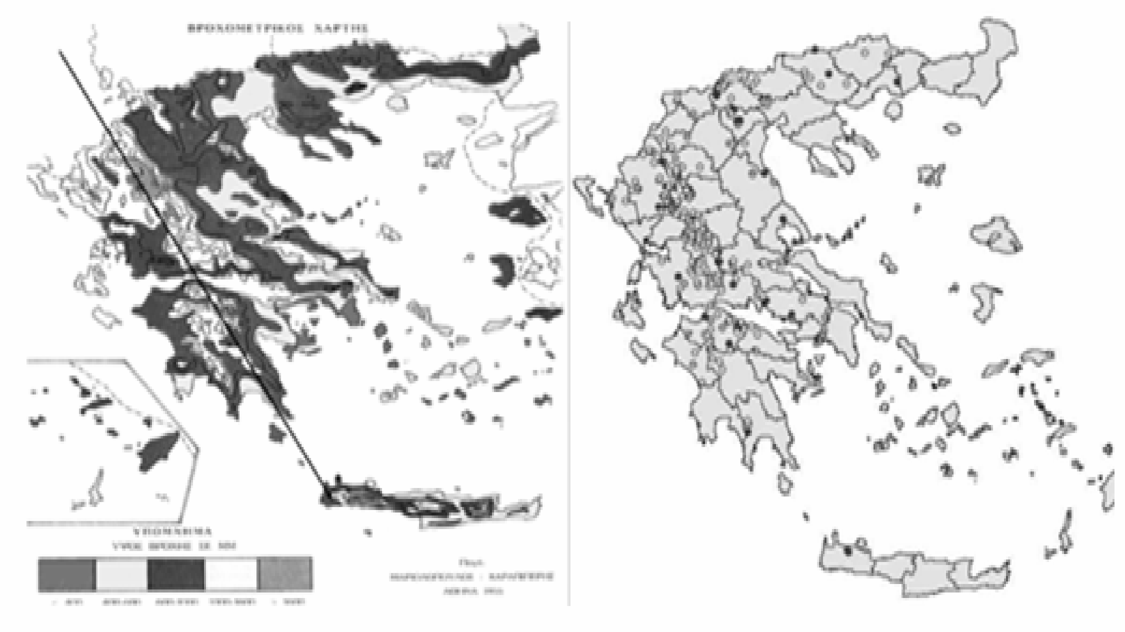

Figure 4. The presence of Pindos Mountain Range controlling the climatometeorological conditions of Greece

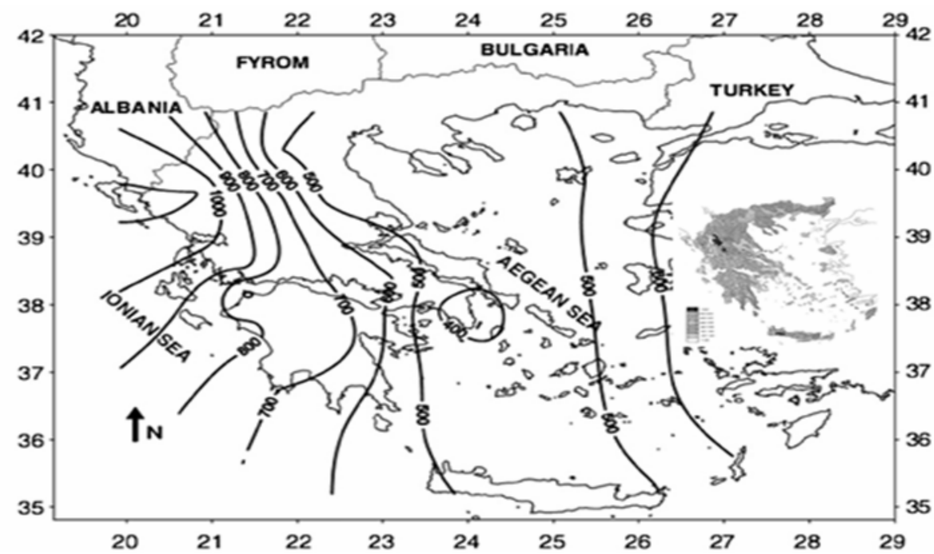

Figure 5. Map of the isoyetial curves of Greece, in mm (1950-2000)

An area of about 45.915 km^2, corresponding to 35% of total Greek surface 131.913 km^2, was investigated by using simple quasi-linear formulas, water discharge values and data determined by precipitation and evapotranspiration in order to obtain a first theoretical hydropower potential estimation of each Greek watershed, each water basin and district, as a function of mean flow and gross head for the 14 Greek water districts. The theoretical Archimedean hydropower potential is calculated by using the linear formula, $E_{i,\,th}$ (KWh) = 9.81×(Q_i×ΔH_i) × 8,760, with Q_i(m^3/s), as the representative from the flow duration curve water discharge and ΔH_i (m), as the available constant over the year head in watercourse. Figure 6 gives the percentages of the 14 Greek Water Districts investigated areas and the theoretical Archimedean hydropotential, in GWh.

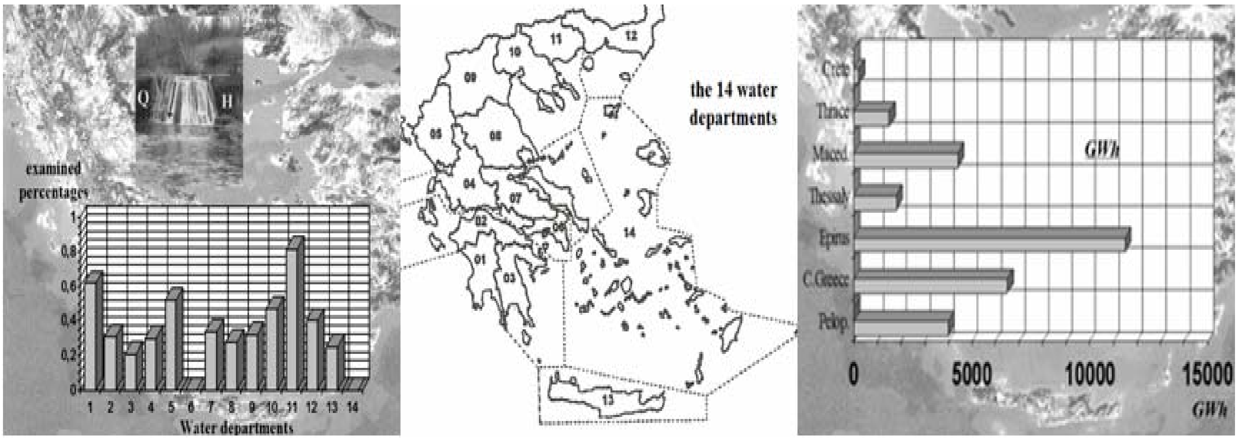

Figure 6. Percentages of the 14 Greek Water Districts investigated areas and the theoretical Archimedean hydropotential, in GWh

The theoretical specific Archimedean small hydrocapacity (KW/Km²) had been calculated easily in the basis of the obtained energy output. A mean value of 74.7 (KW/Km²) 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/Km². Such 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. The small hydroelectric potential role of Pindos mountain range and a series of other mounts (e.g. the Vermion, Olympos, Athos, Taygetos etc.) is obvious. The total theoretical Archimedean hydropower potential of the natural watercourses obtained for the estimated Greek area is around E_{th} = 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 Archimedean small hydropotential 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. According to this 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 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.

4. Towards a "double spears Archimedean hydropower development"

According to the under evolution research, within ARCHIMEDES III program, the cochlear screws could find very promising modern applications, as efficient hydraulic turbomachines [7-9]. Pleiades of promising small hydro sites in Greece are presented in Figure 7, in which is also given a "2 Hydro Spears Macedonian Phalanx" representation, with the important small hydroelectric role of Pindos mountain range, along the first Archimedean spear, from Epirus, Thessaly, Central Greece, Peloponnesus, and the role of the mounts of Vermion, Veras, Paikon, Rodope of Northern Greece, Macedonia and Thrace, along the second Archimedean spear. It is important to note that the two spears Macedonian Hydro Phalanx characterize the hydropower development of Greece, including the first hydropower stations being in operation since 1954 in Agras, Louros, Ladon and the larger hydropower stations in Central Macedonia, in Thrace, in Thessaly and in West Central Greece.

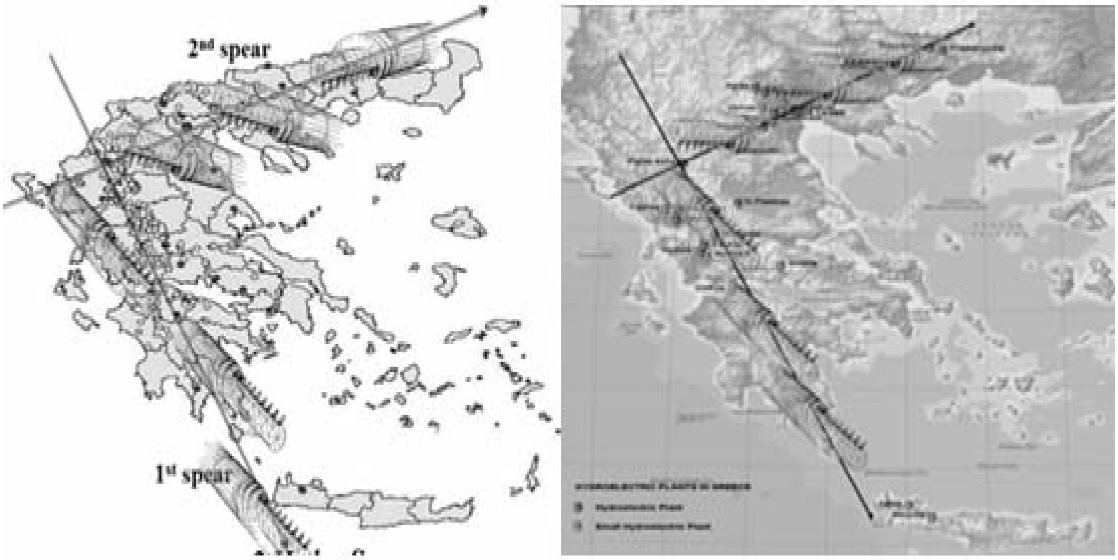

Figure 7. The two Hydro Spears of Greece

The very significant untapped small hydrodynamic potential, of about 30 TWh, according to the present inventory, the current Greek economic crisis situation and all systematic efforts relative to the small hydrodynamic behaviour studies of innovative low and zero head Archimedean screw turbines could give an increased impetus in low head hydraulic renewable energy sources.

The two long hydropower spears of this Macedonian development phalanx could be a real offensive Archimedean hydropower development tactic formation of Greece against the present crisis and a source of future hydro-economic prosperity as the glorious hydro-prosperity of the recent past (Figure 8). Figure 8 gives also a schematic representation of one Archimedean Screw Turbine with inclined shaft exploiting the potential of a watercourse having a flow discharge Q and a height H.

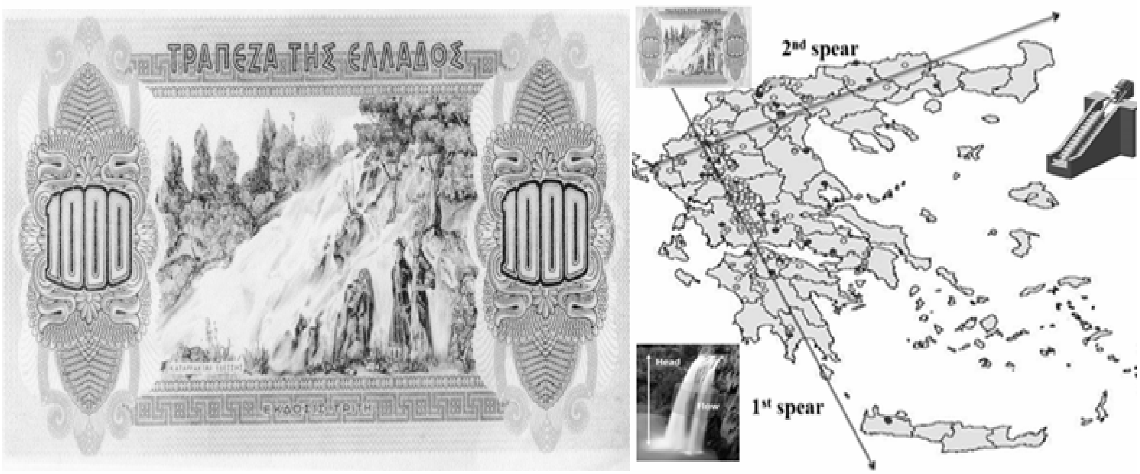

Figure 8. The “2 Hydro Spears Macedonian Phalanx Archimedean Hydro Development” of Greece

For such a Greek Archimedean small hydropower development effort, mainly along the “North-South Small Hydropower Development Spear”, series of questions to be answered are real technical dilemmas. These dilemmas are illustrated in Figure 9. First dilemma: what are more efficient, Archimedean screws in series or in parallel? Second dilemma: if we have a site with screw in series how many screws should be connected? Third dilemma: if we have a site with screws in parallel how many screws should be connected? Fourth dilemma: if we have a site with the combined solution of screws in parallel and screws in series how many screws should be connected for each case? The Fifth Archimedean screw dilemma concerns all the various environmental sensible regions (e.g. Holy Mount of Olympus, Mount of Athos, Samothrace Island etc.) (Figure 9).

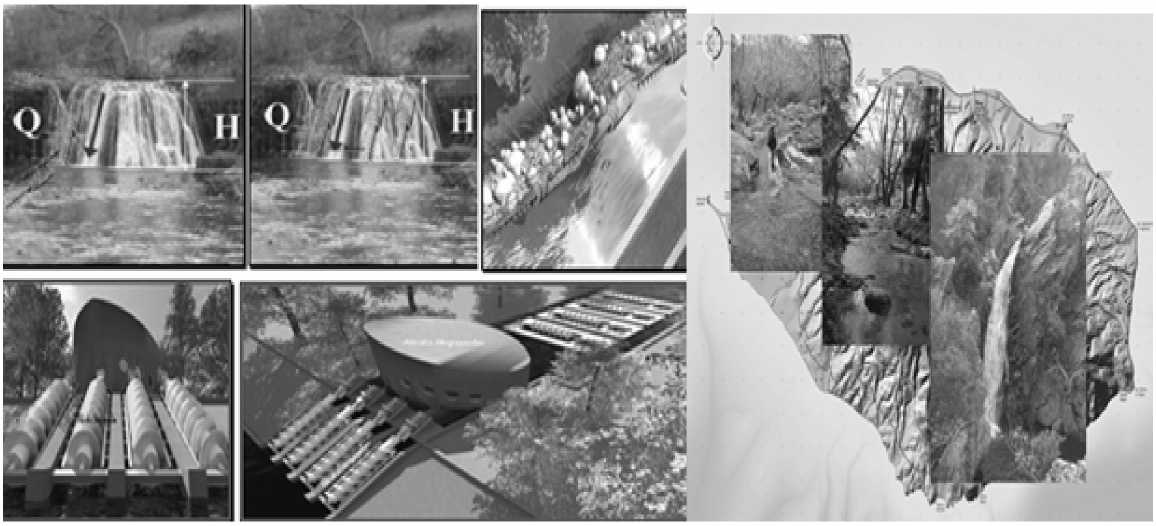

Figure 9. First, second, third, fourth and fifth Archimedean hydropower development dilemmas (photos A. Stergiopoulou)

For a particular Archimedean Screw Turbine case study, concerning a first site, in the Drainage Channel 66 (Figure 10), in Imathia Prefecture, the maximum flow of the screw turbine is estimated to be 4.67 m^3/s. The net head is calculated by estimating the hydraulic losses or after assumption of 3% head losses. The gross head was 1.50m. Then the net head becomes 1.45m. The generated power on the turbine axis is P_t=49.821 KW (with η_{turb}=0.75) and the generated electrical power is P=41.501 KW (with η_{gen}=0.98 and η_{gear}=0.85). It is estimated that the AST would be operated at the maximum power of 41.501KW with a design flow approximately at least 4.67 m^3/s in the river for 150 days per year. For the rest of the year the turbine would be operated with reduced power. The annual energy production is estimated on the basis of the capacity factor CF = time of design operation/8760. In our case, CF is around 0.65. The annual energy production E(KWh)=P(KW).CF.8760 is calculated E(KWh)=236 307 KWh/year. A first estimation of the installation cost gives a total amount of 121 000 E, with 58 000E for the equipment of AST, turbine and generator, 40 000E for the civil works, 15 000E the electrical system and the connections, 8 000E other. A quick first economical analysis would probably give a very interesting P.P. (payback period) of 5-6 years, a very good N.P.V. (Net Present Value) and an efficient I.R.R. (Internal Rate of Return). In general AST power development in this particular site is good idea for investment in Archimedean green energy.

Figure 10. A general view of a first site of the drainage channel 66 for a possible AST future development (photos A. Stergiopoulou)

For a second site, in the Tripotamos river catchment area, near the town of Veria, for a future Archimedean Small Hydro exploitation, with H=2.34m and the flow variation curve (Q(m3/s), t=days) illustrated in Figure 11, the river F.D.C curve and the useful F.D.C. curve in common with a preliminary study propose a final Archimedean plant, with nominal flow 2 m3/s, efficiency of the screw turbine 84.75 %, efficiency of the generator 93 (%), efficiency of the multiplicator 91.2(%), installed power P=33 KW, and energy produced per year E=107 976,8 KWh.

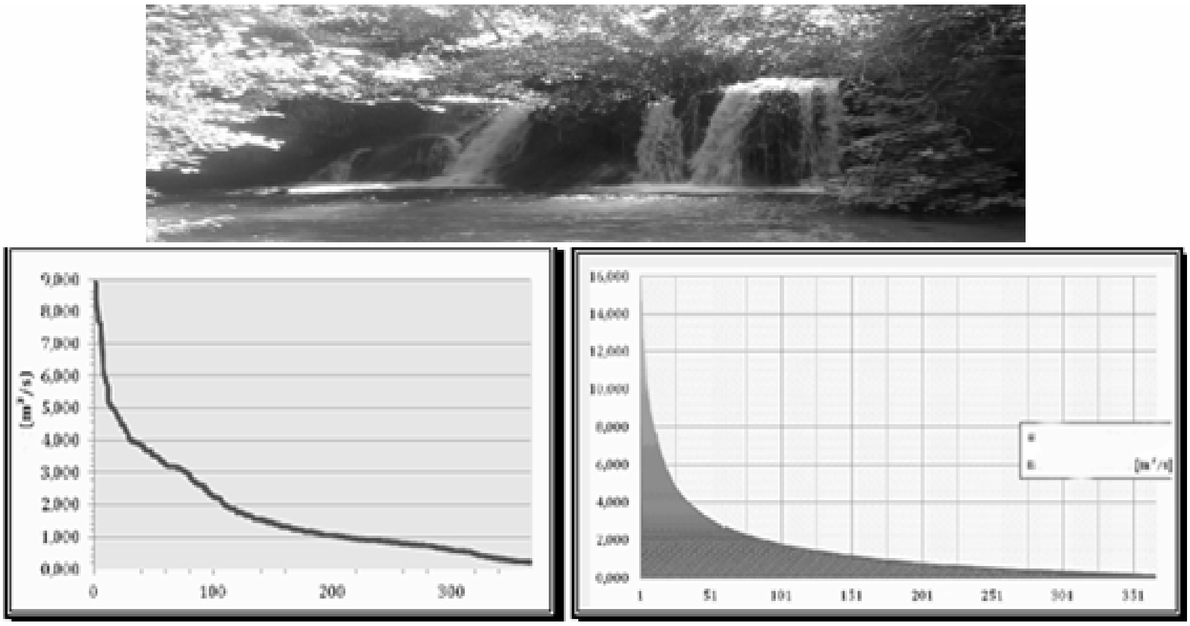

Figure 11. A site for an Archimedean Small Hydro exploitation with F.D.C curves

For a third site, in the Arapitsa River catchments area, near a small irrigation weir, downstream of the town of Naoussa, a potential future Archimedean Small Hydro exploitation for H=4.68 m and the same flow data, should be based probably on 2 similar screw turbines in series (Figure 12). The total installed power P = 2 x 33 = 66 KW and a yearly produced energy E= 2 x 107 976,8 =215 953,16KWh.

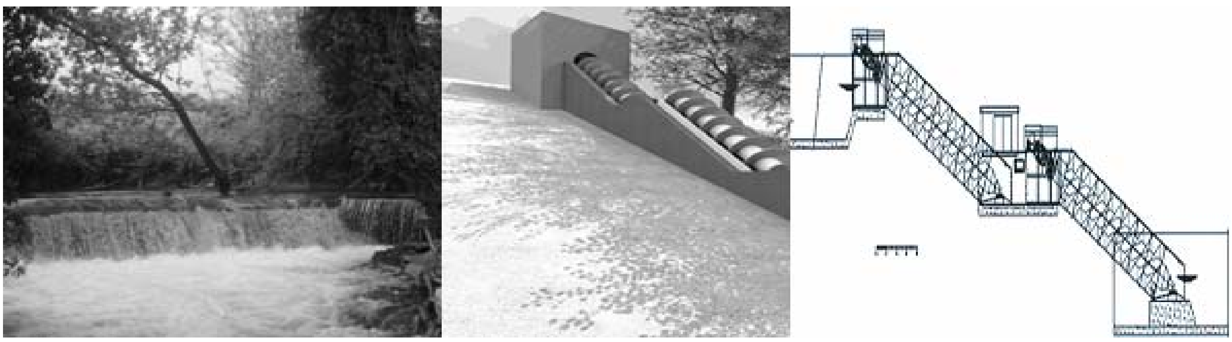

Figure 12. Typical schemes with two AST's, in series, in one irrigation weir in Arapitsa
(photos A. Stergiopoulou)

For a fourth site, in the drainage channel 66, with a head of 2.34m and a design flow 4m3/s, it is possible to install in parallel two similar screw turbines, having an individual hydrocapacity of 33KW and a yearly productivity of 107 976, 8 KWh giving a total install capacity of 66 KW and a total yearly energy production of 215 953,16KWh.

5. Conclusions

Beyond Pindos mountain range a series of other mounts play a supplementary role with Pindos range along the first Archimedean development spear from Epirus to Thessaly and Peloponnesus. According to the present research a Pleiades of promising small hydro plants could be developed in Greece along a first North-South hydropower development spear. Another big series of hydropower plants could be installed in the sites along a second hydro development West-East spear, on the basis of the mounts Vermion, Voras, Rodope of Northern Greece, Macedonia and Thrace. The final goal of this paper was to give an affirmative answer to the following question: “Can growth and development come back in Greece?” This can be indeed achieved by following the proposed here two Spears of Small Hydropower Development & Growth Phalanx harnessing the unexploited and very promising potential. This Small Hydropower Development & Growth Phalanx with several hundreds of Archimedean small hydropower plants, including the Archimedean schemes, in series and parallel exploiting the climatic, topographic and hydraulic conditions of the two spears of Greece could be a real offensive hydropower development tactic formation of Greece against the present crisis, able to return from the past the lost and forgotten hydropower prosperity. According to the presented here, very promising and unexploited small hydropower potential, inventory of the whole country, Greece seems to be, beyond the horizon of the Era of Transition, and in the economic crisis of nowadays, a real “Archimedean Screw Hydropower Development Terra Incognita”. The included innovative Archimedean hydropower schemes, in cascade and in parallel, for a series of low-head sites and for a series of horizontal floating screws, exploiting the kinetic energy of rivers, open channels, tidal and sea currents, are good examples for further efficient soft and green development and exploitation of the “Hellenic Archimedean Small Hydro Terra Incognita”.

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