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THE WIND ENERGY POTENTIAL OF AZERBAIJAN AND ITS USE AT THE CASPIAN SEA OFFSHORE

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ABSTRACT
The paper analyzes the status and prospects of usage of alternative and renewable energy sources. The technical and economic parameters of creation of Offshore Wind Park at fixed offshore oil platforms in the Azerbaijani sector of the Caspian Sea are provided. I is shown that in order to meet the electricity needs at the permanent offshore oil platforms, apparently, the establishment of wind energy turbines forming the Wind Park at offshore and the transportation of generated electricity by underwater cables will be the most economic one.

Keywords: *renewable, alternative, energy, offshore, wind, park.*

INTRODUCTION
Nowadays, the wind energy speedily develops in many countries around the world. The world wind energy resources are extremely great and, according to sources [1-9], technically accessible total wind power is estimated about 53000 TWt h/y, which approximately 4 times exceeds the current annual world electricity consumption. Necessity to solve the environmental problems would lead to increase the share of energy generated from renewable sources within the general structure of energy production, and first of all developing the hydrogen power, use of biomass, solar and wind power.

METHODS
It is necessary to notice, that wind energy by beginning of XXI century became full-fledged and visible area of electricity power industry in spite of the fact that in 1999 the share of wind energy in electricity production industry in the world peaked slightly above 0,5 %. Having noticed the successes of individual countries, the international organizations, such as European Wind Energy Association (EWEA), Forum for Energy and Development and Greenpeace International have put forward the program «Wind Force 10» which aimed to achieve the 10 percent share of wind energy in the world electricity power production in 2020 (tab. 1).

Table 1The program «Wind Force 10»

Years	Growth percent per year, %	Annual input of capacity, MBт	The general capacity by the end of year, MWt		Annual production of electricity energy on wind energy units, TWt·h	Annual consumption of electricity energy in the world, TWt·h	Share of wind energy, %
			The forecast	The fact			
1999	20	3120	13273	13520	29,1	14919	0,19
2000	20	3744	17017	18449	37,3	15381	0,24
2001	20	4493	21510	23794	47,1	15858	0,30
2002	20	5391	26901	30278	58,9	16350	0,36
2003	20	6470	33371	39357	73,1	16857	0,43
2004	30	8411	41781	46880	91,5	17379	0,53
2005	30	10939	52715	59084	115,4	17918	0,64
2006	30	14214	66929	74223	146,6	18474	0,79
2007	30	18478	85407		187,0	19046	0,98
2008	30	24021	109428		268,4	19937	1,37
2009	30	31228	140656		245,0	20245	1,70
2010	30	40596	181252		444,6	20873	2,13
2015	20	94304	537059		1333,8	23894	5,58
2020	10	150000	1209466		2966,6	27351	10,86
2030	10	15000	2545232		6242,9	33178	18,82
2040	10	15000	3017017		7928,7	38509	20,60

It was assumed, that the overall production of electricity power in the world would increase from 14919 TWt·h in 1999 up to 27351 TWt·h in 2020, i.e. almost 2 times more. At the moment of

Program emergence the purpose laid in it seemed for many experts to be unreal. However, the Program monitoring by experts has shown that starting 1999 to 2006 the development of wind energy anticipates the plans. Apparently from tab. 1, according to the Program in 2006 the established capacity should be equal 66929 MWt, but actually it reached 74223 MWt.

In 2004-2005 the authors of Program «Wind Force 10» have decided, that conditions for the wind energy development in the world allow to set a more ambitious task - achievement in 2020 of wind energy share in the world electricity energy production equaling 12 %, and accordingly the Program has received the new name «Wind Force 12».

The tasks set up within this Program for various continents of a globe are present in tab. 2. According to this Program, the established wind energy capacity in the world in 2020 should reach 1254 GWt comparing to 1209 GWt of the Program «Wind Force 10».

Table 2 The program «Wind Force 12». Achievements by 2020 of 12 % wind energy share in the world electricity power production. Forecast data by world's regions.

	OECD Europe	The countries with economy in transition	China	Eastern Asia	OECD Pacific ocean	Southern Asia	Middle East	Africa	Latin America	OECD North America	The world
The established capacity in 2020, GWt	230	130	170	70	90	50	25	25	100	310	1254,03
Electricity power production on wind energy units in 2020, TWt·h	626	318,9	416,9	171,5	230,1	122,6	61,3	61,3	245,2	800	3054
Prevention of CO_2,emission , billion t/year	375,6	221,6	325,2	133,9	138,1	95,6	36,8	36,8	147,1	480	1832
Investments for the period till 2020, billion euro	130,6	79,8	104,7	43	51,1	30,8	14	15,4	61,4	176	706,9
Annual input of capacity, GWt	15	22	30	10	10	18	3	3	17	30	158,728
Employment of thousand workplaces per year	222	325,6	444	148	148	266,4	44,4	44,4	251,8	444	2300

Specific cost of the established capacity in 2020 - Euro/kWt;
The cost of the electricity power from wind energy units in 2020 - 2,45 Eurocent/kWt.h;
OECD Europe - EU-15 Plus the Czech Republic, Hungary, Iceland, Norway, Switzerland and Turkey;
The countries with economy in transition: Albania, Bulgaria, Romania, Slovak Republic, the Former Yugoslavia, the Former USSR and Poland;
Eastern Asia: Brunei, Democratic People's Republic of Korea, Indonesia, Malaysia, Philippines, Singapore, Republic of Korea, Taiwan, Thailand, Vietnam and some small countries, including Polynesian islands.
OECD Pacific ocean: Japan, Australia, New Zealand.
Southern Asia: India, Pakistan, Bangladesh, Sri Lanka and Nepal.
Middle East: Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, the United Arab Emirates, Yemen;
Africa: the majority of African states.
Latin America: all central and southern states.
OECD North America: USA and Canada.

The purposes of Program «Wind Force 12» have been seriously perceived by all wind energy associations of the countries.

Distinctive feature of wind energy development of last decade is the fast development of Offshore Wind Force due to the obvious land surface limits in Europe. In the forthcoming five years the Offshore Wind Force would reach a remarkable development, and particularly in UK and Germany (to see the tab. 3).

Table 3 Status and prospects of building of Offshore Wind Forces

	Country	**The established capacity, MWt**

		By the end of 2002	In 2003-2010 of	Plans till 2020
1	Belgium	0	216	–
2	UK	124	1406,5	7583
3	Germany	0	5442,3	25000
4	Denmark	397,9	158,4	400
5	Ireland	25	547	1205
6	Spain	0	20	2563
7	Canada	0	20	–
8	The Netherlands	18	219	100
9	Poland	0	120	–
10	USA	0	472,5	–
11	France	0	102	60
12	Finland	0	207	–
13	Sweden	23,3	419,5	2364
	Total		9350,2	

Sources: 1. Renewable Energy World, July-August, 2005 г. 2. EWEA. The current status the wind industry. 2003 г. 3. Bimonthly Magazine – July/August 2003 г. 4. German Wind Energy Association (BWE).

Recently a lot of work and attempts are made to build floating offshore solutions. The first successful floating wind turbine solution in the world, *is working for three (3) years now* in the Aegean Sea. It is an innovative ecological solution that has been developed in Greece and has been awarded by European Union. On a special floating platform a wind turbine and photovoltaic systems, produce and supply, through advanced electrical and electronic energy conversion components, energy to a desalination unit which uses reverse osmosis technique, in order to produce potable water from the sea.

The technical solution is also important because it uses varying power input (like the produced by almost all renewable energy systems, which doesn't feature a constant frequency and voltage) to supply any system that needs constant input to operate successfully (such as desalination, hydrogen production etc).

The gained experience indicates that in many areas of Azerbaijan the wide use of wind energy installations has the big prospects. The annual wind energy capacity of Azerbaijan amounts approximately 800 MWt taking into consideration the geographical location, natural resources and economic infrastructure.

According to the initial calculations this capacity means 2,4 billion kWt-h of electricity energy. Hence it means the save of 1 million ton of standard coal and, most important, the prevention of a large quantity of CO_2 emissions polluting the environment.

The long-term meteorological observations during 1965-2000 have revealed the wind regime on Baku located Absheron peninsula as follows (tab. 4) [10]:

Table 4

Annual average speed, km/s	Annual maximum speed, km/s	Number of days per year when the wind speed reaches 15 km/s	Number of days per year when the wind speed reaches above 15 km/s
5,8	40	67	154

As it is well known, one of the most energy-intensive spheres of Azerbaijan's economy is the oil and gas industry which annually consumes over 1 billion in kWt-h of electricity power. It is naturally to presume the motivation of the State Oil Company of Azerbaijan Republic (SOCAR) to exploit wind energy installations, which are well studied both from the point of view of energy source, allowing to save significant positions of consumed energy, as well as from the point of view of ecologically-friendly production and continuous supply of the electricity power for the SOCAR enterprises during the emergencies occurred due to the faults in power supply.

It should be noticed that SOCAR pays to "Bakuenergy" company more than 150 million manat (around 187 million USD) for 1 billion kWt-h of electricity energy. Besides, taking into account the specific features of petroleum industry and with purpose to meet own requirements, SOCAR generates 73,4 million kWt-h of the electric power, thus having consumed 2.32 million м^3 of natural gas for 4,5 million manat.

According to the regulations applied in Azerbaijan, the generation of 1 kWt-h of electricity requires 409,4 gr. oil fuel or 269 gr. diesel or 0,5 м^3 gas. Actually, "Azerenergy" Joint Stock company within one year consumed for electricity generation 1,6 million tons of oil fuel and 3,81 billion м^3 of natural gas, while SOCAR spent 2,32 million tons of diesel and 33,4 million м^3 of natural gas.

Wind energy installations alongside with its technical and technological parameters, are characterized by synergy features such as, use of renewable energy sources ecologically-friendly and harmless to environment (absence of emissions CO_2, HO, SO etc.) and supply of continuous electricity energy for the oil wells.

Wind energy installation with capacity of 1 MWt could generate 5 million kWt-h of electricity energy per year, return the investments within 5-6 years and continuously supply the electricity energy within 20-25 years with the minimum operational expenses.

The carried out technical and economic calculations have shown, that the manufacture of wind energy installations with capacity 150, 1000 and 1600 kWt in Azerbaijan could save 40-45% of the overall expenses (taking into account expenses on transportation) compare to manufacture of the same installations in Germany.

According to the plans it will be produced 50-60 sets of such installations per year in Azerbaijan. Thus, it will allow to meet SOCAR's requirements of electricity energy within 6-7 years and to save the hydrocarbon volumes necessary for generation of 1 billion kWt-h of electricity.

CONCLUSIONS

«Offshore wind park» which will be established on fixed oil platforms in the Azerbaijani sector of Caspian sea, in the long term represents the vast economic, ecological and technical interest.

It is possible to ascertain, that the wind installation designs include the numerous achievements in the list of engineering sciences, such as aerodynamics, mechanics, electrical engineering, mechanical engineering, chemistry, electronics, system of control, communications and metrology.

The manufacture and use in Azerbaijan of wind energy installations will allow to establish the ecologically-friendly, reliable and economically effective energy power system on SOCAR's enterprises.

REFERENCES

[1] Janahmadov A.Kh., Amirov F.G..Status and prospects of use of nontraditional renewable energy sources (Состояние и перспективы использования нетрадиционных возобновляемых источников энергии) //Assembly in mechanical engineering, instrument making, № 10, 2009, pages 51-55.
[2] Sibikin Yu.D., Sibikin M.Yu. Nontraditional renewable energy sources (Нетрадиционные возобновляющие источники энергии). M: Radio Software. 2009. 232 pages.

[3] Popel O.S, TumanovV.L. Renewable energy sources: status and development prospects (Возобновляемые источники энергии: состояние и перспективы развития). Alternative energy and ecology, 2007, № 22 (46)
[4] www.clean-wind.ru
[5] Sidorov V.V. Wind energy installations and systems. (Ветроэнергетические установки и системы.) M.: Vneshtorgizdat. – 1990.

[6] Bezrukikh P.P and others. Concept of wind energy use in Russia (Концепция использования ветровой энергии в России.) // M.: Book – Penta. – 2005

[7] J. Twidell, A. Weir. Renewable energy resources (Возобновляемые источники энергии). Translation from english under editorship of Korobkov V.A.. – M.: Energoatomizdat. – 1990

[8] Wind energy (Ветроэнергетика).). Translation from english under editorship of Shefter Ya.I. – M.: Energoatomizdat. – 1982

[9] Bezrukikh P.P and others. Nontraditional renewable energy sources (Нетрадиционные возобновляющие источники энергии).– M.: AMI PRESS. – 2002
[10] Janahmadov A.Kh. and others.. Wind energy installations (Ветроэнергетические установки). Baku, Chashyogly, 2009. 164 pages.

Kazakhstan Renewable Energy Sources: Clear Energy Market Promotion, Competitiveness and Benefits

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Abstract: Demand for clear energy is growing significantly, customers are adapting to this changing marketplace: USA plans to increase consumption of energy from renewable resources (RES) more than 50% by 2030, 20% wind energy in particular. Such aspects as change of energy demand, investments, impact of legislative support to promote RES have been developed and analyzed with use of MARKAL- integrated economic-environmental model adopted in Kazakhstan. Benefits of RES, in particular improvement of project bankability, competitiveness of wind farms considered trough two mechanisms interrelation- Renewable Energy Credits and Joint Implementation under Kyoto. Kazakhstan aimed to promote RES has set a target to increase share of alternative sources of energy in energy balance up to 5% by 2024, in particular use of wind energy potential for electricity production in amount of 5 billion kWh in 2024, legislative support on RES development in place since 2009.

The findings are: RES demand growth and competitiveness begins in 2016-2020, capacity potential assessed up to 4,5 GW; in spite of high capital costs the RES are attractive by absence of fuel, low operating and maintenance expenses, short period of construction, RES legislative support will promote development since 2010-2012 but will not render the essential influence upon the general level of the investments in case of coal energy replacement; Decentralising power reduces losses in transmission, increases network security and reduces overall emissions in the long term. RES Project developers may apply to Kyoto by seeking additional finance for carbon reduction through selling verified credits in addition to electricity and Renewable Energy Certificates (RECs). RECs could be converted into ERUs which could be sold on international market either under EIT or through JI, in this case eligibility requirements should be satisfied. Benefits for RES support: Climate Change Mitigation, Urban Air Quality, Energy Security, Hedge against fossil fuels markets, Energy decentralisation.

Keywords: integrated model, RES, mitigation

1. Introduction

Growing concern over climate change at the governmental level, coupled with attention to emissions in local markets, is bringing companies and organizations to include clean energy renewable sib their energy portfolios. More than 25 states in the US now have specific targets requiring retail energy providers to procure renewable energy and those numbers are expected to grow. Demand for clear energy is evident, according to the recent US governmental report consumption of energy form renewable resources (RES) could increase more than 50% by 2030 [1], 20% wind energy in particular. Several cities with both OECD and non-OECD countries have developed policies to encourage renewable energy use. For cities in developing countries, this has been encouraged by the additional drivers of reducing local air pollution and moving towards sustainable development growth. Overall however, only small proportion of local governments worldwide have developed policies and projects specifically to better utilize their RES and capture the benefits[2]. Kazakhstan is one of such countries. Kazakhstan possesses significant resources of renewable energy in the form of hydro energy, solar energy and wind energy. The total installed capacity of electricity stations is about 18.5 GWe, the share of thermal power stations is 87% from the total capacity, hydro stations - about 12%, and others about 1%. However, the potential of hydro energy is assessed to be 170 million kWh per year and wind energy 1820 million kWh per year. These resources haven't achieved a wide application until the present time. Wind energy is in our focus. In 2009 the new law of the Republic of Kazakhstan "«ABOUT SUPPORT OF USE OF RENEWABLE SOURCES OF ENERGY»[3] and supporting regulations were adopted. Accordingly the national Program on RES development [4] the target has been set to increase share of alternative sources of energy in energy balance up to 5% by 2024, in particular use of wind energy potential for electricity production in amount of 5 billion kWh in 2024.

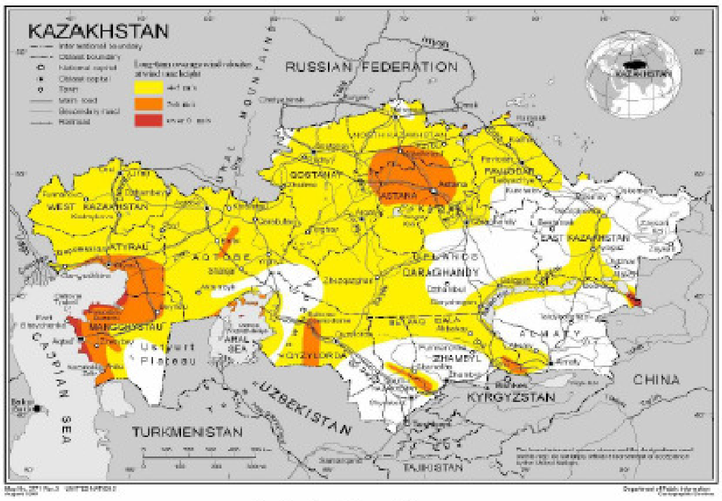
2. Potential and competitiveness of RES in Kazakhstan: economical aspects of wind energy development

Kazakhstan is the largest emitter of greenhouse gases in Central Asia and the main actor to promote RES development.
In 1990 total net greenhouse gas emissions were 320 million tons of CO2 equivalent. According to the 2004 data of IEA emissions of energy related CO2 per GDP in Kazakhstan was about 6 CO2 kg/USD[1]. Energy sector contributed about 80% of total emissions, with about 45% coming from energy industries (electricity and heat production). By ratifying the United Nations Framework Convention on Climate Change (UNFCCC) in 1995, Kazakhstan accepted the commitment to formulate, implement, publish and regularly update national and, where appropriate, regional programs containing measures to mitigate climate change. Government strategy of fulfilling its commitments to the UNFCCC includes utilization of the country's wind resources. The authors contributed the support elaboration and adoption of RES regulation and RES promotion in Kazakhstan.
About 50% of Kazakhstan's territory has average wind speeds about 4-5 m/sec at a height of 30m, the deminimus figure for good technical potential wind energy development. Wind Atlas (50meters)[2] has been developed during wind monitoring program to depict precisely the potential of wind energy in Kazakhstan [4] for investors and wind park developers, see the Figure 1.

Figure 1. Wind atlas of Kazakhstan

One of the issues, concerning all Kazakhstan regions, is of the supply of energy to remote rural consumers. The large scale of the territory of Kazakhstan (see also Figure 1) and low the density of population in rural area means that significant rural transmission lines extension is necessary, which currently forms about 360 thousands km. Maintenance of the power circuits for such an extension, as well as significant losses (25-50%) of energy transmitted will greatly increase energy cost. In Kazakhstan 67 bn kWh are carried on a system of 24 000km, equivalent to 2,8MW/km. In other words the Kazakhstan power industry must invest in 10 times as much infrastructure for an equivalent amount of transmission as the UK[3], for instance. Such reliance on infrastructure means either significant cost, or significant losses due to long transmission and aging systems. Increasing power supplies to such remote areas to meet expanding demand would involve significant capital expenditure to upgrade, replace and renew transmission infrastructure in addition to the capital expenditure for the upgrade, replacement and renewal of generation plant.

Coal fired power stations currently operating in Kazakhstan are selling electricity at a price of about 1 US cent/kWh, broadly similar to the marginal cost of operation. New capacity, which will be necessary to meet the rapidly increasing demand for power in many areas of the country, will not be able to operate at such low income levels but will charge at a level to cover the cost of capital investment. The cost of electricity from wind is estimated as 2-4,5 KZT/kWh [5]. Analysis provided shows that the real cost of power transported to remote consumers with small capacity may reach up to 5 cents/KW/h, which makes energy supply of remote small consumers economically unfeasible. An economic alternative for power supply to remote consumers would be distributed small scale generation using renewable sources of energy. Developing renewable energies and related technologies generates jobs and attracts new investment, particularly in rural, economically depressed areas.



Wind atlas of Kazakhstan

[1] UNDP report" Prospective of Wind Power Development in Kazakhstan", Almaty, 2006 p- UNDP/GEF and Government of Kazakhstan project "Kazakhstan- Wind Power Market Development Initiative"

[2] Energieteam,2006, Wind Monitoring programme for Kazakhstan Report ,part I "Identification of potential interesting sites for further in-situ measurements", *Website*, available at: http://www.windenergy.kz/

In order to meet increasing demands for power in areas remote from the centers of power production it is necessary to consider the investment required to upgrade and expand existing and to construct new transmission infrastructure. In depth investigation of RES competitiveness, impact of introduction regulatory and market mechanisms on RES demand change, issues of investments were investigated with MARKAL modeling[4].

According to scenarios developed with MARKAL model [6] wind power plants are not competitive in the power sector of Kazakhstan until to at least since 2016.Although available from 2008, the uptake is delayed and slow: 5 MW in 2016, 50 MW in 2020 and 2 GW only in 2024, see Figure 2.

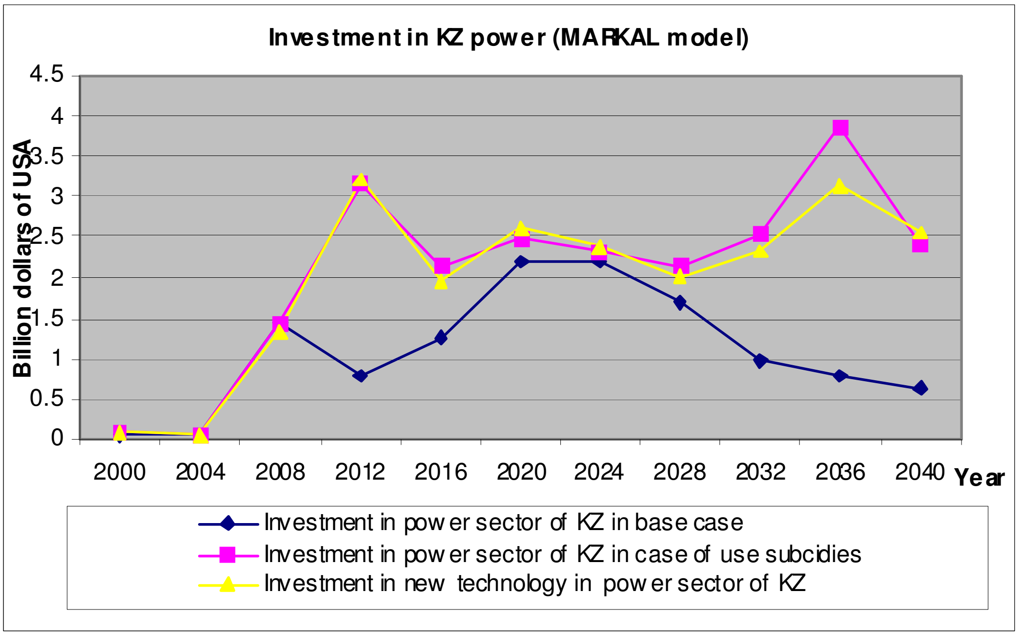


Figure 2. Investment dynamics in power sector, Kazakhstan

Analysis of scenarios presented (see Figure 2) shows that in the base case the development of the electricity and heat generating systems in the next twenty years requires expenditures of the order of 1.5 – 2 billion US dollars every four years in the average. In the renewable scenario the expenditure jump to twice as much in the four year period around 2012. This is due mainly to the increase of fossil fuel prices and the need to build high efficiency plants, less to the construction of 0.5 GW of small hydro power plants.

What conditions make an earlier introduction of wind power plants possible? To explore the possibilities, subsidy scenarios have been built [7]. According to it the installation of wind power plants starts earlier if the wind electricity is subsidized with 3.2 US cents/kWh. In this case in 2016 wind power produces 0.58 TWh, which is about 0.5% of the total electric generation, up from 0.1% in the base case, in 2024 it covers 3% of the demand with 4.1 TWh. With a stronger subsidy of 5.8 US cents/kWh the systems starts building wind power plants event earlier, in 2008, and produces 0.23 TWh. In the period 2016-2020 the subsidy can be reduced to 1.2 US cents/kWh, without reduction of wind electricity generation. In this scenario wind power increases 10 fold form 2012 to 2020.

The presence of subsidies for wind electricity increases the cost of the system slightly, about 40-55 million US dollars by 2008, up to about 100 million US dollars in 2016 – corresponding to 5% of total expenses. Due to higher investments on wind farms in the early years, the investments in 2020 are lower. Total investments on wind power plants between 2011 and 2022 are about 200 million USD. In the longer term the expenditure of the power sector is similar across scenarios [7].

Subsidies can help developing wind power plants in Kazakhstan in the short term, when they are not yet competitive with the cheap domestic coal. However, the overall weight of wind subsidies on total investments on power plants in the coming decades is in the order of few percent points, and is going to disappear in 2020, when wind electricity becomes competitive with fossil fuel fired power plants.

Additional analysis has been done with four scenarios on dynamics of CO2 emission from power sector, accordingly: base case, use of more efficient technology and RES, change of fuel prices and use of only more efficient technologies [7], see Figure 3 below. Business as Usual (BaU) scenario defined with MARKAL-Kazakhstan model refers to the reference energy system development as it is [6]. While comparing the impact of two mechanisms: the scenario

[3] In the United Kingdom the total power production is nearly 300 bn kWh/year, carried on a transmission system of 14 000km, author's remark.
4 MARKAL is a tool of the analysis for cost evaluation on following of the supposed development policy based on the energy sector and selection of the optimum measures on change legislative, regulative and institutional framework for increasing of efficiency in long-term prospect, author's remark.

of use of more efficient technology and RES ink one) and scenario of changing of fuel prices(yellow one) it is evident that GHG emission reduction is more essential because of more efficient technologies and RES use implementation, in this case the GHG emission reduction potential in 2024 could be about 34 million ton CO2 (Figure 3).

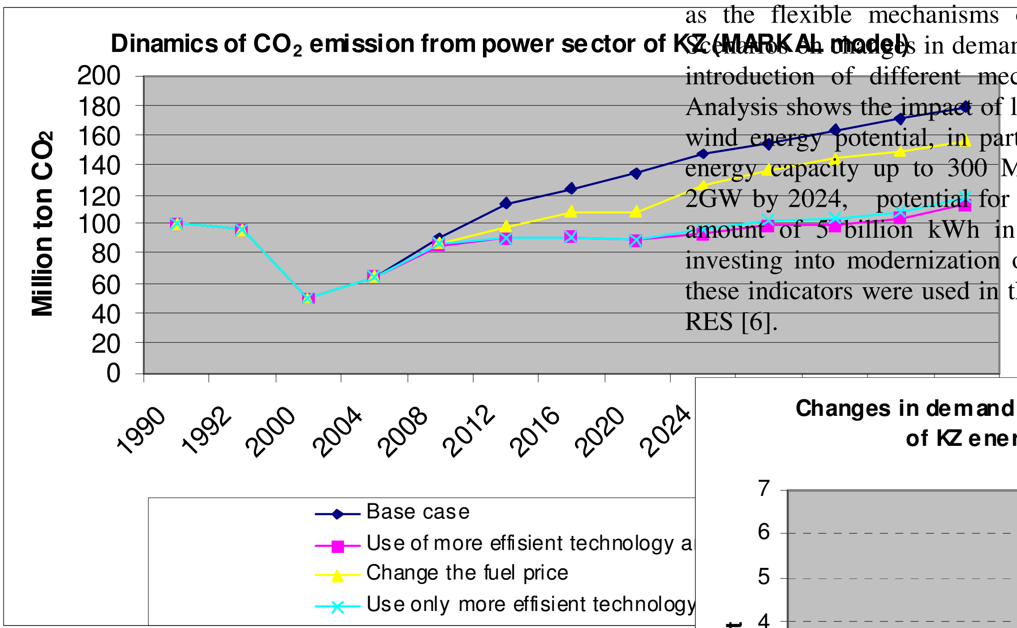


Figure 3.Dinamics of CO2 from power sector of Kazakhstan

More important than the subsidy is the gradual increase of fossil fuel prices for thermoelectric generation to international prices. In particular it will be necessary to:

- Increase the price of natural gas from the present domestic value of 50-60 US dollars per thousand cubic meter (1.46-1.75 USD/GJ) to the present international market value of 150-280 US dollars per thousand cubic meter (4.4-8.2 USD/GJ) in 2024-2028; also the domestic price of coal has to approach international prices;
- Limit the installed capacity of natural gas power plants in the period 2024-2040 to about 4.5 GW instead of about 12 GW as shown in the base case;
- Fix the capacity of nuclear power plants to 2 GW (zero in the base case); and
- Limit the market of new coal power plants to about 17 GW (instead of 23 in the base case).

At these conditions wind starts being used in 2016. In 2020 the installed capacity is 0.8 GW and generates about 1.7 TWh; in 2024, the installed capacity is 2 GW and generates about 4 TWh, i.e. 2.5% of the total. If the demand for electricity continues to grow, small hydro and wind can arrive to an installed capacity of 5.6 GW in 2028

3. Examination of RES legislation and market mechanism's impact on RES promotion

Global practice is to compensate for disadvantages in the market by granting renewable energy generation certain privileges. State regulation provides support for the development of renewable energy and can be combined with international financial mechanisms such as the flexible mechanisms of the Kyoto Protocol. Scenarios of changes in demand for RES power due to introduction of different mechanisms see Figure 4. Analysis shows the impact of legislative support use of wind energy potential, in particular increase of wind energy capacity up to 300 MW by 2015 and about 2GW by 2024, potential for electricity production in amount of 5 billion kWh in 2024 in conditions of investing into modernization of generating capacities, these indicators were used in the National .program on RES [6].

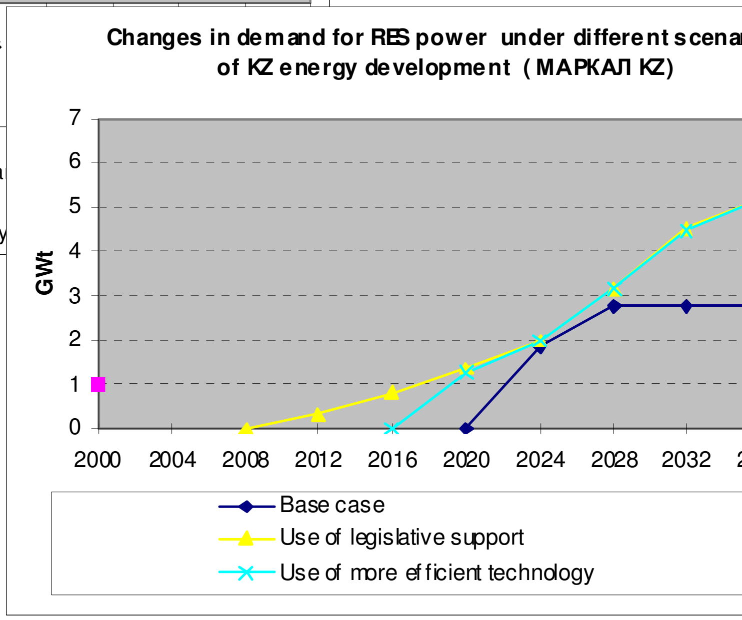


Figure4. Changes in demand for RES power under different scenarios of Kazakhstan energy sector development

The price of power supplied to a remote area of Kazakhstan therefore should reflect the marginal cost of production + the cost of capital employed in new plant + marginal cost of transmission (which must include losses)+ the cost of capital employed in the new infrastructure. The price of power from a newly-constructed local wind farm compares well to this total when the true costs are reflected [8].

In many instances, an alternative is to acquire Renewable Energy Credits (RECs). When you purchase a REC, you pay for a special amount of clean energy that is delivered to the larger power grid, which has a corresponding impact on the growth of clean energy use. This purchase helps the RE generator cover additional costs associated with these new technologies, and encourages the operation and development of more clean energy. This mechanism has been considered as support of RES promotion in Kazakhstan [8].

Regulation can ensure that the true value of wind energy is reflected in the incomes while Carbon Credits generated by a wind farm can be traded on international markets to provide a valuable additional income. Project developers via tendering submit project proposals to an established national authority responsible for their approval. On closure of the tenders, the authority will select the best proposals, based on certificate price and credibility of proposal, up to the total capacity stated in the tender announcement.

Because of capacity and type of RE projects eligible under KP (in particular small scale ones up to 15 MW) the modalities and procedures (M&P) are suitable for our attention for the purpose of our analysis on interrelation of both mechanisms.

While participating in SABIT program 2010 one of the authors of the article has been acquainted with another mechanism called the Renewable Portfolio Standard (RPS). It is a popular energy policy tool in US.29 States & DC have an RPS, California's RPS goal for new Renewable generation is the most aggressive in the country (CA: 33% by 2020)[5]. The RPS requires that a minimum (and growing) percentage of renewable generation be included in the electricity mix. The benefits of an RPS include:

- long-term contacts with utilities help reduce risk for the developer and help secure financing
- larger economies of scale for renewable technologies brings down the cost
- environmental protection& public health-clear air, climate change
- Hedging against volatile natural gas\prices
- jobs, economic development
- lower prices due to competitive procurement process.

This approach could be examined in- depth for adaptation in Kazakhstan. At present we have a declarative target o increase share of alternative sources of energy in energy balance up to 5% by 2024 mentioned in RES National Program [4].

4. Examination of risks and extra benefits in RE projects relating to Kyoto

In case if the REC price is too low to attract finance to his project in the national tender the developer can make a voluntary choice to follow Kyoto. In this case developer shall bear risks related to accreditation under Kyoto which could be rather high in comparison to expected benefits.

While looking for financing sources related to Kyoto the developer could refer to several surveys, implemented recently in Kazakhstan [8, 9] and should remember that ERUs generated during JI project implementation can represent only a small part of project cash flow. The impact on RE project financial internal rates of return (IRRs) for a range of CDM and JI undertaken by the World Bank (WB) at a price of $4 per ton CO_2 equivalent is 0.5–2.5% (hydro, wind) and carbon can contribute about $2.00–3.40 per MWh delivered. Thus, revenues of this order of magnitude will not make renewable energy projects viable unless they are already close to commercial viability. Project costs related to carbon value involved depend on complexity of the project. The Up-front costs of 40,000-115,000 (1-15% of ERU value) are significant and mean that an additional level of risk is imposed upon a proposed project

Project developers may apply to Kyoto on a voluntary basis to improve the bankability of their project by seeking additional finance for carbon reduction through selling verified credits in addition to electricity and RECs. In this case the developer will bear all risks on accreditation and registration under Kyoto. Besides, other benefits could be the following:

1. Under Kyoto RECs may confirm the origin that electricity is generated from renewable energy sources for the purpose of UNFCCC and the Kyoto Protocol.
2. RECs could be converted into emission reduction units which could be sold later on international market. Eligibility requirements to Kyoto Protocol should be satisfied.
3. Share of RES could be interpreted as indicator of effective use of resources for achieving of Sustainable Development and contribute to UNFCCC.

Key findings

- The hidden costs of non-renewable energy (to environment, to human health, and otherwise) make renewable energy, in many cases, more desirable the fossil fuels or nuclear power. For regions with very good wind potential and an energy deficit in Kazakhstan, wind farms can be an economical alternative for the construction of new coal power stations, at the same time possessing indisputable ecological advantages.
- RES demand growth and competitiveness begins in 2016-2020 for Kazakhstan, capacity potential assessed up to 4,5 GW. Benefits for RES support in Kazakhstan include: Climate Change Mitigation, Urban Air Quality, Energy Security, Hedge against fossil fuels markets, Energy decentralisation.

[5] DSIRE: www.dsireusa.org California's Renewable Energy Policy, Brian McCollough, Le-Quyen Nguyen, February 23,2010

- RES legislative support will promote development since 2010-2012 but will not render the essential influence upon the general level of the investments in case of coal energy replacement.
- Mechanisms such as RECs, PRS and Kyoto could be advantage perspective for RES development in Kazakhstan.
- RES Project developers may apply to Kyoto by seeking additional finance for carbon reduction through selling verified credits in addition to electricity and Renewable Energy Certificates (RECs) and provide adequate viability of RE projects and increase the competitiveness of the certificate bid price. RECs could be converted into ERUs which could be sold on international market either under Emission International Traiding or through Joint Implementation, in this case eligibility requirements should be satisfied. The revenue from sale of carbon credits could be returned to the local municipality that invested in an accredited renewable energy project.
- The local approach to renewable energy project deployment can help to demonstrate what is possible, at what costs and who the winners and losers might be. Social experimentation retailing to renewable energy deployment and climate change mitigation can be undertaken at local level, and where successful, adopted nationally. Decision makers therefore need to stimulate action at the local government level in order to fully integrate RES and climate considerations into urban development strategies.

References

1. Dan Birns, 2010, *Presentation to SABIT Delegation* (Lyubov Inyutina, Kazakhstani participant of SABIT 2010), *Website*, available at: http://www.eere.energy.gov, http://www.sabitprogram.org/
2. OECD/IEA, 2009, *Executive Summary of the Report " Cities, towns& Renewable Energy"*, *Website*, available at: www.iea.org/about/copyright.asp
3. Law of the Republic of Kazakhstan *«ABOUT SUPPORT OF USE OF RENEWABLE SOURCES OF ENERGY»* ,2009, *Website*, available at: http://www.windenergy.kz/
4. Ministry of Energy and Mineral Resources of the Republic of Kazakhstan /UNDP, 2007, *"National Program on Wind Energy development in Kazakhstan up to 2015 with perspective up to 2024"*, *Website*, available at: http://www.windenergy.kz/
5. Energieteam,2006, Wind Monitoring programme for Kazakhstan Report ,part I "Identification of potential interesting sites for further in-situ measurements", *Website*, available at: http://www.windenergy.kz/
6. Sergey Inyutin, Lyubov Inyutina, 2009*, "Climate Change policy and Energy Conservation Measures in Kazakhstan", Website*, available at http://www.promitheasnet.kepa.uoa.gr
7. Alex Cherednichenko, 2008, *"Kazakhstan Today"*, *Website*, available at: http://news.gazeta.kz/art.asp?aid=227552
8. Lyubov Inyutina, 2009, *"Compiling RES Legislation for Kazakhstan"* , UNDP/ REEP report, part 2, *Almaty*
9. Inyutina L., Inyutin S., Omarbekuly T., 2007. *"Methods of selection of the most efficient technology taking into account ecological factors by the example of polypropylene production"*, TarSU Bulletin, issue 2.

Quo Vadis Archimedes Nowadays in Greece? Towards Modern Archimedean Turbines for Recovering Greek Small Hydropower Potential

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Abstract: The aim of the present paper is to prove the rediscovering of the always modern Archimedean ideas under the form of innovative Archimedean small hydropower plants and the efficient exploitation of all the watercourses and open hydraulic channels of Greece, having, according to the recent research inventories of the Hydraulic Laboratory of ASPETE, a theoretical Archimedean hydropotential of around 30TWh and a hydrocapacity of about 3.412 MW. By following the similarity methodology of the Buckingham's π-theorem a series of innovative small-scale models of new Archimedean turbines were designed, developed and tested in the water tanks and channels of ASPETE. A floating Archimedean hydro-generator has been tested in an irrigation channel and in the canal of the mysterious sea river current of Cephalonia. The very promising experimental results and the recent ASPETE and NTUA researches and innovative studies for demonstration Archimedean projects, in cascade and in parallel, seems to give a good answer to the question "Quo Vadis Archimedes nowadays in Greece?". These results prove that technically feasible Archimedean hydraulic energy conversion could become the future lead green technology and be the alternative solution for hydro electricity generation in a large number of sites throughout the whole country.

Keywords: Small Hydropower, Archimedean Turbines, Renewable Energy Sources

20. Introduction

A short overview giving useful information concerning the important hydraulic renewable energy past proves that intelligent water falling and lifting devices and hydro wheels technologies have a very long history in Greece. It seems that, everything is starting during antiquity 2300 years ago, before Archimedes and long before the great theoretical works of investigators such as Leonardo da Vinci, Galileo, Torricelli, Pascal, Newton, Bernoulli, and Euler, during Hellenistic time, in the technological context of Macedonian Alexandria, in the famous Library and Museum, where the spirit of Aristotle's was present, with various machines and mechanisms, gears, planetaria, celestial globes, the

Antikythera Mechanism, with pumps, various mills driven by water wheels etc.

Invention of the water screw is traditionally credited to the scientist and engineer Archimedes of Syracuse, on the basis of numerous Greek and Latin texts. The creation of the water screw is probably based on the study of the spiral, for which Archimedes wrote a treatise entitled "On Spirals", in 225 B.C. This screw pump was first mentioned by Diodorus of Sicily (first century B.C.), Athenaeus of Naucratis (ca. 200 B.C.), by Moschion, by Vitruvious etc. The Roman engineer Vitruvius gave a detailed and informative description of the construction of an Archimedes screw in his "De Architectura" (Stergiopoulou et al. 2009). There is a historical and archaeological evidence that the use of the water screw was propagated to all Mediterranean countries as well as to the east up to India and to China. The evolution of these spiral hydraulic screw mechanisms continues nowadays thanks to the Archimedean contribution. Despite the fact that the brilliant spirit of Archimedes continues always to be present and its water extraction screw and other spiral hydraulic mechanisms, persisting into modern times, this paper intends to give the rightful place, nowadays in Greece, in the Era of Transition and Crisis, to the Archimedean philosophy, in order to determine the most reliable and ecological way for a very promising future sustainable development. What is new in our work, is the rediscovering of the always modern Archimedean ideas, under the form of innovative Archimedean small hydropower plants, based on the inversion of the energy flow in the Archimedean spiral pump operation, and turning the old Archimedean's screw pumps into new Archimedean screw turbines, including new floating cochlear generator schemes, and then the future efficient exploitation of all the natural watercourses and open hydraulic channels of Greece, having, according to the recent research inventories of the Hydraulic Laboratory of ASPETE, an important theoretical Archimedean hydropotential.

2. Towards an inventory of the Archimedean small hydropower potential of Greece

In Greece, a country with rough terrain, steep slopes and non uniform precipitation distribution, rich in small and large watercourses, the water resource spatiotemporal behaviour is in general irregular with considerable seasonal and yearly fluctuations. Due to the geographical configuration of the country, the steep and rough terrain in the mountainous and semi-mountainous areas, where the existing hydropotential favours the installation of small hydroelectric plants and due to the concentration of multiple water uses in the flat areas, such Archimedean installations could serve a multiple purpose philosophy and resolve conflicts of interest and use. By investigating in ASPETE a Greek area of about 45.915 Km², corresponding to 35% of the total Greek area 131.913 Km², for the 14 water districts of Greece (Figure 1), and by using simple quasi - linear formulas and water discharge data and data determined by precipitation, evapotranspiration, infiltration through subsoil porous and karstic media, it was possible to obtain a rough estimation of the theoretical Archimedean small hydropotential of each water district and each watershed, including the main man-made hydraulic works, as a function of mean flow and gross head. The total theoretical Archimedean hydropower potential estimated for the 14 water districts (1: W. Peloponnese, 2: N. Peloponnese, 3: E. Peloponnese, 4: W.C. Greece, 5: Epirus, 6: Attica, 7: E.C.Greece, 8: Thessaly, 9: W. Macedonia, 10: C. Macedonia, 11:E. Macedonia, 12: Thrace, 13:Crete, 14:Aegean Islands) of the whole country is around E_{th}=30TWh, corresponding to an overall theoretical hydro capacity of about 3.412 MW (Stergiopoulos et al. 2008).

Figure 1: Greek Water Districts

The distribution of the theoretical specific small hydro capacity (KW/Km²) can be calculated easily and gives approximately a mean value of 74.7 (KW/Km²) for the total investigated area and an Archimedean small hydropower density of 0.651GWh/Km². The following figure describes the distribution of the calculated small theoretical Archimedean hydropotential, in GWh, throughout the administrative districts of Crete, Thrace, Macedonia, Thessaly, Epirus, C. Greece and Peloponnese.

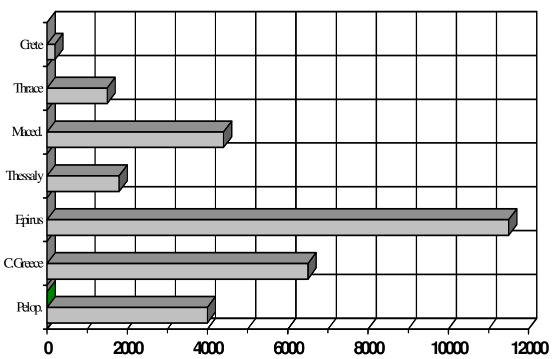

Figure 2: Calculated theoretical Archimedean small hydropotential in GWh per administrative district

These preliminary inventory results demonstrate the predominance of the water districts of Epirus and of Macedonia and the important role mainly of the presence of the Pindos Mountain Range, related to the important annual rainfall difference between the North-Western Greece (1.000 to 2.000mm) and the Eastern Greece (400 to 500 mm/year). The calculated mean Epirus-Macedonia specific theoretical hydropotential values are 2 GWh/Km² and 250 KW/Km². A general idea of the most promising small hydro sites in Greece is given in the following figure, where the important role of a series of other mounts (e.g. the Vermion, Olympos, Athos, Oiti, Vardoussia, Chelmos etc) is obvious· (Stergiopoulos et al. 2009a).

Figure 3: The most promising small hydro sites in Greece

Nowadays, in the time of the climate change, when the rational water use and management and the optimal sustainable development of small hydropower plants, is of a high priority for all countries and for Greece, the estimated unexploited Archimedean small hydro potential of Greece seems to be very promising and there are many alternative sites for an efficient sustainable Archimedean small hydro development (Stergiopoulos et al. 2009b).

3. The famous Archimedean spiral pump screw

The historian Moschion, states that, the King of Syracuse requested that Archimedes build the biggest luxury ship possible, named Syracusia, and that the Great Engineer launched this ship by means of an "ingenious endless spiral screw propulsion device". This famous Archimedean screw or cochlias, one of the oldest machines still in use for lifting water for irrigation and drainage purposes, consisting of either a spiral tube around an inclined axis or an inclined tube containing a tight-fitting, broad-threaded screw, could be operated by hand and raise water efficiently**.** Vitruvius giving in his "De Architectura" a detailed and informative description of an Archimedes screw contributed greatly to keeping this spiral pump device well known throughout the ages (Stergiopoulou et al. 2009). This ingenious pump device functioning in a simple and elegant manner by rotating an inclined cylinder bearing helical blades around its axis whose bottom is immersed in the water to be pumped. As the screw turns, water is trapped between the helical blades and the walls, thus rises up the length of the screw and drains out the top. A view of the famous Vitruvius's eight-bladed Archimedean screw, together with a three - bladed Archimedes' screw and a modern representation of a traditional screw turning by hand, given in figure 4.

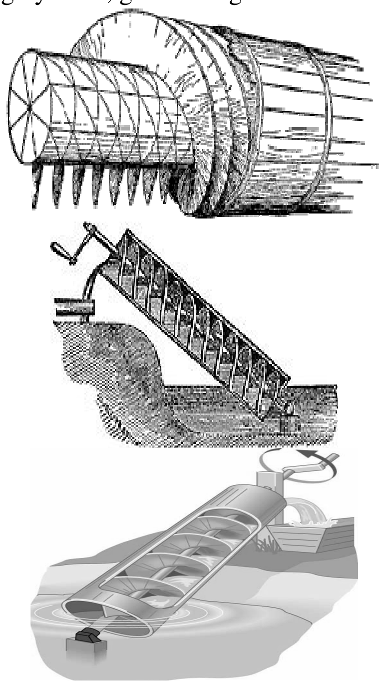

Figure 4: A series of Archimedean pump screws

The geometry of an Archimedes screw, the best known of the early pumps and also persisting into modern times, especially for low head applications, is governed by certain external and certain internal parameters. The external parameters (its outer radius, length, and slope) are usually determined by the location of the screw and how much water is to be lifted. The internal parameters (its inner radius, number of blades, and the pitch of the blades), however, are free to be chosen to optimize the performance of the screw. The inner radius and pitch that maximize the volume of water lifted in one turn of the screw is note easy to be found. The evolution of the spiral screw mechanisms continues nowadays in various domains besides the water applications thanks to the overtime Archimedean philosophy contribution.

It seems that actually the determination of the optimal parameter cochlear geometrical design values, in relation with the famous Vitruvius description, continues to remain without answer for modern Archimedes screws.

4. Towards the rebirth of the Archimedean screw as a modern hydropower tool

It is well known that pumps and turbines are two energy conversion devices families, with the pumps turning electrical or mechanical energy into fluid energy and the turbines turning fluid energy into electrical or mechanical energy forms. The Archimedean screw, in the well known since antiquity pumping role, consisting of an axis with helical blades, lying in a channel with a semi-circular or even closed circular cross section exploits the hydraulic head of energy per weight unit, $H=z+ P/(\rho.g)+ V^2/(2.g)$, with z the head, P the pressure, V the water velocity, ρ the density. What is new in the present paper is the inversion of the energy flow in its operation, turns the old Archimedean's screw pump into a new Archimedean screw turbine, a powerful generator for the extraction of hydraulic energy in all natural and man-made watercourses of Greece. Thousands of years after it was invented the spiral rotor for pumping water the Archimedean screw has also found nowadays a new very promising application, operating in reverse as an energy converter, for low head differences. The following figure shows the rediscovering of the old Archimedean screw, under the form of new Archimedean screw hydropower turbine, producing electricity, and gives a schematic Archimedean small hydropower plant using one cochlear low head generator device. There are few moving parts, so less parts to get damaged and go wrong. Water flows from the top and out from the bottom, transferring its potential energy to the screw by rotating it at a constant velocity. The top of the screw is coupled to a gearbox which drives a generator via a belt.

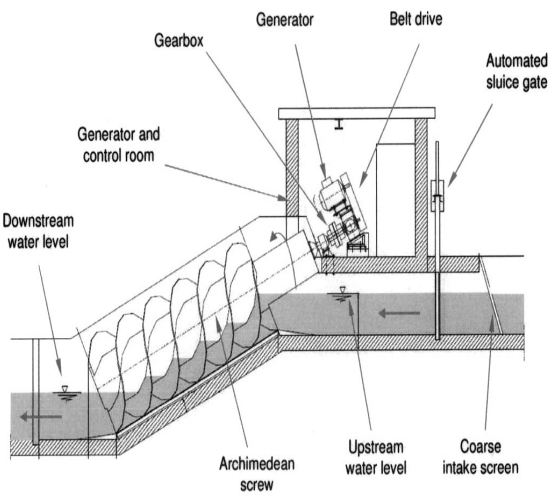

Figure 5: Schematic of typical Archimedean Screw turbine installation

The new twist on the very old Archimedes's ideas was newly seen in the Hydraulic Department of ASPETE for a series of sites and small waterfalls throughout Greece having various water discharges and various available heads, for a series of experimental and numerical simulations. During the last years we had made in the Hydraulic Laboratory of ASPETE important research efforts towards the rediscovering of the always modern Archimedean ideas under the form of Archimedean spiral rotors and new Archimedean small hydropower plants. This new low-head hydropower technology applied in various water systems data could became very popular in Greece and other countries. The artistic views of a rediscovered low - maintenance and ecologically sound small Archimedean plant are given in figure 6.

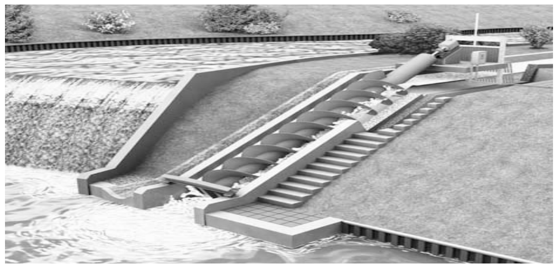

Figure 6: Artistic views of two small Archimedean plants.

For the above special artistic site case, having as design point conditions, an average head 4m and a rated discharge of about 14.0m3/s, the installed capacity of the Archimedean small hydroelectric plant is around 500 KW, and the expected energy production of about 4.0 GWh/yr (Stergiopoulou et al. 2009). The proposed rebirth of the Archimedean screw, nowadays in Greece, as a modern hydropower tool could cover various hydropower requirements of hundreds of sites in natural watercourses and man-made hydraulic open channels having a small head. The very promising installation of a series of various Archimedean small hydropower plants in all the 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, for instance on the many river weirs which exist. A series of new Archimedean screw turbines could be designed for low heads, in the range of 1 to 10m, with flow rates between 0.1 to $50m^3/s$ and should be inclined at an angle, between 22 and 40 degrees from the horizontal. For greater heads a cascade of two or more similar energy spiral rotors could give an efficient hydropower solution. For the case of important water discharges the new Archimedean technology imposes two or more similar energy spiral screws in parallel. Two possible future demonstration Archimedean energy cases, the first with rotors in parallel, for important flows, and the second with spiral screws in series, for relatively important heads, are illustrated in the next figure.

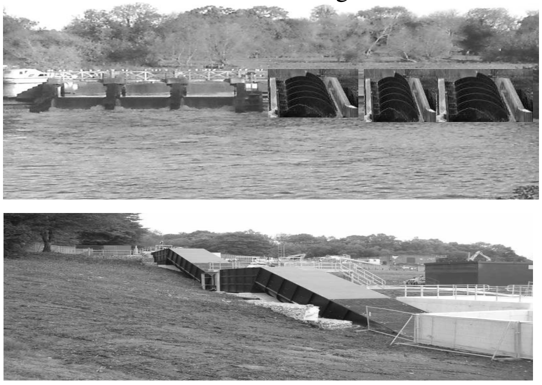

Figure 7: Archimedean hydropower plants with rotors in parallel and in series.

5. The first steps towards hydropower Archimedean Screws in ASPETE and NTUA

In the Hydraulic Department of ASPETE we had made, in collaboration with NTUA, by following the similarity methodology of the Buckingham's π-theorem, some experimental and theoretical researches towards the inversion of the energy flow in Archimedian screw operation, and a series of innovative small-scale models of new Archimedean turbines were designed, developed and tested in the water tanks and channels of ASPETE. Buckingham's π theorem states that, if a quantity dependent on n physical variables and k is the number of primary independent dimensions, then the dimensionless dependent variable corresponding to this quantity can be expressed in terms of only n-k dimensionless variables. Then the equation relating all the variables will have (n-k) dimensionless and independent of each other π groups. The final equation obtained is in the form of $\pi_1 = f(\pi_2, \pi_3, \ldots.. \pi_{n-m})$. It is well known that in Fluid Mechanics, there are only three independent dimensions, mass (M), length (L) and time (T). Thus, k = 3. In most fluid problems, the physical variables are the density (ρ), the velocity (V), the body length (l or c), the viscosity (μ) and the speed of sound (a). Thus, n = 5. The two dimensionless variables are the Reynolds number (Re) and the Mach number (M). By selecting ρ, D, and N as variables containing the fundamental dimensions to be combined with the remaining variables and giving $\pi_1 = \mu^a \rho^b D^c N^d$ or $\pi_1 = \rho D^2 N/\mu$ = Re, and deriving other π-terms $\pi_2 = M^2$ and $\pi_3 = P/[\rho D^5 N^3]$, $\pi_4 = Q/[D^3 N]$, $\pi_5 = H/[D^2 N^2]$. A large number of prototype/model equations can be used for scaling both for turbines. During our experimental and theoretical efforts for scaling Archimedean turbines we had used the following efficiency prototype/model correlation developed by Moody $(1-\eta_1)/(1-\eta_2) = (D_2/D_1)^{0.25} (H_2/H_1)^{0.1}$, where η is the efficiency, D the diameter, H the hydraulic head, and the indices 1 and 2 correspond to the prototype and model conditions. Experiments have shown that, for geometrically similar Archimedean cochlear turbomachines and for incompressible flows, the Reynolds number effect is small and may be ignored and we could assume the relationships f{P, D, N, Q, H, η}=0, or $H/[D^2N^2] = f'\{Q/[D^3N], \eta\}$, where P is the installed capacity, N the rotation speed and Q the flow discharge. Taking into account that the first two groups are both functions of the third and weak functions of Re are usually ignored it is easy to obtain the following relations $Q_1/Q_2=(N^2_1D^2_1)/(N^2_2D^2_2)$, $Q_1/Q_2 = (N_1D^3_1)/(N_2D^3_2)$, $P_1/P_2 = (N^3_1D^5_1)/(N^3_2D^5_2)$. By following the similarity methodology a first spiral wheel, having the dimensionless ratios, s/d = 2, d_m/d = 0,24 and g/d = 0,04, with s the spiral lead, d the circular duct dimension, d_m the circular mandrel dimension, and g the thickness of the spiral profile of figure 8. Our calculations and first measurements of the Archimedean spiral turbine rotors showed the important effect of inflow water level to diameter, and seem to give efficiencies between 78 and 83%, making these an interesting alternative for turbines in low head hydropower applications.

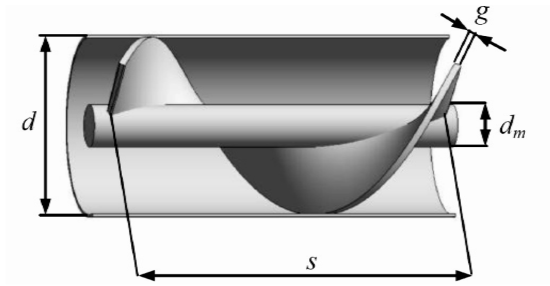

Figure 8: Definition of the dimensionless ratios of a spiral wheel used in ASPETE

A series of innovative small-scale models of new Archimedean turbines were designed, by following the similarity methodology of the Buckingham's π-theorem, and developed in the Hydraulic Department of ASPETE with the collaboration of N.T.U.A.. A view of two of these models, tested in the water tanks and channels of ASPETE, is given in figure 9 (Stergiopoulou 2010).

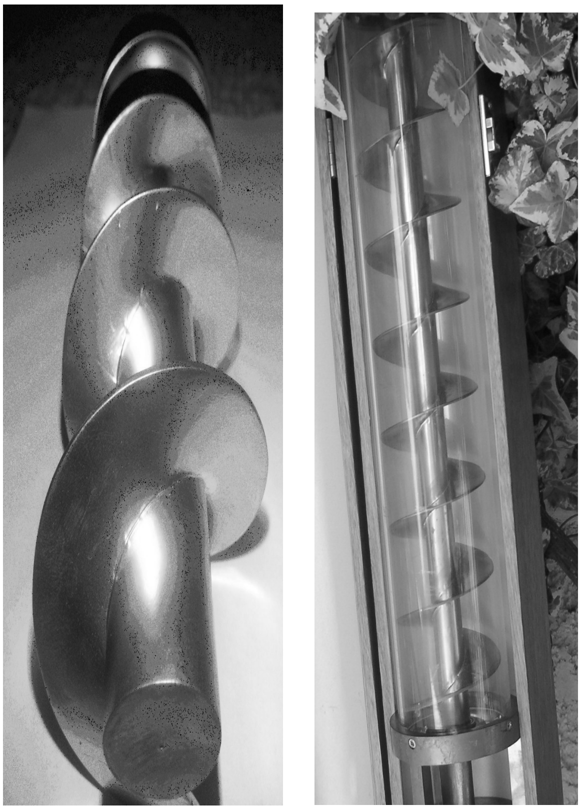

Figure 9: Small-scale models of Archimedean rotors developed in ASPETE.

Some of our first CFD Archimedean calculation efforts are illustrated in the next figure.

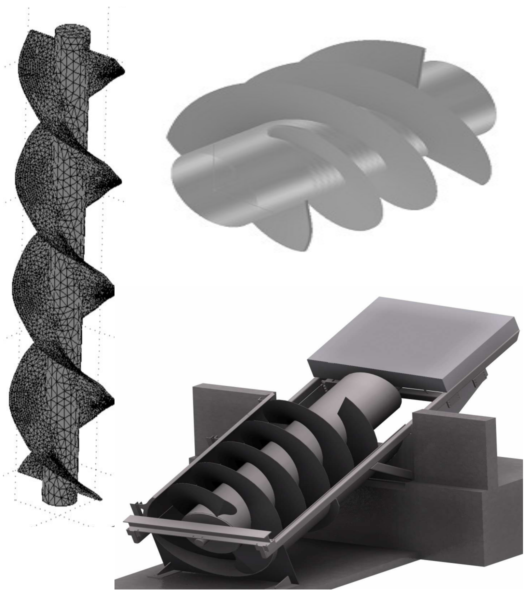

Figure 10: Some first CFD Archimedean calculations in ASPETE

During the last two years a series of various Archimedean experiences had been made in the open flume hydraulic channel experimental channel of the Hydraulic Laboratory of ASPETE concerning various Archimedean wheel configurations, by using our small-scale models. A representative Archimedean experiences in the open channel of ASPETE a vertical Archimedean wheel is schematically illustrated in figure 11.

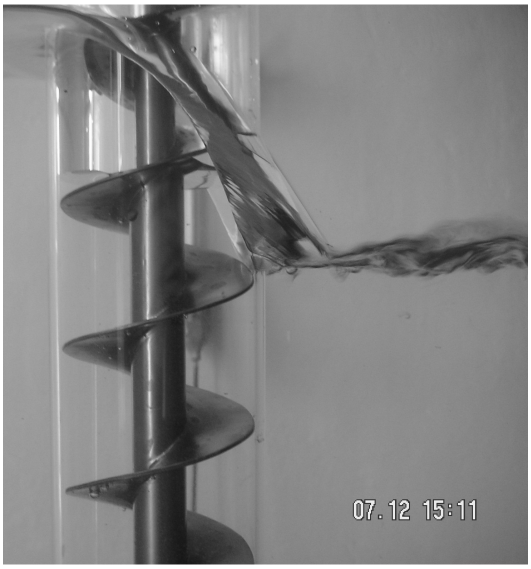

Figure 11: A representative Archimedean experience in the open flume channel of ASPETE

The following figure gives typical information concerning Archimedean flow visualization through a spiral wheel in the Hydrogen Bubbles Water Electrolysis Experimental Installation of the Hydraulic Laboratory of ASPETE.

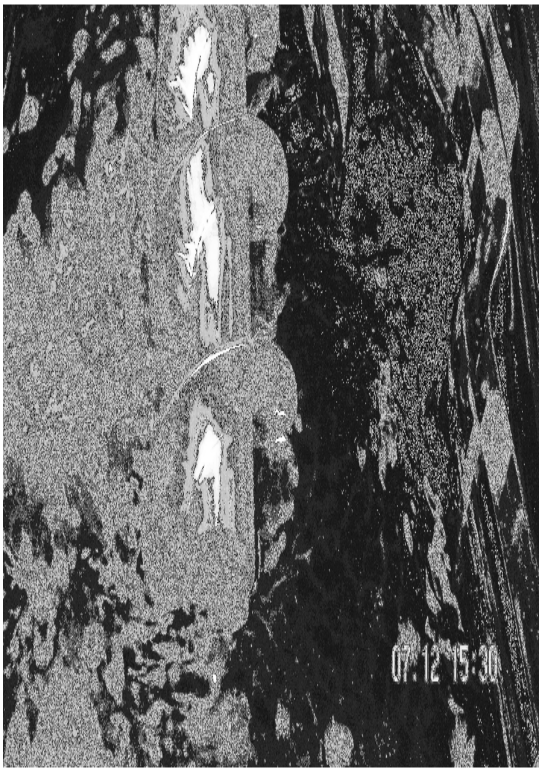

Figure 12: An Archimedean experience in the Hydrogen Bubbles Water Electrolysis Experimental Installation of ASPETE

6. Innovative floating Archimedean Energy Screws

It is well known that a hydro power generating facility makes use of the energy difference between two different levels of flowing water by transferring the water from natural bed of the stream at the higher level to the bed at the lower level and effectively extracting its potential energy, which is then made available at the rotor shaft for further use. Recent ASPETE and NTUA common efforts proved the useful exploitation of the new Archimedean screw technique and the efficient rediscovering of the old Archimedean screws under the form of second type of Archimedean hydropower turbines of horizontal floating cochlear rotors, without works, harnessing the unexploited flowing hydraulic potential of natural streams and open channels hydraulic works.

A series of floating Archimedean energy screws could be installed for recovering the hydraulic kinetic energy potential of large watercourses, of irrigation channels. In the following figure is given an artistic view of two Archimedean spiral rotors in an irrigation channel (D7 of Agrinion). A first model of floating Archimedean hydro-generator has been tested in this channel having a good hydrodynamic behavior giving some very promising preliminary results.

Figure 13: Floating Archimedean Energy Screws in D7 irrigation channel of Agrinion

A modified version of the first model of a floating Archimedean hydro-generator has been tested in the canal of the mysterious continuous sea river current of Cephalonia. It is important to mention that the beautiful island of Cephalonia is the site of one of the most astonishing hydrological phenomena in the world, with a strange seawater massive current flowing continuously into the karstic substratum of the island through sinkholes, which have formed in fractures in the rock on the south - west coast of the Livadi Gulf near the town of Argostoli. This seawater current reappears on the opposite coast of the island at brackish springs, near the town of Sami. The underground seawater current route between Argostoli and Sami is about 15Km long. Such inflow-outflow seawater current phenomenon has not been observed in other karstic islands in the Mediterranean or in other parts of the world. This exclusive special feature of Cephalonia, of the continuous seawater current inflow in the Livadi Gulf and seawater current outflow in the gulf of Sami, with the reappearance of the salt water after a mysterious disappearance into the rocks, seems to be the most astonishing marine current phenomenon of the world, the Cephalonia's coastal paradox, a real world unique mystery (Stergiopoulos et al. 2010). According to our research studies it seems that this throughout Cephalonia's island sea mysterious current flow is sufficiently powerful to drive new well-designed Archimedean spiral power screws.

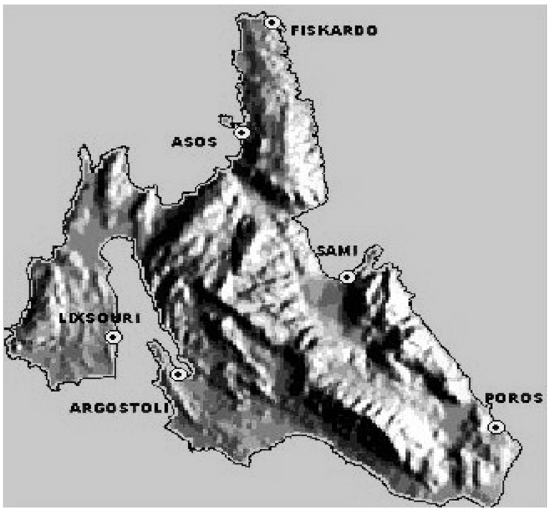

Figure 14: Representation of Cephalonia

We believe that the over the time continuous current inflow of seawater in the western coast of the island of Cephalonia, near the city of Argostoli, and reappearing, after a 15Km long underground route throughout the island, at the eastern coast in the opposite side of the island, in the gulf of Sami, is a massive and sufficiently powerful flow to drive a series of horizontal floating Archimedean spiral water wheels, a real Archimedean small hydropower farm, without civil works, and produce valuable electricity. The following figure concerns the modified version of the first horizontal floating Archimedean spiral hydro-generator which has been tested in the canal of the mysterious continuous sea river current of Cephalonia having a good hydrodynamic behavior and giving very promising preliminary results for the optimal energy recovering of this very astonishing marine current.

Figure 15: Proposal for a floating Archimedean spiral hydro-generator or a floating Archimedean spiral hydro-generator farm in the sea-river current of Cephalonia

7. Some preliminary Archimedean conclusions

According to our recent work in ASPETE and in NTUA it is technically possible to obtain the optimal cochlear exploitation of Greek hydropower potential of more than 3.000 MW Archimedean hydro capacity, by considering, that Archimedean screw turbines could be efficient for various water heads, for a large scale of flow rates and for hundreds of hydro sites with zero head. The proposed here new Archimedean small hydropower philosophy, for small available heads and for zero head cases, should attract an increasing amount of interest in Greece due to their advantages and mainly to the fact that such Archimedean small hydro plants are relatively easy to develop, they can make an important contribution to the energy supply in remote and rural areas, they can play an important role in the regional and national energy scenarios and satisfy different other requirements following a multipurpose philosophy. Although Archimedean spiral screws well known for a long time, in their pumping role, and in their new applications, operating in reverse mode as energy converters for low and zero head differences, there appears to be no consistent theory which relates the available (or, in the pumping role, the required) energy to the screw geometry and determines its mechanical efficiency limits and its hydrodynamic performances. Low head kinetic hydropower is developing very slowly in Greece despite the fact that there are thousands of very promising potential sites at small waterfalls, at many river weirs and hydraulic open channels across the country. The proposed Archimedean spiral screws, for small heads and for floating applications, are a new type of turbine in Greece, and they have a series of advantages over conventional turbines (e.g. they require very little fish and debris screening, their installation costs can be lower than comparable Kaplan turbines, they are mechanically simple). For the cases with relatively big values of low-heads, it is possible to install a two, or a multistage Archimedean screw turbines cascade. For the cases of larger values of water discharge the most efficient solution could be obtained by using two or more spiral energy rotors in parallel. Due to their price-performance ratios the Archimedes' screw turbine schemes stand out with excellent cost effectiveness compared to the higher-capacity but more expensive turbines (Stergiopoulou 2010).

According to our preliminary results it seems that the efficiency of the proposed new Archimedean screw turbines is higher than that of other turbines (e.g. Pelton, Francis, Kaplan) and all the other traditional water wheels. Archimedes' screws turbines mean high profitability, taking into account the ratio between low investment and maintenance costs and the achieved annual turnover is very positive. We expect that more small Greek companies could be interested in getting involved in these Archimedean hydro energy schemes if small hydropower renewable energy received more funding. An important further research effort should be made in order to simulate the complex hydraulic flow through the blades of the Archimedean helical energy rotors, to predict the hydraulic losses, to develop a consistent theory linking the screw's geometry with its mechanical efficiency and its hydrodynamic performances under design and off-design operation conditions and to optimize this multipurpose precious technical Archimedean heritage machine. The innovative small-scale models of new Archimedean rotors designed, developed and tested in the water tanks and channels of ASPETE and the floating Archimedean hydro-generator tested in an irrigation channel and in the canal of the mysterious sea river current of Cephalonia, the very promising preliminary experimental results and the recent ASPETE and NTUA researches and innovative studies for demonstration Archimedean projects, in cascade and in parallel, seems to give a good answer to the question "Quo Vadis Archimedes nowadays in Greece?". However, the government of Greece needs to improve support for such cost-effective renewable energy initiatives in order to inspire young people, students, engineers and technical universities to review and to rebirth new ideas from the glorious past of the ancient Greece and from the over the ages modern spirit of Archimedes. The dream and hope of the authors of the present paper is that the technically feasible and environmentally friendly Archimedean hydraulic energy conversion could become the future lead green technology and be the alternative solution for hydro electricity generation in a large number of sites throughout the whole country.

References

1. *Stergiopoulou, A., Stergiopoulos, V., 2009. "From the old Archimedean Screw Pumps to the new Archimedean Screw Turbines for Hydropower Production in Greece",* Proceedings of the 2nd International Conference on Environmental Management, Engineering, Planning and Economics (CEMEPE) & SECOTOX Conference, pp.299-305, Mykonos, June 21-26.

2. *Stergiopoulos, V., Stergiopoulou, A.,* 2008. *"Towards Olganos Small Hydro Parks at the Macedonian Vermion Mount"*, Proceedings of the 15th International Seminar on Hydropower Plants in the Context of the Climate Change, Vienna University of Technology, pp. 607-618, TU Wien, 26-28 November.

3. *Stergiopoulos, V., Stergiopoulou, A., 2008. "Beyond the Helicon's and the Olganos Type Small Hydropower Plants in Greece",* Proceedings of Wasserbaukolloquium 2009 - Wasserkraft im Zeichen des Klimawandels, Dresdener Wasserbauliche Mitteilungen Heft 39 pp.369-378, Technische Universitat Dresden, Dresden 12-13 Marz.

4. *Stergiopoulos, V., Stergiopoulou, A., 2009. "Small Hydropower Plants in the Shadow of the Holy Mountains Olympus and Athos"*, Proceedings of the International Conference HYDRO 2009, Lyon, October 26-28.

5. *Stergiopoulos, V. and Stergiopoulou, A.*, 2010. *"The paradox of coastal cross flow in Cephalonia island"*, Proceeding of the 6th International Symposium on Environmenetal Hydraulics, Athens

6. *Stergiopoulou, A., 2010. "Theoretical Investigation and Experimental Simulation of the Hydrodynamic Behaviour of Cochlea Turbines",* Ph.D. Thesis, (in preparation in N.T.U.A., supervisor Prof. E. Kalkani).