A Feasibility Study of a Combined Wind - Hydro Power Station in Greece

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In
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Declaration of Author's Right

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Abstract

This thesis tries to investigate applied rules and conditions in Greece in order to develop a combined wind/hydro power plant in a remote Island such as Crete Island. Crete has a great wind potential such as the majority of Greek Islands, but the exist installed wind power cannot be fully absorbed Moreover, the electricity cost is very high and the operation of conventional plants is not only damaging for the environment a bur also very expensive. Crete has an autonomous grid and that means it is sensitive to disturbances and thus the operation of large wind farms helps to increasing the stability problems. This thesis studies a combined wind/hydro power system aiming at producing low cost electricity and in increasing the penetration of RES in Crete. Additionally, a parametric analysis is performed on techno-economic basis in order to find the optimum size of each part of wind/hydro power system: i. the number and nominal power of wind turbines, ii. The nominal power of hydro station and the optimum size of the water reservoirs. iii. The number of hours without enough energy (power shortage) and the loss of the operation of this station. Moreover, this thesis aims to produce some general rules about the wind/hydro combination, which could be applied to any case study in the remote islands.

This specific application on the island of Crete in Greece is analysed and the results are presented on worksheets. The calculation results based on real measurements data. This methodology takes into account the stochastic behavior of the weather conditions, uses as input data the 10-minutes wind-speed distribution and the rate of rainwater, which is stored in the hydro reservoir. In conclude the combined wind/hydro power system in Crete is suggested as an absolutely profitable investment.

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Introduction

1.1 Energy Storage

Civilisation depends on energy. Technical progress and development are often connected with the quantity of energy used. A large increase in energy consumption was noted especially after the Second World War. Conventional energy sources provide more than 90% of the overall quantity of energy. Moreover the energy demand is growing and the conventional energy sources are limited and not to be found everywhere.

The last decades have witnessed the utilization of renewable energy sources in a large scale. It is widely known that all energy sources are connected- one way or the other- to the Sun. Most of these sources covert the Sun's energy and store it in different ways. The primary energy flow, however, is not constant. It depends on season, weather conditions and the time of day. Energy demand is not constant either. Therefore the need for a storage system- acting as an intermediate between energy source and consumer- is vital.

Historically, the energy storage problem was solved by piling lumps of wood or by damming springs. Later, coal became the most important energy source. Today there are many forms of energy storage but one of the most convenient is the petrol tank. Technically the storage of oil is not difficult and the time storage depends on when the tap of the tank will turn off. Storage can be maintained without any losses for a long time and the energy density is high.

Recently, renewable energy sources have attracted considerable interest. However, most renewable sources do not provide a constant energy supply and they cannot be directly stored, as a result they require secondary storage systems.

Electrical power systems are the most flexible and convenient energy carriers from producers to consumers. The main disadvantage of electricity as an energy carrier is the impossibility of storing it. The problem of energy storage becomes more and more crucial as the development of the power systems leads to an increase of their capacity.

In an electricity power system, which is based on thermal, nuclear and renewable generation, the storage procedure has a wide field of application and a number of duties to be fulfilled. These duties must be taken under consideration in order to gain the optimisation of the supply. An energy storage department could have a number of duties on a power network system as shown in the following table 1.1 [1]

Generation duties	**Auxiliary services**	**Transmission and distribution**
Energy management	Frequency response	Voltage control
Load levelling	Spinning reserve	Power quality
Peak generation	Standby reserve	System reliability
Ramping/load following	Long term reserve	
Incorporation of renewable		

Table 1.1

Demand of stationary storage arises from the utilisation of renewable energy sources, which - directly or indirectly – are related to the solar radiation on the surface of Earth. As soon as solar energy begins to displace fossil fuels, the need for efficient storage methods will increase. It is often suggested that energy storage will be essential if the renewable energy sources - such as wind, solar and wave - are developed on large scale. The use of storage on a power network, when including renewable generation, can provide a lot of benefits in different areas.

- Efficient storage balances generation with demand over a long period of time and allows for a more extensive use of renewable energy sources
- System control arising from random generators (such as wind) can be mitigated with a storage system and therefore the proportion of renewable generation can be increased on the network
- Conventional units, which are used as auxiliary units, could be replaced by energy storage.

- Power plants, which operate with constant energy supply, could be combined with energy storage to provide energy at peak times.

1.2 Renewable energy sources

Renewable energy technologies use primary energy resources that are infinite. Renewable technologies include wind energy, solar energy, water energy, geothermal energy, and biomass. The main attractions of renewable energy are their security of supply and the fact that they are environmentally friendly compared to fossil fuels. Most forms of renewable energy - such as hydro or solar - are available within the borders of one country thus making their utilization easier.

In the 1970's a substantial boost was given to renewable energy, when two disruptions in oil production occurred in the Middle East. Research into the development and deployment of renewable energy grew, but the increasing political stability in the Middle East in the 1980's and the following reduction of oil prices made it difficult for renewable energies to compete in the market. Hydropower was the main exception being as it is a competitive technology for more than a century. At present time wind power is competitive in some markets due to the reduction of its cost.

Global climate is changing due to an increasing amount of greenhouse gases that are emitted usually from conventional technologies. The deriving health effects make the use of renewable energy sources gain a significant advantage over the use of conventional technologies.

Many governments have subsidized the capital costs of renewable energy investments in order to increase renewable energy production and the main reason for this is the environmental friendliness of renewable energy.

Renewable energy sources can play an important role in meeting the energy demand in the following years. There are a lot of scenarios, which forecast the percentage of renewable energy contribution to the global or European energy generation but many of them have been characterized too optimistic. The European Union is one of the pioneers in developing and applying renewable energy. It also supports several research programs for the further exploitation of renewable energy.

The European Union is working towards a target of renewable energy providing 12% of total electricity supplies by 2010. The White Paper issued by the European Commission in 1997 attempted to predict which generation technologies could make a major contribution to European energy supplies.

Energy Source	1995 TWh	2010 TWh
Wind	4	80
Hydro	307	355
-Large (10 MW plus)	270	300
-Small (under 10 MW)	37	55
Solar photovoltaic	0.03	3
Biomass	22.5	230
Geothermal	3.5	7

Table 1.2

This Paper specified that wind and biomass were the two technologies most likely to make the largest increase in renewable energy generation. Table 1.2 presents the estimated contribution of renewable energy to European Union electrical energy supply.

1.3 Wind energy

Wind energy generation already has a cost competitive to conventional sources of generation. There are a lot of organizations, which help the additional development of wind energy in Europe and in the rest of the world. At the current time a large wind energy industry is developing in Denmark, Germany and California. It is well known that wind energy has been used by many of the European countries for thousands of years. In Denmark the use of wind energy began from the nineteenth century and lasted up until the late 1960s. However, California was the one responsible for giving wind energy a boost in order to transit from the small-scale generation to a large and significant generation.

The greatest wind potential exists in many parts of Europe. The following graph presents wind power systems installed (MW) in the European Union by the end of 2002.

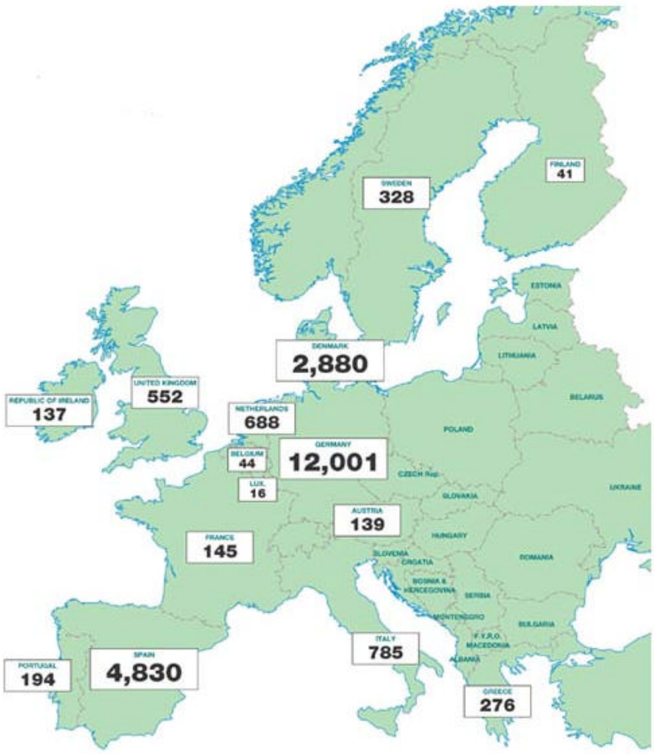


Figure 1.1

The installed capacity in Europe has increased by about 40% per year in the last six years. Today wind energy projects across Europe produce enough electricity to cover the domestic needs of 5 million people. The wind energy industry has set a goal for 60,000 MW of wind energy capacity to be installed by 2010. Wind power is ready to make a significant impact on the energy scene in Europe and develop a major export industry. [2]

Wind energy can be exploited in several ways: for example wind turbines installed in island or rural communities in developing countries can displace fossil fuels. In developed countries, wind turbines can provide electricity directly into the grid. This will be the key for the future and wind energy concentrates all the requirements (e.g. advanced technology, policy) in order to contribute significantly towards meeting the global energy demand.

1.4 Hydropower and sustainability

If the criterion for characterized an energy source as renewable energy source is based on the idea of an infinite energy source, then clearly hydropower must be considered a renewable energy source since the ‘‘fuel’’ for hydropower is water, which is renewable and is not consumed in the electricity generating process. Renewables have attracted the public attention during the past. Hydroelectricity, as a technology, started in the last decade of the 19th century.

A lot of hydropower projects, which were developed too early, are in operation without environmental problems but some others not. Hydropower projects may have negative environmental effects on a river unless plenty of protecting measures are taken. A large-scale hydro project with a reservoir will convert some amount of land-ecosystem to sea ecosystem. On occasions there are environmental parameters that may affect in a negative manner the public opinion. It is necessary, therefore, to reduce the harm to the ecosystem to the minimum possible through careful designing of the power plant while at the same time stressing the fact that there are numerous beneficial public effects, such as flood control, water supply, low-cost energy and increased opportunities for recreation.

In many countries, there is already a substantial amount of hydroelectric production. A subsidy to existing hydropower producers would just create more profit and would not necessarily achieve the objective of increasing the amount of renewable energy. Even if subsidies were restricted only to new hydro plants, the issue of the environmental friendliness of hydropower would remain increasingly important. But it is difficult to make a generalized statement about the environmental friendliness of hydropower, as each project has a specific-site, some of them are environmentally highly advantageous and others are not.

Small hydropower is defined as renewable and qualified for government support more easily than large hydropower. Hence this myth has arisen that small hydropower is more environmentally friendly and renewable than large hydro. The perception that large hydro is less environmentally friendly than other forms of renewable energy, and the following problems with public acceptance of large hydro projects, are responsible for missing opportunities to increase the share of renewable energy. In some developed countries, almost all the economically viable hydropower sites have already been consolidated. On the other hand the remaining ones are not competitive compared to coal or natural gas generation. However, some of these high cost hydro sites may be far more cost effective than some other forms of renewable energy (e.g. solar energy). A subsidy to develop these remaining sites would give greater environmental and economic benefits than some of the subsidies currently being granted. [3]

1.5 Penetration of RES

The penetration of renewable energy (especially wind energy) has a significant impact on the electrical system and requires a detailed analysis for each type of renewable energy sources. The different number of penetrations of renewable energy depends on the nature of the various systems as well.

The problem of increasing penetration of renewable energy is becoming more and more difficult, when the renewable energy plants are connected with weak isolate systems (e.g. islands). A list of rules is responsible for the maximum percentage of renewable energy. As a result a storage system is more than necessary in order to help the penetration of renewable energy sources to weak isolated systems. Hydropower is one of the possible solutions, which could be combined harmonically with the rest of the renewable energy sources.

Energy Policy in Greece

2.1 Overview of energy market in Greece

Greece has a population of 10.5 million and a GDP (gross domestic product) about ECU 11500 per capita. The EU averages are ECU 22000. Hence, its energy consumption per capita is relatively smaller than that of other countries and has a small energy market.

More specifically, in 1996 it had a total primary energy supply of 24 Mtoe. An amount of about 62% of the total energy supply is provided by oil. Domestic lignite plus coal provide about one third. Thus oil, lignite, and coal together provide about 95% of the total energy supply. There was no access to natural gas until 1997,except for a small amount of natural gas, which was produced domestically. A new gas system supplying gas imported by Russia and Algeria was operated in 1996. Hydropower contributes 1.6% of the total energy supply through an installed capacity of 2500 MW. Renewables and wastes provide approximately at 3% of the total supply. Lignite is the only significant domestic energy source. The domestic oil production is less than 5% of the total oil demand. Figure 2.1 presents the energy production during the period 1973-1996, and a projection of this up to 2010. [4]

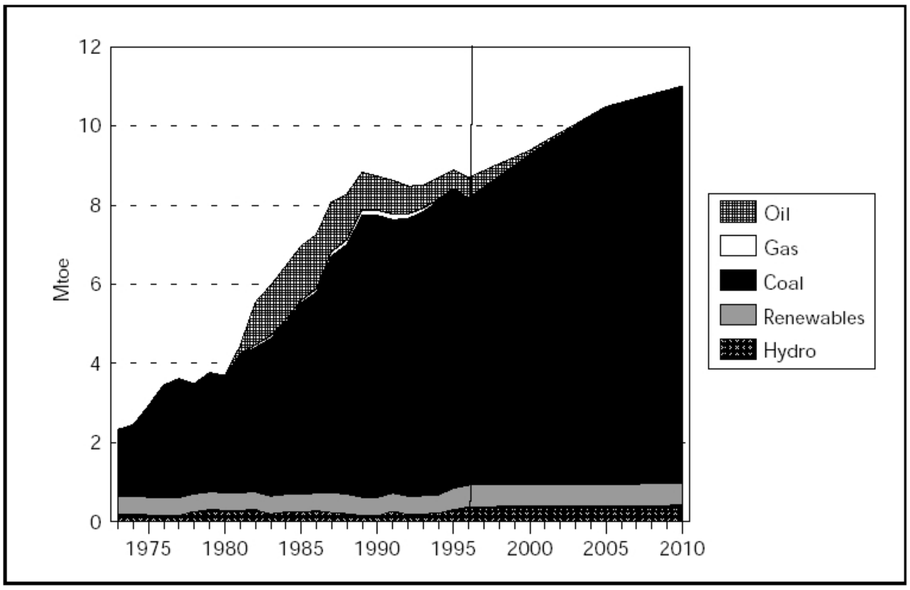


Figure 2.1: Energy Production 1973 to 1996, projection 2010

In addition, figure 2.2 illustrates the energy consumption at the same period. It is obvious that oil is playing an important role in the Greek energy market due to the huge dependence on imported oil.

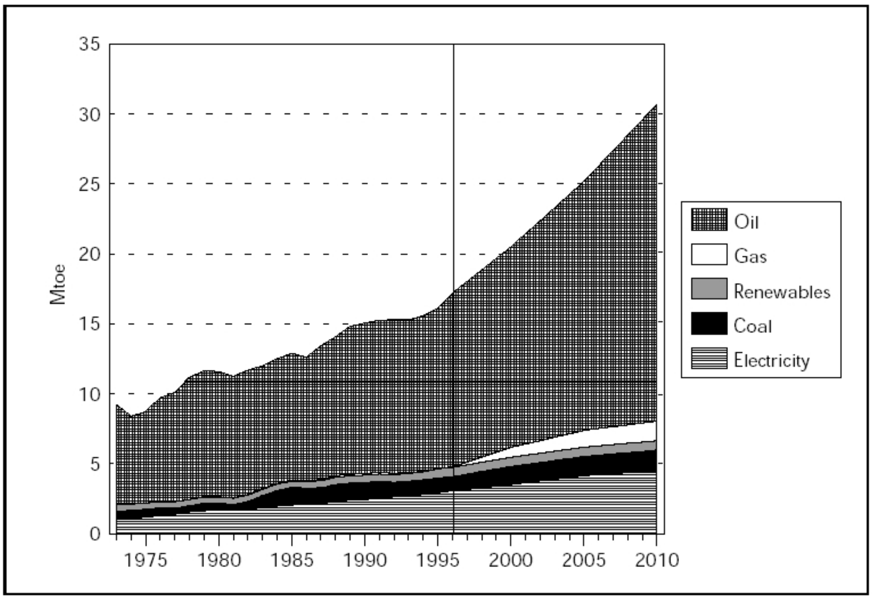


Figure 2.2: Energy Consumption 1973 to 1996, projection 2010

2.2 General energy policy in Greece

The energy market is dominated by public energy firms: i) The Hellenic Petroleum Corporation (known as DEP) has a market share of about 60% of product sales. ii) Natural gas development, which has been guided by the Public Gas Corporation (DEPA). iii) The Public Power Corporation (PPC) which produces about 98% of the electricity. iv) Lignite production is almost entirely controlled by the Public Power Corporation. The three major public energy corporations are summarized in table 2.1. [5]

Initials	Name	Greek Name	Founded	Notes
PPC	Greek Public Power Corporation	DEH	1950	re-organised in 1998, 98% share of electricity market
HP	Hellenic Petroleum Corporation	ELP	1975	20% privatised in 1998 60% share of domestic refined products market
DEPA	Greek Public Gas Corporation	DEPA	1988	after privatisation of Hellenic Petroleum owned by State (85%) and HP (15%) 100% share of developing gas market

Table 2.1: Major public energy companies

Since 1990 Greece's energy policy aims at improving the market competition. Public sector is the key to this structural change in Greece. Privatisation of public sector corporations and the introduction of free competition are major elements of this overall policy.

In 1997, Directive 96/92EC of the European Parliament and Council on common rules for the internal market in electricity came into force. The directive introduces common rules, which concern production and the exploitation of the networks for the transmission and distribution of electrical energy. It takes into consideration the need for the creation of an internal market in electrical energy. Greece as a member of European Council began to change the legislative regulatory in order to meet the terms of the directive. According to the directive, each member state will permit the production of electricity by independent producers, which are selected by regulatory authorities. They will have the possibility to provide the relevant licenses. In Greece, the Regulatory Energy Authority (RAE) has been set up by the Ministry of Development.

Since 1997 the Greek government has started to privatize various public sector corporations, such as industries and banks. In early 1998, the Greek government started the partial privatization of DEP, in spite of the fact that the progress of privatisation faces many serious problems. The main problem is the relationships between the Greek government and the public energy companies. Energy companies provide both information and policy advices to the Greek government. As a result the public companies have more advantages than the private companies. Moreover, a significant difficulty is the intensive opposition of public companies to further privatisation.

The liberalization of the electrical energy market in Greece will be gradual. Initially it will invoice users of medium and large voltages. The following figure shows the structure of the electrical energy market after its liberalization in Greece.

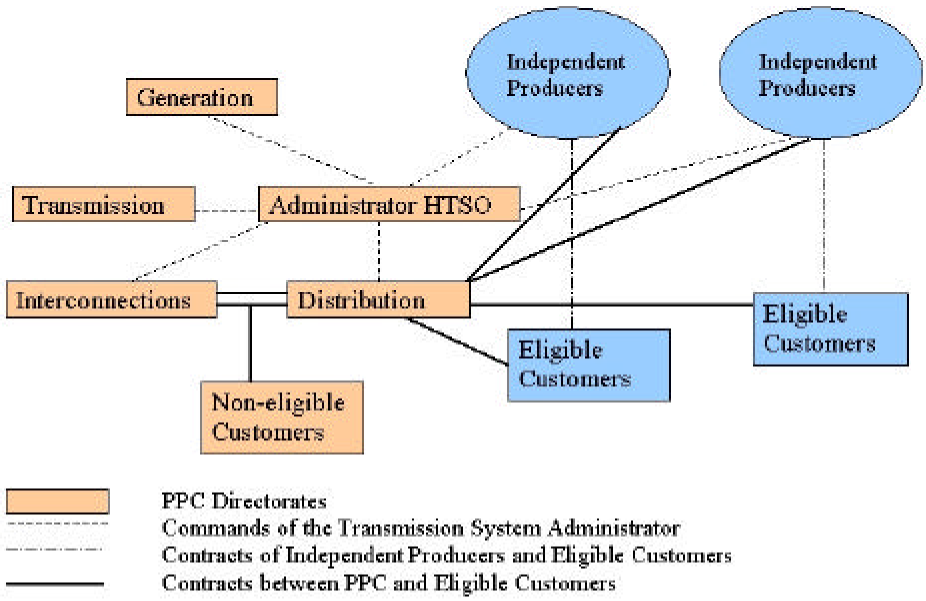


Figure 2.3: The Greek Electrical Energy Market after the Liberalisation

According to the directive 96/92EC and Law 2773/99 the next terms are defined.

- Administrator HTSO is a public company, which is responsible for the Transmission system of Electrical Energy.
- Independent Producers are private and public companies, which are able to make a contract (in order to provide electricity through the PPC's transmission system) with eligible and non-eligible customers if they take the appropriate licenses.
- Eligible Customers are the users of medium and large voltages
- Non-eligible Customers are the users of low voltage.

2.3 Renewable energy supply

At the present time Renewables accounted for about 5% of total primary energy supply (1.4 Mtoe) or 2.8% excluding large hydro. Table 2.2 summarizes the sources of renewable energy in 1996. A change in support measures for energy is likely to increase the role of renewable energy.

Technology / Fuel	Capacity (MW)	Production (ktoe)
Wood	n.a.	702
Large hydro (>10 MW)	2482	363
Vegetal waste	600	184
Solar heat	n.a.	112
Small hydro (<10 W)	41.7	10.7
Wind	27.3	3.1
Geothermal heat	28.8 (thermal)	2.7
Biomass CHP	0.5 (electric)	0.8
Biogas	n.a.	0.6
Photovoltaic	0.2 (peak)	0
Installed & Operational		**1379**

Table 2.2: Renewable Energy Installed Capacities and Production, 1996

Greece’s geography and climate offer a large potential for renewables. According to the Greek Action Plan for Climate Change, the largest future contributions are likely to come from wind energy, solar thermal, and biomass for district heating and electricity generation, and small hydro installations. There are many windy sites suitable for wind turbines, especially on the islands of the Aegean Sea. Greece’s abundant sunshine has the potential to provide a greater contribution to energy supply, mainly through hot water heating.

2.3.1 Wind Energy

The Government estimates an upper limit of some 2000 MW potential for wind power, as compared to 131.3 MW installed as of 2000. According to the existing official data at the end of 2000 in Greece approximately 350 wind turbines will be installed, 156 of them belonging to PPC and the rest 190 to private investors. To be more specific the Greek wind energy programme started in 1982, when PPC installed the first wind turbines 5 x 20kW on a research wind park on the island of Kythnos. Since then, a number of wind projects were undertaken by PPC, most of them realized during the 1990-1993 period, via the EU financing. During the period of 1993-1998 the rise of Greek wind power capacity was practically zero. In October 1998 the first private wind park started its operation in East Crete. Finally, during the last 2 years a drastic increase of private investor's wind power installations has been accomplished (80MW increase), while the PPC's wind power remains approximately the same. [6]

2.3.2 Solar Energy

At present solar energy is used almost exclusively for hot water heating. Greece has about 2.2 million square meters of collector area or 30% of the EU. The Government estimates that the market potential for solar hot water heating is approximately ten times today's 0.1 Mtoe.

A number of small photovoltaic electricity stations is currently in operation. PPC owns four photovoltaic stations of 170 kW (peak) total and some 80 small photovoltaic stations operating on the islands of the Aegean Sea. Other photovoltaic applications include 400 systems for providing electricity to lighthouses owned by the Hellenic Navy. In general, the main market for photovoltaics in Greece will be for stand-alone systems in remote areas. For example, a solar photovoltaic project started in 1997 is the proposed power station of 5 MW near Mires on the south coast of Crete.

2.3.3 Water Energy

Hydropower is exploited in 18 hydropower installations larger than 1 MW and six mini-hydro plants. PPC plans to build six new large hydro plants with a total capacity of 604 MW by the year 2005. A total of 132 MW of small hydro installations has been proposed under Law 2244/94. Some of the biggest projects are supported by the Operational Programme for Energy. The Government expects the installed capacity of small hydro plants to increase remarkably in the future.

2.3.4 Biomass

The Government also expects the installed capacity of biomass projects. Where the combined heat and power using biomass should be included to increase. There has been a number of license applications for landfill gas recovery projects from private investors and municipalities in Athens, Thessaloniki, Chania, and other cities.

2.4 Support for Renewables

A policy on renewables has been developed by the Development Ministry's directorates, Renewable Energy Sources and Energy Saving, General Secretariat of Research and Technology, PPC, Regulatory Energy Authority and the Center for Renewable Energy Sources. CRES plays a key role in coordinating the Government's activities in renewable energy development and research. It carries out programmes on wind energy, biomass, geothermal energy, active and passive solar, photovoltaics, and small hydro.

Investments in renewable energy are supported by various tax measures by guaranteed purchase mechanisms and by grant programmes. Table 2.3 shows the supporting measure in renewables. The 1985 law for the promotion of renewable energy practically led to an immobility of the projects because of the limitation of investments from local government authorities, the complex licensing procedures, and the restriction of price motivations. The 1994 law improved the framework for renewables production and some activity has been observed since its enactment. In March 1998, renewable energy projects (totally power 1.7 MW) had received operating licenses under the new law. An additional 32 projects of the total capacity of 98.5 MW had been given construction licenses. Finally, the 1999 law for the liberalization of electrical energy market led to a dramatical increase of renewable (wind) projects from private investors.

Programme / Law	Technology	Measures
Development Law 1892/90	renewables energy conservation	investment subsidies of 40-50% reduced loan interest rates and accelerated depreciation or tax credits and accelerated depreciation
Electricity Law 2244/94	renewables	guaranteed purchases of electricity produced using renewables at 70-90 % of retail electricity price maximum project size is 50MW small hydro maximum size is 5 MW
Gas Law 2364/95	renewables natural gas appliances	deduction of 75% of purchase and installation costs from taxable income of individuals or unincorporated companies
Electricity Law 2773/99	renewables	investment subsidies of 30-40% for public and private investors liberalisation of electricity market
Operational Programme for Energy	 central active solar wind, passive solar geothermal, small hydro biomass photovoltaic	total of ECU 87.6million for funding grants 35% or 50% 40% 45% 45% 50% or 55%
Joule-Therie programme	renewables	total of ECU 87.6million for R&D projects
Regional Energy Canters	renewables energy conservation	co-ordinate and assist in implementing all energy-related Government programmes no separate budget for investment support

Table 2.3: Measures Supporting Investments in Renewables

The largest single funding source for renewable energy projects is the renewable energy sub-programme of the EU Operational Programme for Energy. The total budget of the renewable energy sub-programme is ECU 171 million.

2.5 Energy Technology Research and Development

The General Secretariat of Research and Technology within the Ministry of Development is responsible for energy-related research. CRES plays a major role in coordinating and carrying out research on renewable energy and energy conservation.

The involvement of the Government, in energy research and development is difficult to be established since it varies significantly from year to year. For the period 1990-96, an average of ECU 8.6 million was spent annually. In the following years the level of funding has almost dropped to one-half. The total budget for energy-related research in 1996 was ECU 10.1 million, which is presented in figure 2.4.The EU has been an important source of research funding, through a number of different programmes. The major support for energy related research is through: [7]

- Funding of academic and industry research units
- Funding of public research organizations such as CRES or the Center for Solid
- Fuels Technology and Application
- Co-funding of projects attracting EU or other international funding.

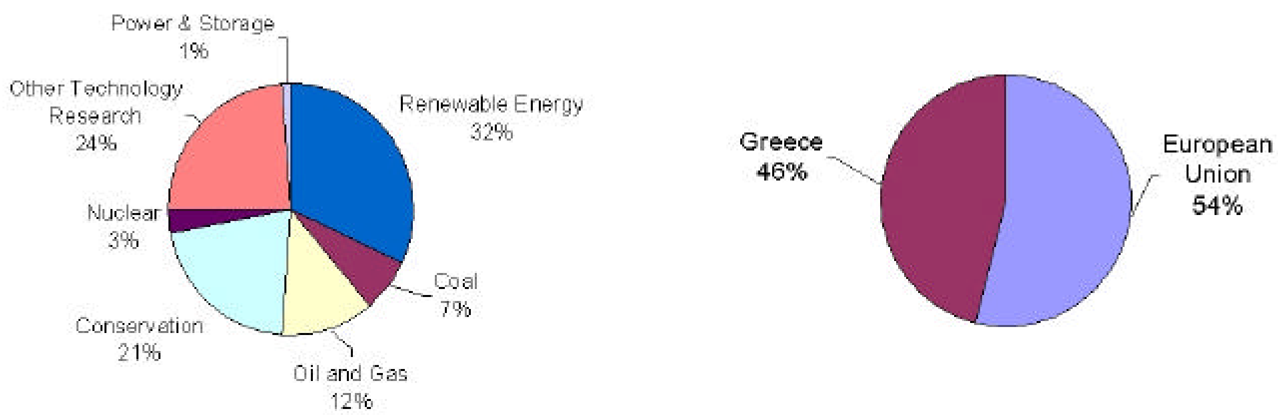


Figure 2.4: Budget for Energy Research

Research programmes can be focused on scientific education and infrastructure (i.e. developing and maintaining research institutions), technology transfer, and support of international co-operative research.

Wind Energy

3.1 Introduction

Wind power, like most sources of energy on earth, originates from the sun. As the earth orbits the sun daily, it receives light and heat. Across the earth there are areas with different temperature, so that heat transfers from one area to another. These heat differences help to create wind: in warmer regions of the earth the air is hot and is therefore at a high pressure, compared with the air in colder regions, where it is at a low pressure. Wind is the movement of the air from high pressure to low pressure areas.

The idea of creating something to capture the power from the wind is not a new idea –wind turbines (windmills) have been used for thousands of year for milling grain, pumping water, and other mechanical power applications. Today, there are over one million wind turbines in operation around the world. Most of them are used for water pumping and for generating electricity. Wind energy offers the potential to generate substantial amounts of electricity without the pollution problems of most conventional forms of electricity generation.

3.2 Global wind potential

Wind power has characterized as the world's fastest growing energy source. Installed capacity has continued to grow at an annual rate in excess of 30%. It has estimated that the world's wind resources are extremely large and well distributed across almost all regions and countries. The total available resource is estimated to be 53,000 Terawatt hours (TWh)/year. During only 2001 the new wind power capacity, which was installed, was approximately 6,800 MW. By the beginning of 2002, global wind power installations had reached 25,000 MW. This provides enough power to satisfy the needs of around 14 million households, more than 35 million people. [8]

Although Europe accounts at 70% of this capacity. Over 45 countries around the world now contribute to the global total, whilst the number of people employed by the industry is estimated to be around 70,000. The movement, which helps the wind power expansion is the increasingly need to control the global climate change. Most countries accept that greenhouse gas emissions must be drastically reduced in order to avoid environmental catastrophe. Wind energy offers both a power source, which completely avoids the emission of carbon dioxide, the main greenhouse gas, but also produces none of the other pollutants associated with either fossil fuel or nuclear generation.

An Important boost for wind energy can be given by Germany, Spain and Denmark in Europe, the U.S.A. and India with also the countries of the developing world. The following table presents the top-wind energy market during 2001.

Country	New Installation MW	Total Installation MW
Germany	2,627	8,734
USA	1,635	4,245
Spain	1,050	3,550
Italy	276	700
India	236	1,456
Japan	217	357
Denmark	115	2,456
UK	107	525
Greece	84	358
China	75	406
Others	402	2,140
World	**6,824**	**24,927**

Table 3.1: Top-wind energy market during 2001

Wind power technologies

3.3.1 Introduction

There are various types of the wind turbine. The follow table presents various types of classification. Modern wind turbines can be classified as either horizontal or vertical axis machines. Another classification is between wind turbines with different methods of controlling.

Various Technologies in Wind Turbines		
Axis	Vertical	Horizontal
Direction	Upwind	Downwind
Blades	Three	Two
Speed	Constant	Variable
Regulation	Stall	Pitch
Generator winding	Single	Double
Gear	With Gear	Gearless
Electronics	Direct AC	AC-DC-AC
Direction	Vertical	Horizontal

Table 3.2: Various technologies in Wind Turbines

3.3.2 Horizontal and Vertical axis

Horizontal axis wind turbines generally have either two or three blades or else a large number of blades. Wind turbines with large numbers of blades have what appears to be virtually a solid disc covered as high-solidity devices. In constant, the swept area of wind turbines with few blades is largely void and only a very small fraction appears to be solid. These are referred as low-solidity.

Vertical axis wind turbines have an axis of rotation that is vertical, and so unlike the horizontal counterparts, they can harness winds from any direction without the need to reposition the rotor when the wind direction changes. [9]

Figure 3.1 shows the main two types of wind turbine configurations.

- **Rotor blades**: the rotor blades are the elements of the turbine that capture the wind energy and covert it into a rotational from.
- **Hub**: The hub is the connection point for the rotor blades and the low speed shaft.
- Gearbox: **The gearbox takes the rotational speed from the low speed shaft and transforms it into a faster rotation on the high-speed shaft.**
- **Generator**: The generator is connected to the high-speed shaft and is the component of the system that converts the rotational energy of the shaft into an electrical output.

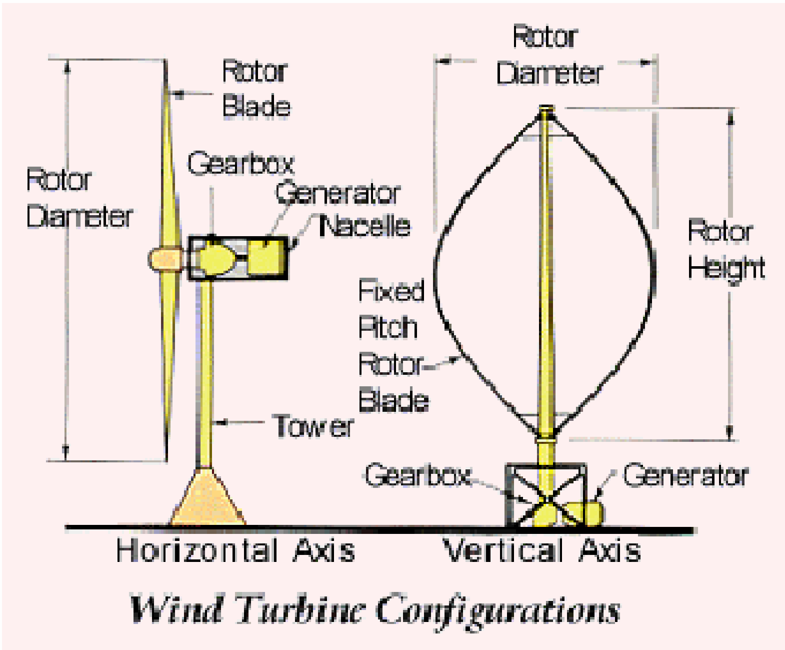


Figure 3.1: Wind turbine configurations

- **Tower**: The tower is used to support the nacelle and rotor blades.
- **Nacelle**: The nacelle is the unit located at the top of the tower that encapsulates all the components of the turbine.
- **Electronic equipment**: Such as controls, electrical cables, ground support equipment and interconnection equipment. [10]

3.3.3 Stall and pitch control

There are two main methods of controlling the power output from the rotor blades. The angle of the rotor blades can be actively adjusted by the machine control system. This is known as pitch control.

The other method is known as stall control. This is sometimes described as passive control, since it is the inherent aerodynamic properties of the blade, which determine power output, there are no moving parts to adjust. The twist and thickness of the rotor blade vary along its length in such a way that turbulence occurs behind the blade whenever the wind speed becomes too high. This turbulence causes some of the wind's energy to be shed, minimising power output at higher speeds. Stall control machines also have brakes on the blade tips to bring the rotor to a standstill, if the turbine needs to be stopped for any reason. [11]

3.3.4 Power and energy from wind turbines

The power output of wind turbine varies depending on wind speed, the swept area of the turbine, the density of air and the coefficient of performance. The power output of a wind turbine is: $P_{out} = 0.5 * p * A * C_p * u^3$

where, Cp is a fraction of the wind speed, the angular velocity of the rotor and the pitch angle.

p is the density of air (kgr/m^3)

A is the swept area of the wind turbine(m^2)

u is the wind speed (m/sec)

Therefore every turbine has a characteristic wind speed-power curve. Figure 3.2 shows a characteristic wind speed-power curve. it could be determined how much energy a particular turbine on a given site under given wind conditions can produce.

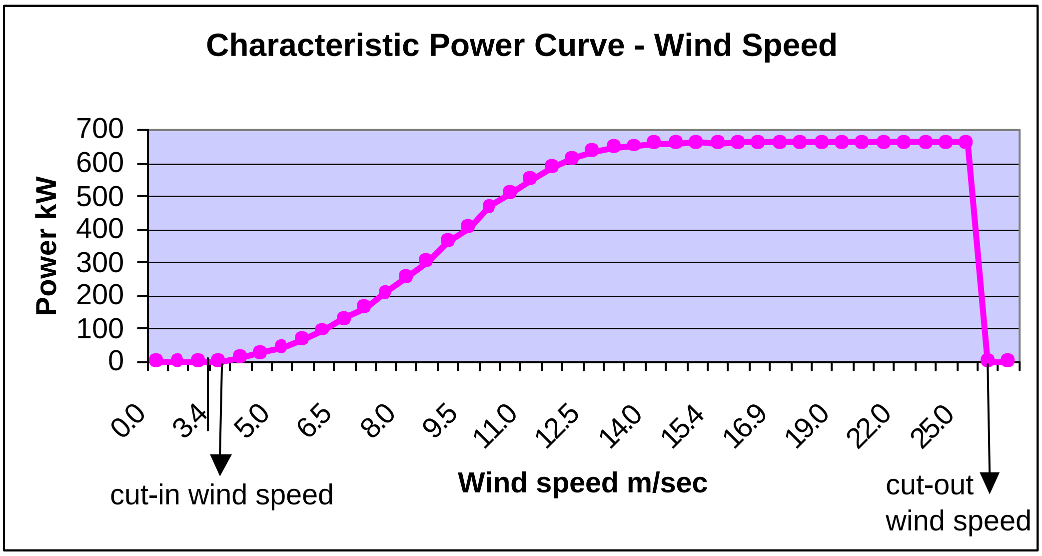


Figure 3.2: Characteristic wind speed-power curve

Obviously each wind turbine operates between the cut-in wind speed and the cut-out wind speed. This means that the turbine only produces energy with wind speeds within the operating range of the turbine.

3.3.5 Future development of wind turbines

Wind turbine development trends to large-scale turbines. Development of larger wind turbines is becoming more and more commercially. Large wind turbines are more suitable for offshore locations and the land sites are limited. Moreover, larger wind turbines not only decrease the number of installed turbines but also increase the installed power per region. Many research programmes around the word work close with turbines manufactures in order to improve and increase the size of the wind turbines. The future research areas consist of the development of airfoils, the structural test analysis, the design of blades, the improvement of row material, the control of turbines and the research in understanding better the wind energy. The expected benefits of the improvement of the whole turbine are the reduction of the capital and operating cost per installed kW and the increase of the energy capture.

Environmental impact

3.4.1 Introduction

Wind energy has both positive and negative environmental impacts. One of the positive environmental impacts of wind turbines is that the production of electricity from the wind is clean. Nothing is burned or "used up" to produce wind power. Wind energy does not pollute the air or water, produces no carbon dioxide or any greenhouse gases. The below table is shown the amounts of greenhouse gases, which will be avoided by using wind power. On the other hand, the negative environmental impacts of wind turbines are noise, electromagnetic interference and visual impact.

Year	EWEA Goals for MW installed wind power capacity	Production TWh/year	CO_2 reduction Tonnes/year	SO_2 reduction Tonnes/year	NO_x reduction Tonnes/year
2000	8,000	16	14,400,000	48,000	40,000
2005	20,000	40	34,200,000	114,000	95,000
2010	40,000	80	64,800,000	216,000	180,000
2020	100,000	200	134,400,000	480,000	400,000

Table 3.3:Annual avoided emissions achievable by projected wind energy in the EU

3.4.2 Wind turbine noise

Modern wind turbines are quiet and are becoming quieter. Sound is measured in decibels (dB) using a logarithmic scale. The environmental measurements of sound are made in dB(A) which include a correction for the sensitivity of the human ear. The sound pressure level at a distance of 40m from a typical turbine is 50–60 dB(A); about the same level of a conversational speech. A farm of ten wind turbines, with the nearest at a distance of 500m would create a sound level of about 42 dB(A) which is equivalent to the sound level inside an office.

When wind turbines have been designed carefully then they feature a lower noise level. Much effort has been made to create the present quiet machines. A lot of attention has been paid to both the design of the blades and to the mechanical parts of the machine. As a result noise is not an important problem for modern wind turbines, when they are carefully sited. [13]

3.4.3 Electromagnetic interference

Any large moving structure can produce electromagnetic interference (EMI). Wind turbines can cause EMI by reflecting signals from the rotor blades. Interference occurs because the reflected signal is delayed due to the difference in path length. EMI is most severe for metallic materials, rather than for wooden blades. Glass reinforced plastic (GRP) used in most modern blades, can minimize the EMI effect. It is true that the civilian and military communication signals may be affected by EMI, wind turbine developers may contact the relevant civilian and military authorities in order to prevent any EMI problems. In any case, wind turbines and telecommunications systems already coexist without serious problems in many developments throughout the world.

3.4.4 Visual impact

The reaction to the sight of a wind farm is highly subjective. Many people see them as a welcome symbol of clean energy whereas others find them an unwelcome addition to the landscape. In order to succeed a careful and agreeable integration of developments in the landscape, the industry has used a number of computer programmes such as computer-generated photomontages and animations. The difference between a 1.5 MW turbine and a 0.5 MW is minimal. The wind energy market tends towards larger and therefore fewer wind turbines, in order to reduce the visual effect of the installed capacity. Moreover, many designers have been employed by several wind turbine manufacturers in order to improve the appearance of their machines.

The effects of the periodic reflection (glinting) or interruption (shadow flicker) of sunlight have been considered as important problems. The figure below shows an example of calculating of the shadow flicker effect. There are two houses in the picture marked as A and B, which are 6 and 7 hub heights respectively away from the turbine in the center. The diagram shows that House A will experience a shadow effect from the wind turbine for 5 hours per year. House B for about 12 hours per year. [14]

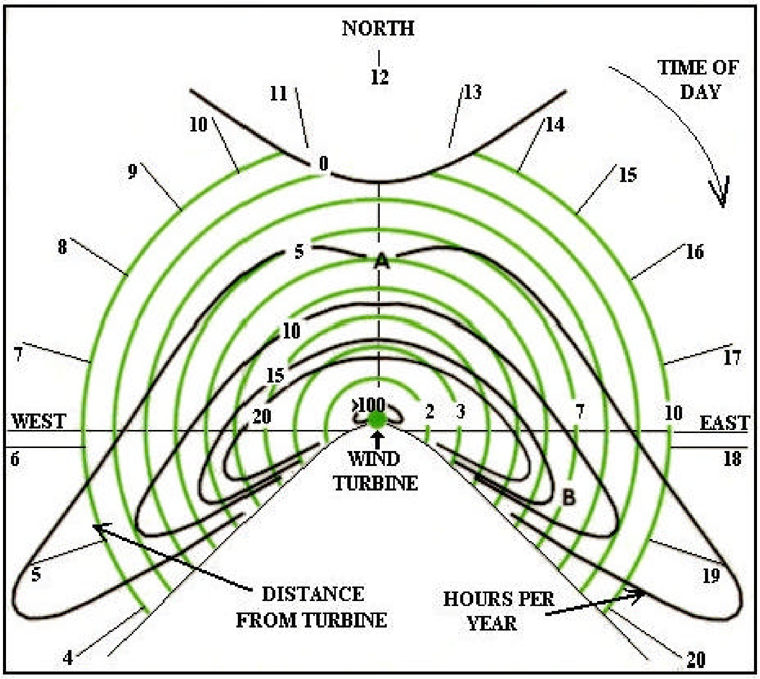


Figure 3.3 An example of a shadow flicker calculation

A common rule used in Denmark is a minimum distance of 6-8 rotor diameters between the wind turbine and the closest neighbor should be established.

Economics

3.5 Overview of economics

To generate electricity from the wind makes economic as well as environmental sense. The wind is a clean renewable energy source already contributing to the World's energy needs. The economics of wind energy have changed dramatically over the past twenty years, as the cost of wind power has fallen approximately 90 percent during that period. However, the wind industry is not fully so developed. For this reason, the factors affecting the cost of wind energy are still rapidly changing and wind energy's costs will continue to decrease as the industry grows and matures. In every country the price of electricity depends not only on the cost of generating it but also on the many different factors that affect the market, such as energy subsidies and taxes. The cost of generating electricity from wind comprises of:

- Capital costs (the installation cost of the wind turbines and connecting them to the grid)
- Running costs (operation and maintenance)
- The cost of financing (how the capital cost is repaid)

Installation costs include foundations, road construction (necessary to move the turbine and the sections of the tower to the building site), a transformer (for the local electrical grid), telephone connection for remote control and surveillance of the turbine, and cabling costs.

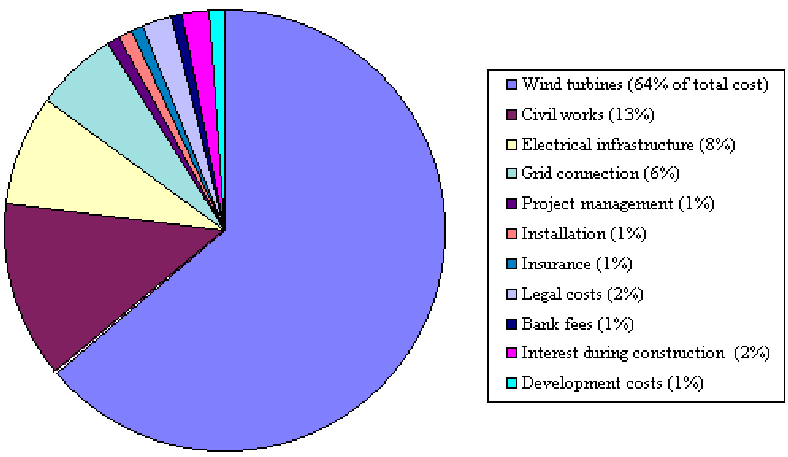


Figure 3.4

Obviously, installation costs vary since the costs of roads and foundations depend on site conditions. The capital cost of wind turbines is high, between 75% and 90% of the total. The capital cost breakdown of a typical 5 MW project is shown above figure.

When the turbines are brand-new the maintenance costs are generally very low but they increase somewhat as the turbine ages. It is widely known that the newer generations of turbines have relatively lower repair and maintenance costs than the older generations. For newer machines the estimates range from around 1.5 to 2 per cent per year of the original turbine investment. The largest part is a fixed price paid per year for the regular service of the turbines.

There are two main factors affecting the cost of electricity generated from the wind, and therefore its final price:

- Technical factors, such as wind speed and the nature of the turbines etc.
- The financial factors, such as interest rate of return, repayment years etc.

The most important technical factors affecting the cost of electricity generated from the wind is the available wind power that is a function of the cube of the wind speed. Therefore if the wind blows at twice the speed its energy content will increase eight fold. In practice, turbines at a site where the wind speed averages eight meters per second will produce around 80% more electricity than those where the average wind speed is six meters per second.

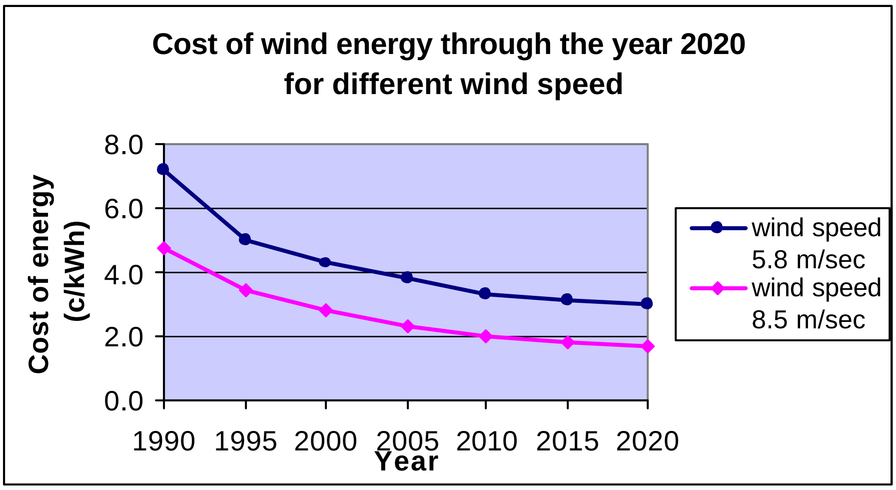


Figure 3.5: Generating cost vs wind speed

Figure 3.5 shows an estimation of the future cost of wind-generated electricity for regions with wind speeds of 5.8 m/sec and 8.5 m/sec.

The influence of financial factors on the electricity cost from wind is presented in figures 3.6 and 3.7.

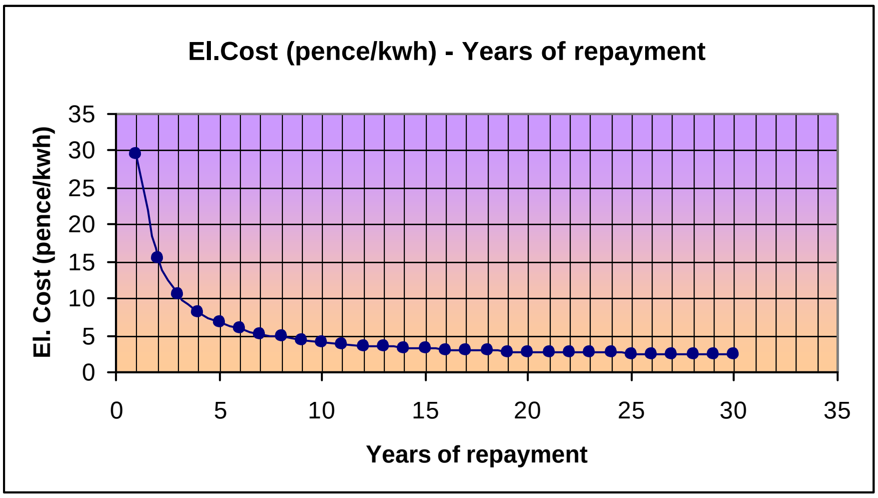


Figure 3.6

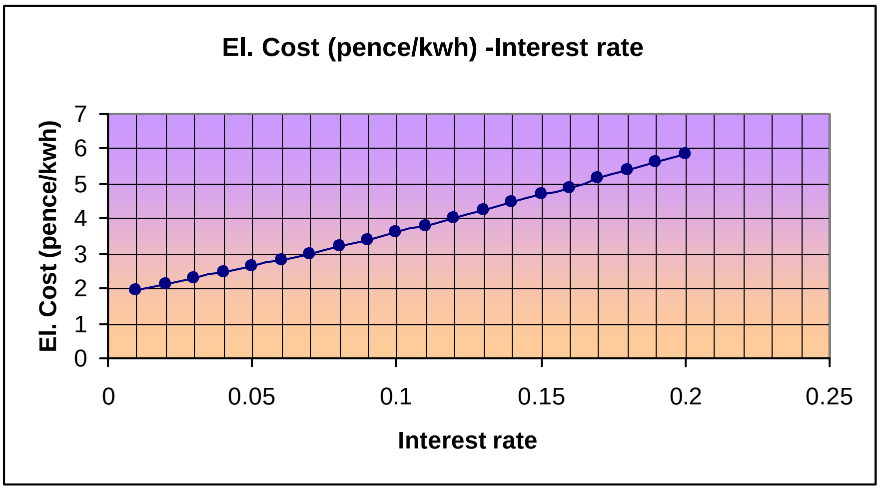


Figure 3.7

Specifically, figure 3.6 presents the differing electricity costs depending on the chosen period of time in which the loan is to be repaid. It is also obvious that the electricity cost is significantly increased as the years of repayment the loan are reduced. Furthermore, figure 3.7 illustrates that the changes in interest rate have almost linear affect on the price of the electricity.

The economics of wind energy are already strong, despite the relative youth of the industry. The downward trend in costs is predicted to continue. The strongest influence will be exerted by the downward trend in wind turbine prices. As the world market in wind turbines continues to boom, wind turbine prices will continue to fall.
The global wind energy market is expanding rapidly, creating opportunities for employment through the export of wind energy goods and services.

Hydropower

4.1 Introduction

Hydropower is one of the renewable technologies converts the pressure energy and kinetic energy of water into more easily used electrical energy. The prime mover in the case of hydropower is a water wheel or hydraulic turbine, which transforms the energy or water into mechanical energy. Earlier in the history of energy development and use, water wheels provided power by direct connection or with pulley and gear systems to drive various machines, such as grist-mills and textile mills. Since ancient times, water wheels have been used for lifting water from a lower to a higher elevation in irrigation systems. The earliest watermills were probably vertical-axis corn mills, which are known as Norse or Greek mills. Further developments were also achieved by the Romans and later on by the Saxons

4.2 Global hydropower capacity

The energy potential of hydropower is determined by the volume of run –off water and by the distance it falls before reaching the ocean. The seasonal variations in run –off affect to the theoretical potential, an estimation of the theoretical annual potential of world hydropower capacity is from 36000 to 44000 (TWh).

Region	Technically exploitable potential TWh/year	Total hydro installed capacity GW	Hydro generation in 1998 TWh	C/A percent
Africa	1,150	15.84	36	3
South Asia & Middle East	2,280	45.44	171	8
China	1,920	32.69	109	6
Former Soviet Union	3,830	62.20	220	6
Japan	130	20.26	87	67
North America	970	129.09	536	55
South America	3,190	75.98	335	11
Central America	350	10.71	32	9
Eastern Europe	160	16.56	49	31
Western Europe	910	128.44	436	48
Austalasia	200	12.00	37	19
World	**15,090**	**549**	**2,040**	**14**

Table 4.1

However, there is the technical potential, which is estimated by many criteria such as economic, environmental and geological. The above table presents the word's technically exploitable hydropower potential and existing development by region.

The final technically exploitable hydropower potential is substantially smaller than the initial technical due to the plenty of economic and environmental barriers. Although, the economic potential of hydropower estimates around 40-60% of the technical potential. According to the table 4.1, most of the undeveloped potential lies in the former Soviet Union and in the developing countries. [15]

4.3 Hydropower Technologies

At the present time there are a lot of different types of hydropower technologies due to the variations of geological conditions at any hydropower site. Need of further utilisation of hydropower has a result to expand the different types of hydropower developments:

4.3.1 Run –of – river developments

A dam with a short penstock (supply pipe) directs the water to the turbines, using the natural flow of the river with very little alteration to the terrain stream channel at the site and little impoundment or the water.

4.3.2 Diversion and canal developments

The water is diverted from the natural channel into a canal or a long penstock, thus changing the flow or the water in the stream for a considerable distance.

4.3.3 Storage regulation developments

An extensive impoundment at the power plant or at reservoirs upstream of the power plant permits changing the flow of the river by storing water during high-flow periods to increase the water available during the low-flow periods, thus it supplies the demand for energy in a more efficient manner. The word storage is used for long-time impounding of water to meet the seasonal fluctuation in water availability and the fluctuations in energy demand, moreover it is used for short-time (daily) impounding of water to meet the short-time changes of energy demand.

4.3.4 Tidal power developments

In some estuaries, tidal power can be economically controlled to develop electric energy. These developments use the water flowing back and forth as a result of tidal action and the fact that there is a significant difference in elevation of the water surface in the estuary from one stage of tide to another.

4.3.5 Pumped hydro Storage

Pumped hydro storage is the only large energy storage technique widely used in power systems. Fore decades, pumped hydro storage have used as an economical way to store dynamic energy (converting to electrical) in very large quantities. During peak load periods the stored water is discharged through the pumps and with the help of turbines generating electricity in order to meet the energy demand. Pumped hydro storage usually comprises: an upper reservoir, pump, turbine, motor, generator, penstock and a lower reservoir. A common pumped hydro storage is presented in the follow figure.

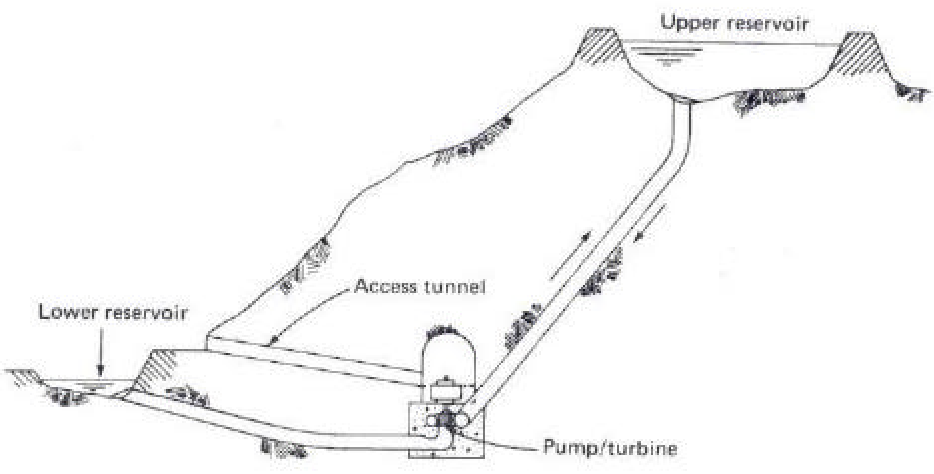


Figure 4.1: A diagram of pumped hydro storage

The pumped hydro storage is energy-storing system, which has a net energy loss. Losses associated with the conversion processes, water turbines and pumps are very efficient machines and it is possible to retrieve nearly 77% of the input electrical energy. Figure 4.2 illustrates the energy storage cycle for a large pumped plant. It is obvious how much energy is used and produced in the pumped storage operation. [16]

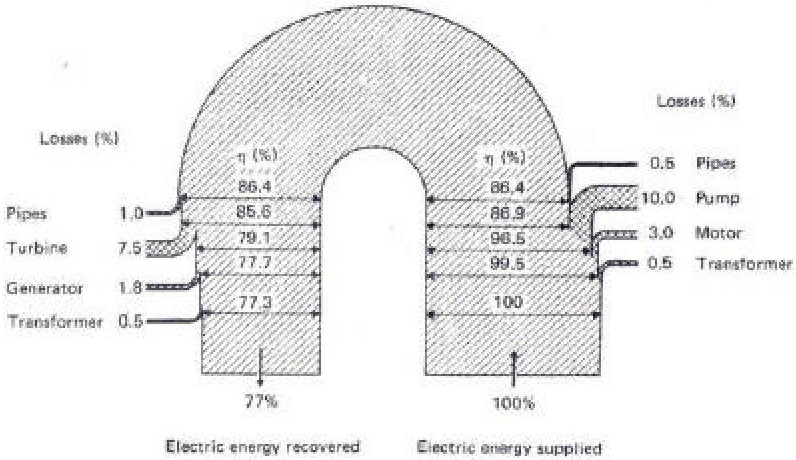


Figure 4.2: Energy storage cycle for a large pumped plant

Water Turbines

4.4.1 Types of Water Turbines

The hydropower technology and its developments have evolved since the introduction of two well-known types of turbine: the Francis (reaction-type of turbine) and the Pelton (impulse-type of turbine). These two early types of turbines were developed to a considerable sophistication before 1900 and were important in helping to make the electric generator successful and practical. Later, propeller turbines were developed.

A common turbine has vanes, blades, or buckets that rotate about an axis by the action or the water. The rotating part or the turbine or water wheel is often referred to as the runner, Rotary action of the turbine in turn drives an electrical generator that produces electrical energy or could drive other rotating machinery.

Hydraulic turbines are machines that develop torque from the dynamic and pressure action of water. They can be grouped into two types. One type is an impulse turbine, (which takes its name because, the energy delivered in a series of short impulses) and it exploits the kinetic energy of a high-velocity jet of water to transform the water energy into mechanical energy. The second type is a reaction turbine, which develops power from the combined action or pressure energy and kinetic energy of the water.

The most famous impulse turbines are Pelton wheels. The impulse type is essentially operating in air at normal atmospheric pressure. Impulse turbines are usually high head units and used at locations where heads are 1000ft or more.

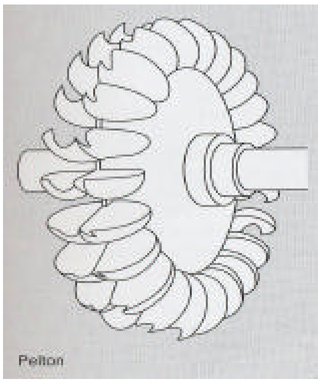


Figure 4.3: Pelton runner

They are also used at lower heads for small capacity units. The ration of the wheel diameter to the spouting velocity of the water determines the applicability of an impulse turbine. The figure 4.3 presents the type of Pelton runner. [17]

Another type of an impulse turbine is the Turgo impulse turbine, which is invented in 1920 in England. The turbine changed the double cups to the single, and the water enters of one side and leaves on the other. The water enters as a jet (impulse turbine), striking the cups in turn and like a Pelton is most efficient when the speed of the cups is half the speed of the water jet. But it has the ability to handle more volume of water than Pelton wheel of the same diameter. Therefore it has an advantage for power generation at medium heads. The figure 4.4 shows the type of Turgo runner. [18]

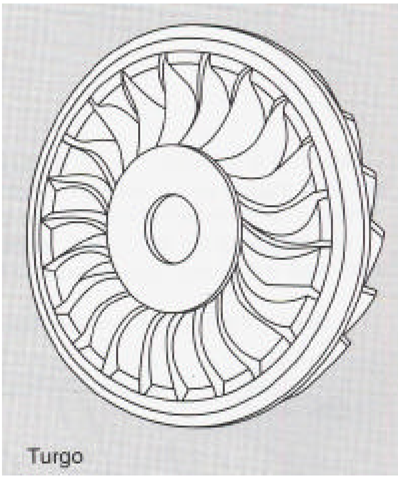


Figure 4.4: Turgo runner

One more type of an impulse turbine is the cross-flow turbine (Banki or Michell turbine). The water crosses through the runner vanes twice in producing the rotation. The figure 4.5 illustrates the type of cross flow runner.

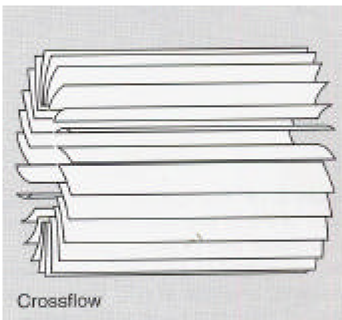


Figure 4.5: Cross flow runner

Advantages of cross-flow turbine are that standard unit sizes are available and even higher rotational speed is obtained than from other impulse turbines. It has the ability to adjust the inlet valves and separate portions of the runner so that a cross-flow can operate over a wide range of flows.

Reaction turbines are classified according to the variation in flow direction through the runner. If the flow is vertical to the axis of rotation, the runner is called radial-flow turbine. If the water flow is partially radial and partially axial, it is called mixed-flow turbine. The most famous reaction turbines (mixed-flow) are Francis turbines. They are operating in installations where the head is as low two meters or as high as 200 meters. An important feature of this type is that the water, which arrives at the runner is usually still under pressure. The figure 4.6 presents the type of Francis runner.

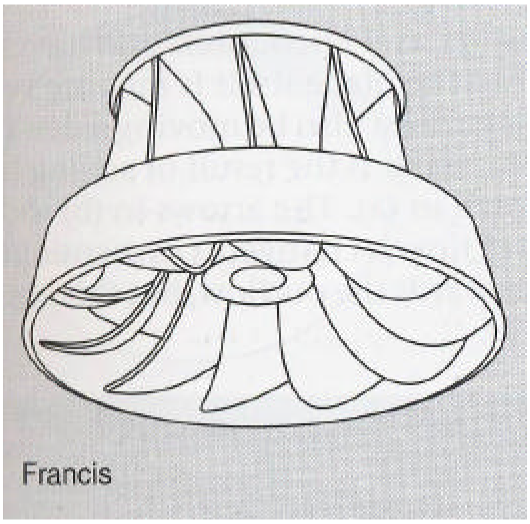


Figure 4.6: Francis runner

Another type of reaction turbine is an Axial-flow propeller turbine. This turbine suitable for very large volume flows and the head is only a few meters. The direction of the flow is axial, parallel to the axis rotation. Some propeller turbines can have the blades of the runner rigidly attached to the hub and they are called fixed-flow runners. The most famous turbine of this type is the Kaplan turbine. One more type of propeller turbines is the Deriaz turbine, which is a mixed-flow propeller unit of the Kaplan type. This turbine was developed for pumped storage applications but can also be used for applications in the medium head range. The figure 4.7 shows the type of Kaplan runner. [19]

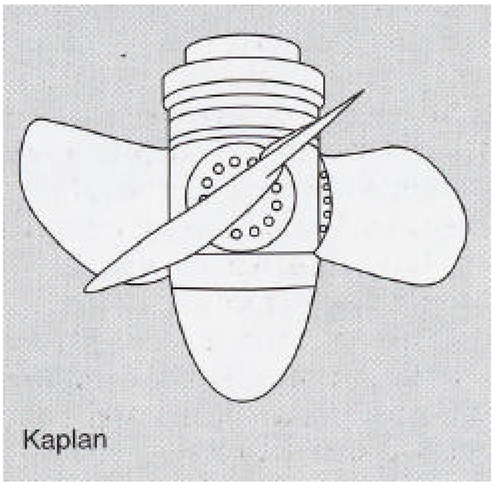


Figure 4.7: Kaplan runner

Furthermore, Muhlemann develops a unique type of turbine the Isogyre pump/turbine, which consists of a double runner with pump impeller on the upper level of the shaft and the turbine runner on the lower level. The runners have a common shaft. This double- wheel design tends to accommodate optimum efficiency in both pumping and generating operations. The following figure shows an Isogyre pump/turbine. [20]

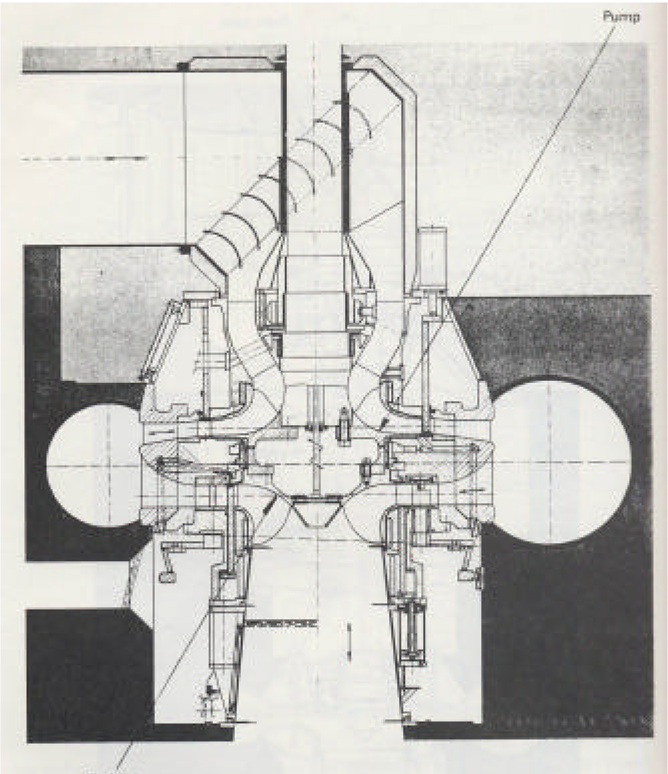


Figure 4.8: Isogyre pump/turbine

4.4.2 Power of Water Turbines

The power output of water turbine varies with the head, the flow rate of the turbine, the density of water, and the overall efficiency of turbine. The power output of a water turbine is: $P = p * g * H * V * n_o$

Where, p the density of water

g the free fall acceleration

H the head

V the flow rate of the turbine

n_o the overall water turbine's efficiency

Practically, in order to estimate the output of water turbine has been developed experience curves, which define the relation between the output of water turbine and the head, the specific speed with the head. Furthermore, it is very easy using experience curves to determine what type of turbine is suitable for a particular development. The selection of appropriate water turbine depends on the specific speed, the head, the rate of rotation and the output of water turbine. Figure 4.9 shows the possible application ranges (according the head) for various types of turbines.

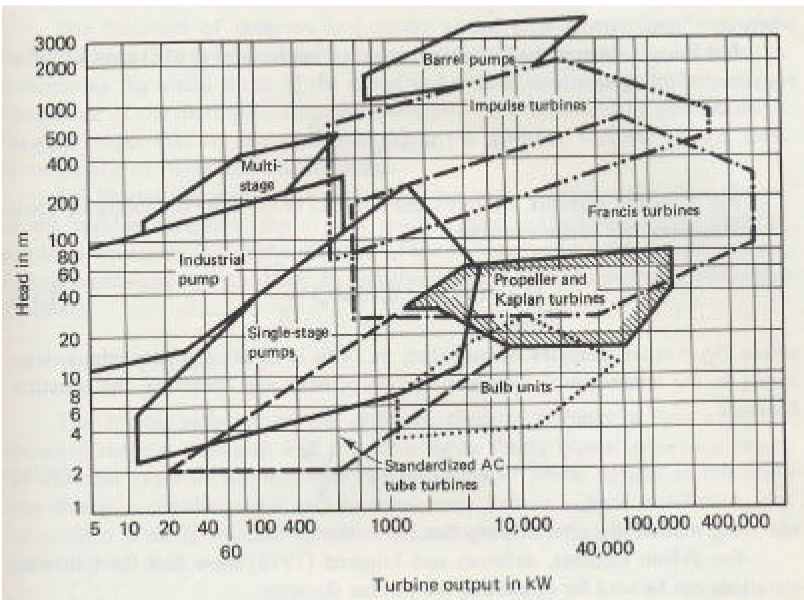


Figure 4.9: Application ranges for various types of turbines

Environmental and Social aspects

4.5.1 Introduction

Hydropower is characterised by a variety of potential effects on the environment both positive and negative. First of all, it produces no CO_2 and has little other effect on the atmosphere compared to the conventional power plants. The noise pollution is negligible too.

With regard to negative effects, it may also affect to flora and fauna of an area. The environmental and related social effects, which hydropower plants produce, are divided in three main categories: a) the hydrological effects meaning water flows, groundwater, and water supply irrigation. b) the landscape effects on the land, its plants and its animals and finally c) the social effects. Naturally, these three categories of effects are not independent of each other.

4.5.2 Hydrological effects

Hydrological effects will without a doubt be significant for the ecology of a land and for the local community, especially in the case of a large-scale installation.

The diversion of a mountain stream into a pipe does not, maybe seriously changes the flow at the valley bottom but it will have a noticeable effect on intermediate levels. Storing part of the water in a reservoir is another problem since it may reduce the final flow as a result of evaporation from a large exposed surface. Furthermore, when groundwater is used in a hydropower plant the surrounding countryside may suffer a number of changes. The diversion of water for other uses has several of impacts, but they vary from site to site. Topography, river flow, climate, ecology and the specifics of a hydropower plant are the main factors upon which the scale of the hydrological effects depends.

4.5.3 Landscape Effects

A hydropower installation may affect the landscape in many ways. The construction process itself causes disturbance even the building period lasts only a few years. These disturbances are magnified when the construction timetable is not met, as is often the case with large-scale hydropower plant.

Dams are often the subject of concern, both due to their visual impact and the possibility of catastrophic failure. Especially regarding the second factor many people feel that the risks associated with different energy systems should be estimated in order to include them in the economic assessment. The estimation made for dams is encouraging. There are some 15 000 dams in the world. Over recent decades the frequency of major disasters involving significant loss of life seems to be about one per 6-10 years. This means that the current rate is one disaster per 120 000 dam-years. (CONAES, 1979)

Dams and problem of the earthquakes are particularly a risk, there is an argument about the above statement, if it is possible the weight of major dam and its associated large volume of water can actually cause earthquakes. Many studies, which have done, said that changes in ground level as much as 36 km away, it may affect on going up the number of earthquakes in this area.

4.5.4 Social Effects

It is widely known that an energy power plant has positive and negative effects, sometimes, there are people, who have benefits of this and others pay for this. The building of dams may have very different consequences on the people immediately affected. The effect of hydropower on the human healthy is the most significant, especially in developing countries where the possibility of spreading of diseases through water is not negligible. Another category of social effects is one associated with people living in a valley, which is to become a water reservoir. This means in short the loss of their family home and village. Historically, on a lot of occasions thousands of people were forced to move from their house in order for a hydropower plant to be built. In addition to these dangers a hydropower plant, which is built close to a river, which periodically overflows its banks may act as a barrier for the harmless flow of water and thus cause devastating floods. On the smaller scale changes such as the loss of a beloved riverside walk may also occur.

It should not be overlooked that the choice is not necessarily between building a hydropower plant or some other form or power station. The alternative of building nothing always presents. There is little agreement on how to incorporate environmental gains and losses into economic data, which are used for comparing options. However a factor not to be put aside is the cost of long-term damages for the people, who are to be displaced due to the construction of new hydropower installations. [21]

Economics

4.6 Cost of hydropower

Hydropower is a well-established technology. There are many different installations of hydropower plants in operation, which produce a large range of electricity. Thus costs of hydropower plants are also highly variable due to many different installations of them. There is a list of factors (site, capacity, environmental and social barriers), which is responsible for the determination of the final cost of each specific hydropower plant. A relation between the capital cost of the plant and the plant capacity has been established. Especially, large hydropower plants have an extremely high capital cost, which increases during the construction time. They have however a propensity to be cheaper per kilowatt-installed than the small ones. Total costs of a large hydropower plant normally vary from $750 to $2000 per installed kilowatt or from $1500 t0 $4000 per reliable kilowatt. The range of the cost depends on the specifics of each site. Table 4.2 presents the Unit cost for best potential hydropower plants in West Africa. [22]

Region	**Unit cost* 1986 $/kW**	**Average unit size MW**	**Number of projects TWh**	**Capacity range MW**
Benin	3,100	41	5	15-72
Bukina Faso	5,640	15	1	15
Ghana	1,680	169	5	51-450
Guinea	1,820	238	8	40-750
Ivory Coast	1,430	166	6	80-328
Liberia	2,740	146	5	74-214
Mali	2,600	78	8	17-300
Niger	2,550	111	2	72-150
Nigeria	1,610	983	3	400-1950
Senegal	2,470	87	2	48-125
Sierra Leone	2,220	228	2	150-305
Togo	4,050	22	2	20-24
	1,920 average	**187 average**	**49 total**	15-1950 **total average**

* Excludes transmission costs and interest during construction

Table 4.2

The most demanding part of the construction of a hydropower plant is the civil works. An average of 60 percent of the total cost is distributed for this purpose, although the amount depends on the plant's design. Moreover, this part is the most time-consuming of the construction. As compensation it has a long lifetime. Furthermore, a hydropower plant has a high cost of transmitting its electricity to consumers due to the isolate sites, which are usually chosen for the installation of hydropower plants.

On the other hand they have very low operating costs compared to large-scale electricity sources. This is one of the most important advantages of hydropower plant in comparison to the conventional plants with high operating costs. A well-established hydropower plant produces without doubt some of the cheapest power in different countries. For example, in Scotland, which has a large proportion of hydropower, the average unit cost in 1994 was only 1.5 p/kWh .

Case Study in Crete

5.1 Introduction

Crete is the biggest island in Greece: area 8335km^2 and a population of 540000. Tourism is the most dynamic activity in the island (more than 3millions tourists in 2000). Today, there are two conventional operational power production plants in Crete, which belong to the Public Power Corporation (PPC). In parallel, PPC operates two small hydro plants, wind turbines and biomass plants, which also provide electricity to the electric grid. The conventional installed power for electricity production is 514.4 MW and the actual RES installed power is 70.6 MW. The actual RES installed power consists of: [23]

- Ten wind farms, which provide more than 10% of the total electricity consumption.

- Two small hydroelectric plants of 0.6 MW

- Biomass plants, which provide almost 12% of the total energy consumption in Crete.

- The solar thermal collectors for hot water production, which are also widely used and produce more than 3% of the total energy demand of the island.

- There are also photovoltaic systems of a total power of 2 MW.

The total electricity consumption reaches 2138.9 GWh (2000) and RES electricity production reaches 204.8 GWh (2000).

Today, there are many energy-programs in the region of Crete, one of them is the "Implementation Plan for RES in Crete", which has been formulated by the National Technical University of Athens and the Regional Energy Agency of Crete. it forecasts that: with the implementation of this plan the total RES electricity production could reach 39.4% in 2005, which is presented in figure 5.1.

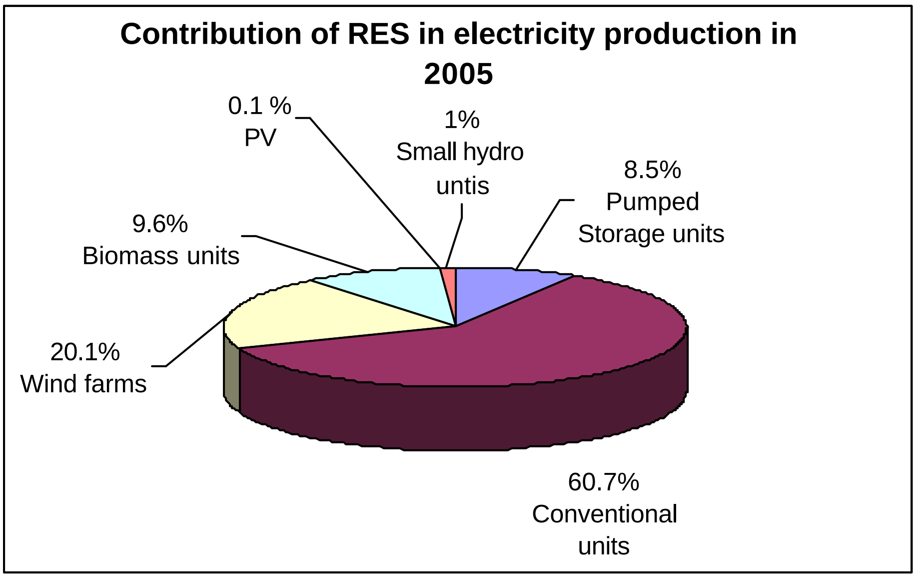


Figure 5.1: Contribution of RES in electricity production in 2005, in Crete

Moreover, Crete produces large amount of energy using RES but it has the common energy problem of the majority of the islands.

- High energy cost
- Great dependence on oil imports

The extensive use of internal combustion engines involves the use of diesel or crude petrol (mazut) as fuel this combined with the difficulties in energy transportation in islands and the weakness of efficient cover of energy demand during the peak seasons, makes use of an autonomous (thermal) power station APS, a very expensive solution.

Figure 5.2 presents the electricity production cost in remote islands in Greece.

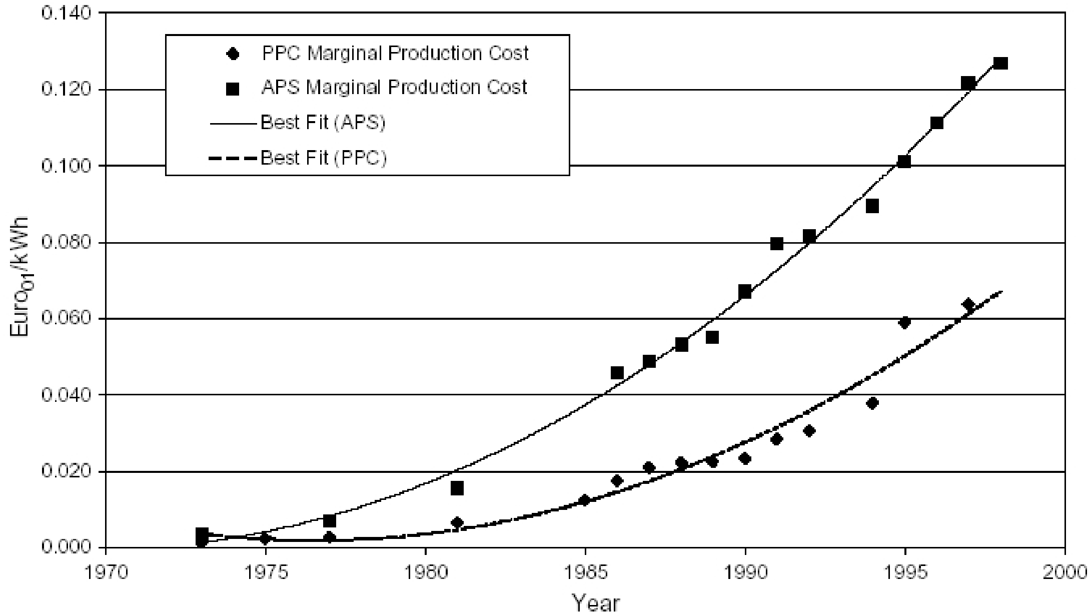


Figure 5.2: Electricity production cost in Greece

There are three possible solutions for the electrical problem in Crete.

1. Construction of new thermal units
2. Connection of the island's grid with the mainland's grid
3. RES exploitation

Connecting the island's grid with the mainland's electrical grid is a very difficult task due to strong undersea streams between Crete and South Peloponese, the high risk of earthquakes, the environmental problems in Peloponese and the lack of security to supply electricity under extreme conditions.

The construction of new thermal plants to cover fully future demand raises significant objections due to public opinion reactions and environmental impacts.

On the other hand RES have a very significant potential in Crete and the public is rather positive to the establishment of RES plants. The development of combined systems, where RES could operate in parallel with autonomous power stations (APSs) is already available in some islands. The APS consists of diesel engines operating at a very high cost per kWh. These systems operating in Greek islands are not connected to the utility grid. Simply combined (known as first-generation) systems revealed various incompatibilities between the RES and APS such as frequency and voltage fluctuations. In all cases, the APS was used as the main energy source and the wind or solar system as the auxiliary source covering only 10% of the total energy demand.

On the contrary, in this combined power system the main idea is the use of multi-renewable energy sources operating autonomously while the diesel engines will be used only when the energy demand is greater than the RES energy production.

A good example of a second-generation combined system is found in Kithnos Island, where a wind turbine (500 kW), a PV station (100 kW) and APS (1990 kW) are operating together. Batteries are also used as storage facilities. Another interesting second-generation combined system is based on the co-operation of wind turbines and small reverse-hydro systems, which are working in parallel with the APS.

This type of system has been proposed for islands where the load is large and the use of batteries is prohibited. The penetration of the RES systems to the island's local grid using batteries as storage facilities is expected only to reach less than 50% of the total energy demand but using the hydro station as storage facility is expected to exceed 80%.

5.2 Assessment of the probable sites

There are numerous potentially suitable areas in Crete for a combined wind hydro power plant to be installed. In many locations in Crete the average annual wind speed exceeds 8 m/sec. The wind potential of Crete has been assessed after a sitting on the 1-25000 maps of Crete in order to investigate the most feasible, technical and economical Wind parks. In the following tables there is a list of those wind parks. [24]

		Vm m/s	N W/Gs	Pr kw	Energy GWh	Cf
HERAKLIO PERFECTURE	1	8	58	58000	198.30	0.39
	2	8	36	36000	123.09	0.39
	3	7.5	28	28000	85.07	0.35
	4	8.5	18	18000	68.40	0.43
	5	9	32	32000	133.79	0.48
	6	9.5	38	38000	173.35	0.52
	7	9	20	20000	83.62	0.48
	8	8	38	38000	129.92	0.39
	9	8	62	62000	211.98	0.39
	10	7.5	64	64000	194.44	0.35
	11	8.5	38	38000	144.40	0.43
	12	8.5	34	34000	129.20	0.43
	13	8	32	32000	109.41	0.39
	14	8.5	58	58000	220.40	0.43
	15	9	44	44000	183.96	0.48
	16	8	44	44000	150.44	0.39
	17	8	47	47000	160.70	0.39
	18	8	28	28000	95.73	0.39
	19	8.5	26	26000	98.80	0.43
	total		745	745000	2,695.00	Cf=0.413

Table 5.1: Wind Potential in Iraklio Perfecture

LASITHI PERFECTURE		Vm m/s	N W/Gs	Pr kw	Energy GWh	Cf
	1	8.5	24	24000	91.20	0.43
	2	8.5	36	36000	136.80	0.43
	3	8	36	36000	123.09	0.39
	4	8.5	48	48000	182.40	0.43
	5	8	42	42000	143.60	0.39
	6	8	37	37000	126.50	0.39
	7	8	38	38000	129.92	0.39
	8	8	32	32000	109.41	0.39
	9	8	34	34000	116.25	0.39
	10	8	86	86000	294.04	0.39
	11	8.5	52	52000	197.60	0.43
	12	9	38	38000	158.88	0.48
	13	8.5	68	68000	258.40	0.43
	14	9.5	76	76000	346.70	0.52
	15	9.5	47	47000	214.41	0.52
	16	9.5	22	22000	100.36	0.52
	17	9	138	138000	576.97	0.48
	18	8.5	25	25000	95.00	0.43
	19	8.5	38	38000	144.40	0.43
	total		917	917000	3,545.93	Cf=0.441

Table 5.2: Wind Potential in Lasithi Perfecture

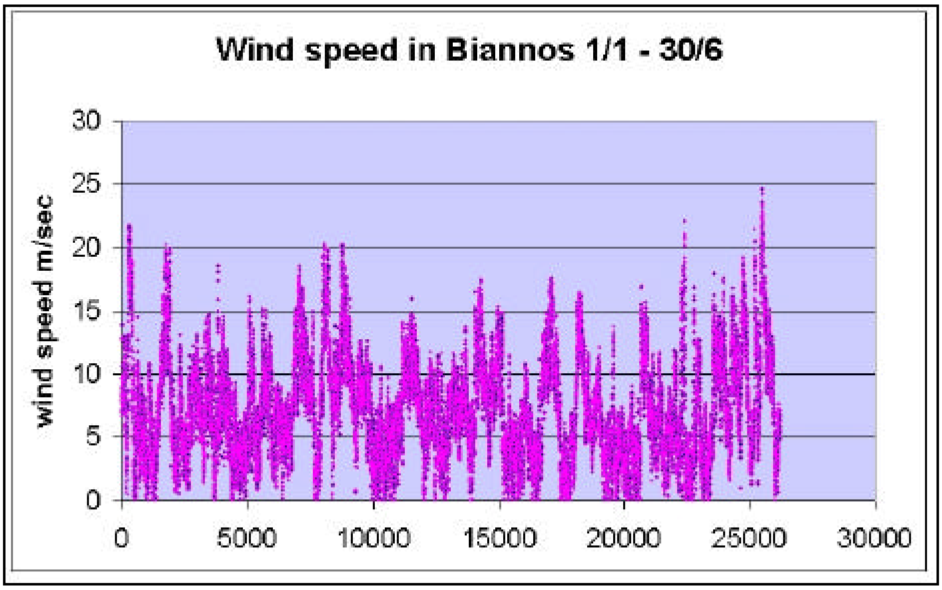
RETHIMNO PERFECTURE		Vm m/s	N W/Gs	Pr kw	Energy GWh	Cf
	1	8	38	38000	129.92	0.39
	2	7.5	48	48000	145.83	0.35
	3	8	35	35000	119.67	0.39
	4	7.5	28	28000	85.07	0.35
	5	7.5	32	32000	97.22	0.35
	6	8	42	42000	143.60	0.39
	7	8	22	22000	75.22	0.39
	8	8	16	16000	54.70	0.39
	9	7.5	18	18000	54.69	0.35
	total		279	279000	905.92	Cf=0.371

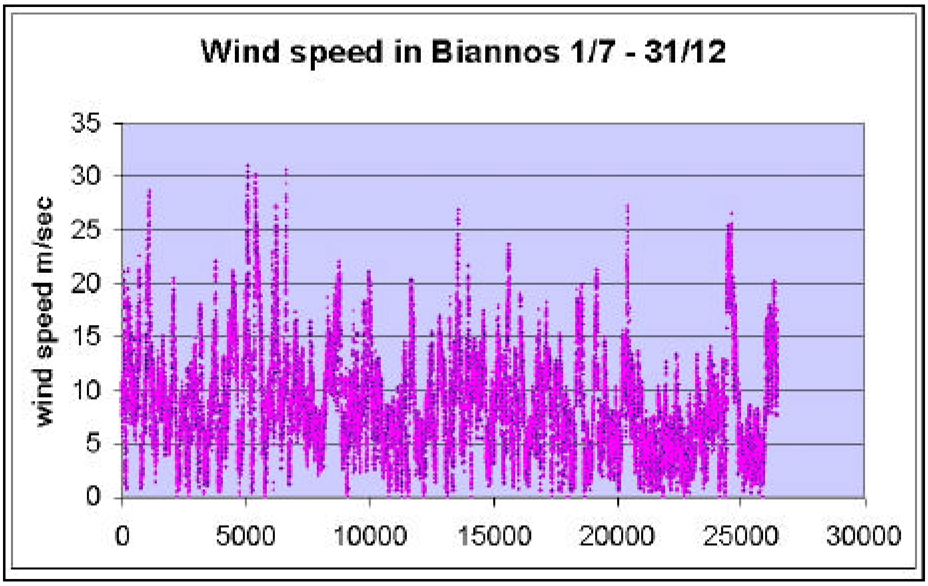
Table 5.3: Wind Potential in Rethimno Perfecture

		Vm m/s	N W/Gs	Pr kw	Energy GWh	Cf
CHANIA PERFECTURE	1	9	38	38000	158.88	0.48
	2	8	78	78000	266.69	0.39
	3	8	32	32000	109.41	0.39
	4	8	44	44000	150.44	0.39
	5	9	38	38000	158.88	0.48
	6	8	88	88000	300.88	0.39
	7	8	22	22000	75.22	0.39
	8	9	18	18000	75.26	0.48
	9	8.5	28	28000	106.40	0.43
	10	9	46	46000	192.32	0.48
	11	8.5	38	38000	144.40	0.43
	12	8	42	42000	143.60	0.39
	13	7.5	58	58000	176.21	0.35
	14	7.5	24	24000	72.91	0.35
	15	8	47	47000	160.70	0.39
	16	7.5	42	42000	127.60	0.35
	17	8	35	35000	119.67	0.39
	18	7.5	48	48000	145.83	0.35
	19	8	28	28000	95.73	0.39
	total		**794**	**794000**	**2,781.03**	**Cf=0.399**

Table 5.4: Wind Potential in Chania Perfecture

So as to decide the most appropriate area to install the power plant it could be taken into consideration the annual wind speed and also the rainfall data of each of these areas. Figures 5.3and 5.4 show the wind speed during the period of one year in Biannos-area. These are 10-minutes real measurements. Biannos is the specific area selected for the following reasons





Figures 5.3 & 5.4: Wind speed in Biannos

- The average annual wind speed exceeds 8 m/s
- It has high annual rainfall, moreover there is a dam with capacity 200.000 m^3
- The area of Biannos located south of Crete very close to Mediterranean Sea
- The activities of this area are agriculture, fishing, and tourist activities during the summer period.

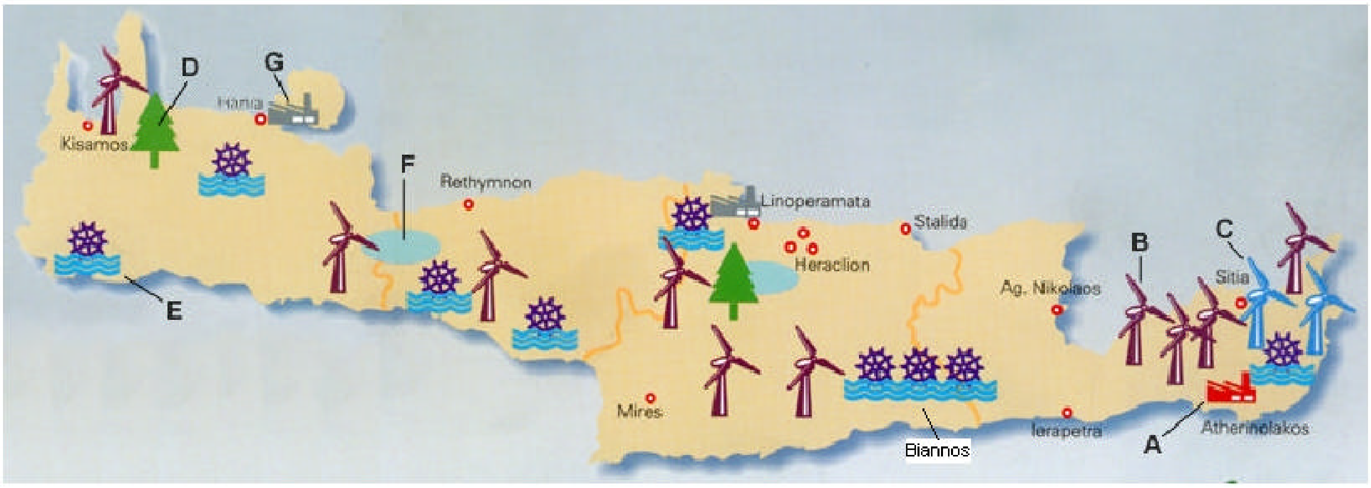


Figure 5.5 presents the existing and future electricity production units in Crete.

The energy consumption in this area (Biannos) for the year 2000 was approximately 20GWh and the energy consumption is increasing at a rate of ~5% per year. For the year 2000, the maximum energy demand was 4000kW and the minimum 800kW. The area of Biannos is connected with the main conventional power station in Linoperamata located in the north side of Crete.

5.3 Optimization of Combined wind/hydro power system

The operation of a wind farm combined with a reversible-hydro power station and a parallel water pump station is described. This case study is aiming at reducing considerably the dependence of the island upon energy produced by petrol and its derivatives. The schematic diagram and the energy flow of the installed hybrid system are shown in Figure 5.6. [25] The operation of this system is based on the following steps:

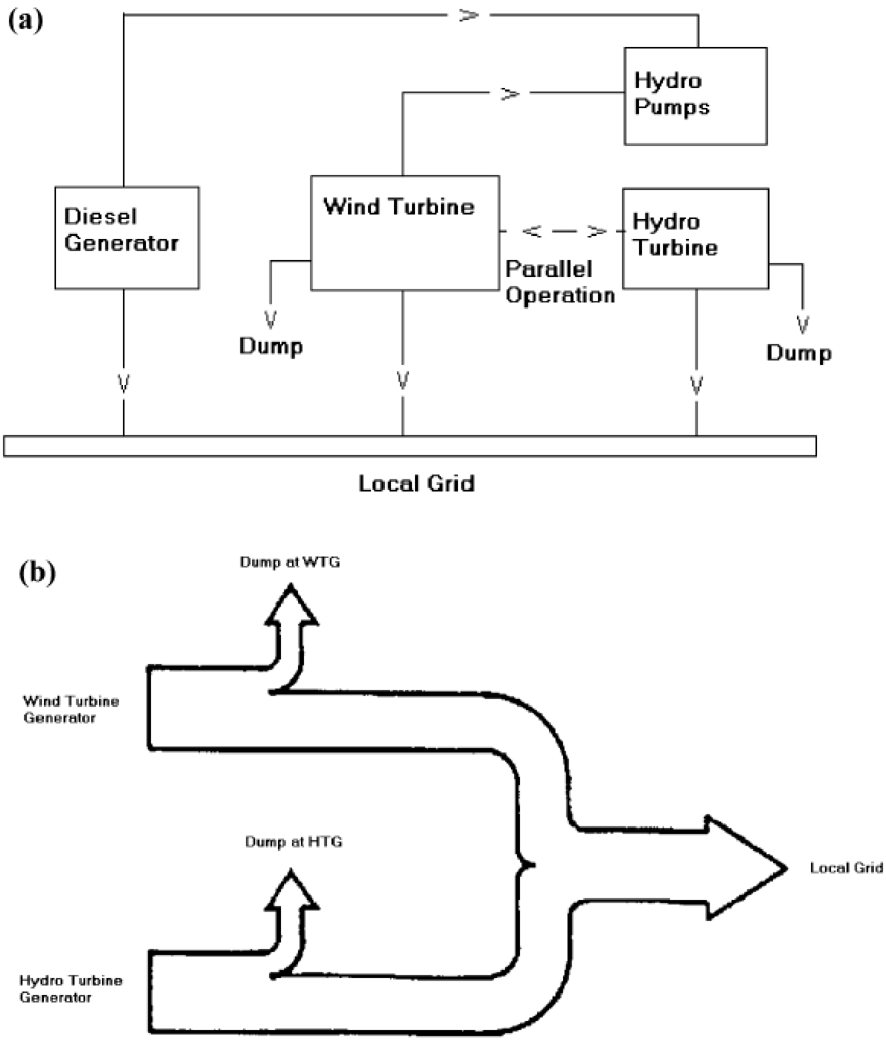


Figure 5.6: Schematic diagram of (a) the combined system and (b) energy flow

The energy produced from the wind farm is fed to the consumers, and when there is excessive amount of energy, it is diverted to the water pump station carrying water from a lower tank to a higher level and storing it in the form of hydrodynamic energy.

When the wind farm doesn't cover the consumer energy demands sufficiently, the hydro system produces energy using the energy of the water stored in the upper reservoir. When the lack of energy (reduced energy production from the wind turbines and low level of water in the reservoir) is anticipated to be long-term, then the system uses the APS power station.

The installation of an energy-consuming unit (such as a desalination plant) that is going to consume the extra energy produced from the wind farm is recommended. The desalination plant will serve small isolated communities in remote areas devoid of water resources.

Figure 5.7 illustrates the proposed solution of combined power system for remote islands.

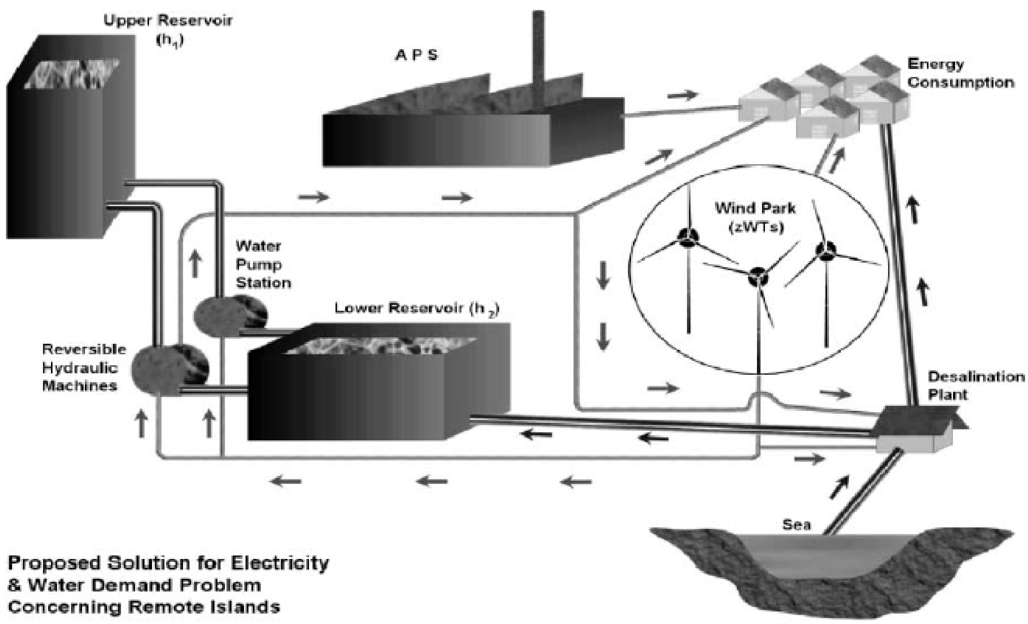


Figure 5.7: A combined power system for remote islands

More precisely, the proposed solution is based on:

i. a wind park of z wind turbines and rated power P_{WP}

ii. a hydropower plant (HPP), which consists of reversible water turbines and rated power P_H

iii. a water pump station, which in the combination of reversible water turbines (operating as water pumps, rated power P_H). Moreover, it should have the capability of absorbing the system's wind power surplus, rated power P_P

iv. two water reservoirs at elevations h_1 and h_2 ($h_1 > h_2$) working in closed circuit and the corresponding pipelines

v. an APS based on several existing internal combustion engines. Rated power P_{APS}

The aim target of this system is to cover the electricity demand P_D of the local community and to minimize the oil consumption in this area.

In order to calculate the power plant it is necessary to specify the rated power of the main wind/hydro power subsystems:

$P_{WP} > P_{Dmax} + dP$

$P_H > P_{Dmax} + dP$

$P_{APS} > P_{Dmax}$

Where P_{Dmax} is the maximum local power demand and dP is the probable future increase of P_{Dmax}.

The following installation design steps were followed:

1. Assessment of the number and size of the wind turbines based on the wind potential along with the present and projected electric-energy demands.

2. Investigation of the water reservoir position and the size in conjunction with the ground configuration and the necessary system autonomy. Also, an analysis

should be carried out regarding the possibility of using closed or open water circulation.

3. Selection of the hydro-system components (i.e. turbines and pumps)

4. Dimension determination of the parallel water-pump system taking into consideration the lowest possible losses and cost of the initial investment.

5. Rational use of the APS towards achieving maximum reduction in petrol consumption.

An essential element in the overall scheme is the use of an effective and proven load-management system, which provides the effective, beneficial distribution of wind energy surplus to essential service demand. This system allows the wind turbines and the hydro-system to operate alone or together as demand and resources dictate.

5.3.1. Wind-farm

The number of wind turbines, of nominal power P each, is determined as $z_{min}<z<z_{max}$ where the minimum number of wind turbines z_{min} is given as follows:

$$Z_{min} = E / (C_f\ P\ T_a\ 8760)$$

Where,

E: is the total annual energy consumption of the local grid taking into account an appropriate safety factor related to the projected increase of the energy demand in the near future.

C_f : is the capacity factor and depends on the local wind potential and wind turbines,

T_a: is the mean value of wind farm's technical availability.

The minimum number of the wind turbines z_{min} takes into account the fact that part of the energy produced by the wind farm will not be fed to the consumers directly but will be stored as hydrodynamic energy in the hydroelectric system. Also, the maximum number of wind turbines z_{max} is determined considering the worst-case scenario, when the total energy consumption will be produced by the stored energy. In this case, z_{max} is given as follows:

$$z_{max} = E / (C_f\ P\ T_a\ n\ 8760)$$

Where n is the total conversion coefficient of the stored energy to consumers. Generally, from experimental studies, it was found that the combined operation of wind/hydro plant incurs losses of the order of 30-50%.

Therefore, the number wind of turbines takes values between:

z_{min} = E / (C_f P T_a 8760 < z < E / (C_f P T_a n 8760) = z_{max}

E = 21,024,000 kWh

C_f = 0.41

P = 660kW

T_a = 0.97

n = 0.65

z_{min} = 9< z < 15 = z_{max}

The minimum and maximum wind energy power in the area of Biannos is shown in figure 5.8.

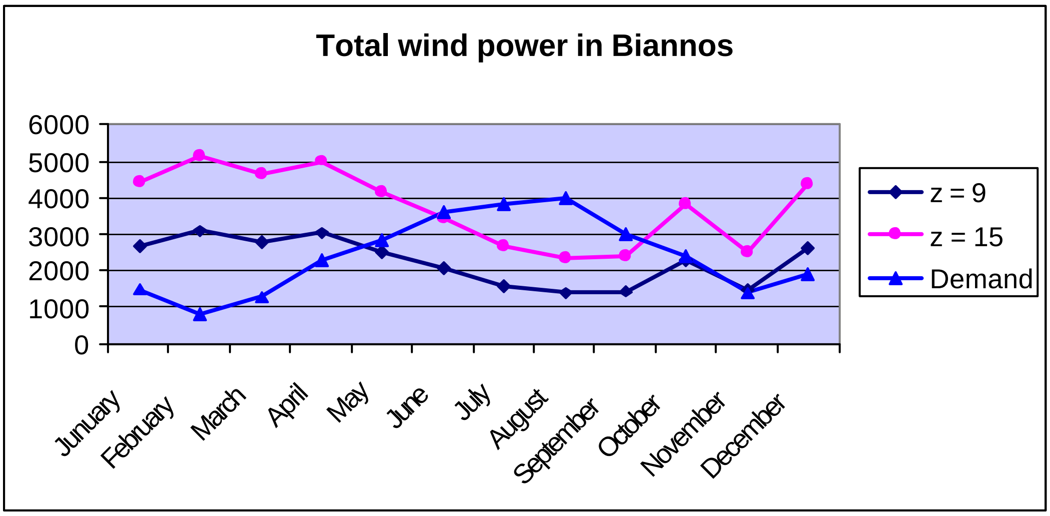


Figure 5.8: The minimum and maximum wind energy power in Biannos

5.3.2. Water reservoirs

The selection of the dimensions of the water reservoir depends on the required system's autonomy, energy needs and the ground configuration as well. The number of the autonomy day's d is given as follows:

$d = n_g * n_t * H * e * v / (E / 365)$

Where n_g the conversion coefficient of the energy generator (%)

n_t the conversion coefficients of the turbine (%),

H the effective head (m),

v the volume water-reservoir area (m^3),

e is the specific weight of water (9.81 kN/m3).

Therefore, the capacity of the reservoir depends on the number of the autonomy days. If I select a number of days between 1 and 3 days, it must be taken values between 285.000m^3 and 850.000m^3.

$v = [d * (E / 365)] / n_g * n_t * H * e$

E = 21,024,000 kWh

H = 117m

$n_g = 0.8$

$n_t = 0.8$

e =9.81 kN/m3

d = 3, $\underline{v_{max} = 850.000m^3}$

d = 1, $\underline{v_{min} = 285.000m^3}$

As the value of the ''typical autonomy days'' d_o is determined by the number of typical days, which only the hydroelectric station can cover the energy requirements. For this small scale power system, the number of autonomy days should be taken between 1 and 3 days, because the further increase of the number of autonomy days as a result the extremely increase of the capital cost.

Two water reservoirs at elevations h_1 and h_2 ($h_1 > h_2$) working in closed circuit. The water level of each reservoir y_1 and y_2 varies between y_{min} and y_{max} , while y_{min} is selected to protect the hydraulic machines from solid particles existing near the reservoir bottom and y_{max} is defined according to the desired energy autonomy of the system.

$$y_{max} = y_{min} + [d_o (E /365)] / p\ g\ H\ A\ n_H\ n_{el}$$

Where, d_o = 3, the number of autonomy days,

p = 1000 Kgr/m^3, the density of water,

g = 9.81m/sec^2 , the free fall acceleration,

H =117m the head,

A = 42500m^2, the cross-section area,

n_H =0.8 the water turbine's efficiency,

n_{el} =0.8 the electric-generator's efficiency.

5.3.3 Hydropower plant

The nominal power of a hydropower plant is determined by the requirement to cover the peak power demand of the local grid with an optimal future increase. Practically, in order to select the power of reversible water turbine the peak load plus an appropriate 30% increase accounting for the future peak demand is taken into account. The output power of each water turbine is given as:

$$P_H = p * g * H * V * n_H * n_{el}$$

Where, p the density of water (Kgr/m^3)

g the free fall acceleration (m/sec^2)

H the head (m)

V the flow rate of the turbine (m^3/sec),

n_H the water turbine's efficiency (%),

n_{el} the electric-generator's efficiency (%).

The output power of each water turbine constituting the hydropower station is a function of turbine net head H and the corresponding rate of flow V:

$$P_H = p * g * H * V * n_H * n_{el}$$

$$H < (h_1 - h_2) - dH_f = (h_1 - h_2) - K_H V^2$$

Where, dH_f the total hydraulic losses when the water circuit is used for energy production.

Using the data by the manufactures of the water turbines, it is obvious the relation between V the flow rate of the turbine with the H Head and the power of the turbine. [26]

$$H = H(V, a)$$

$$n_H = n_H(V, a)$$

$$P_H = P_H(V, a)$$

Where, a is the opening angle of the control valve which is known as opening parameter of turbine.

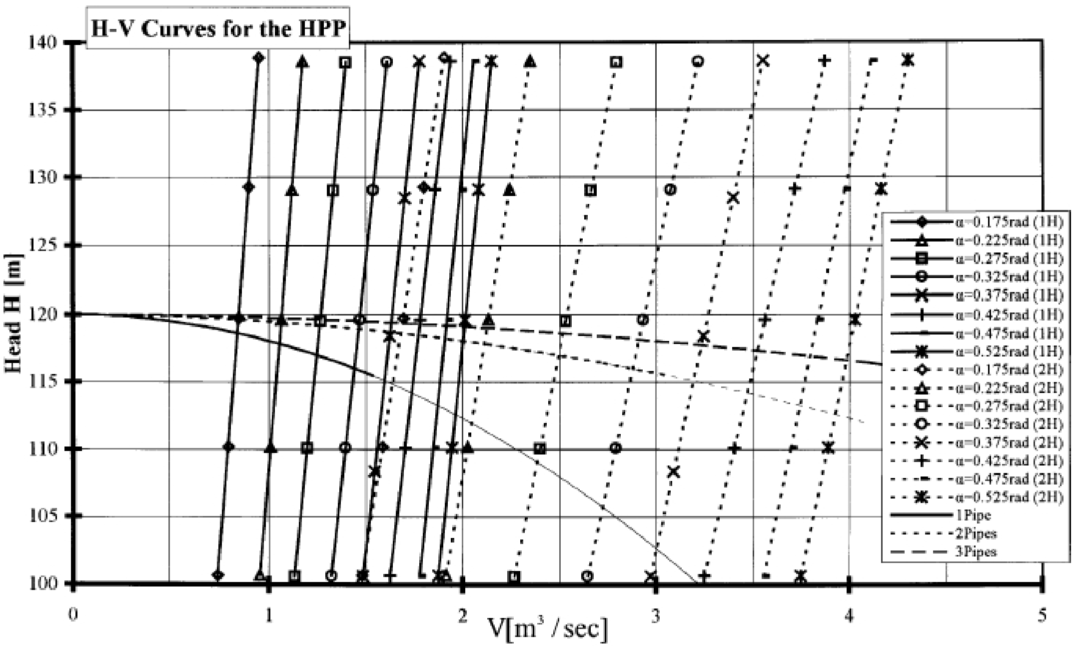


Figure 5.9: Operational (H-V) curves for the power hydro station

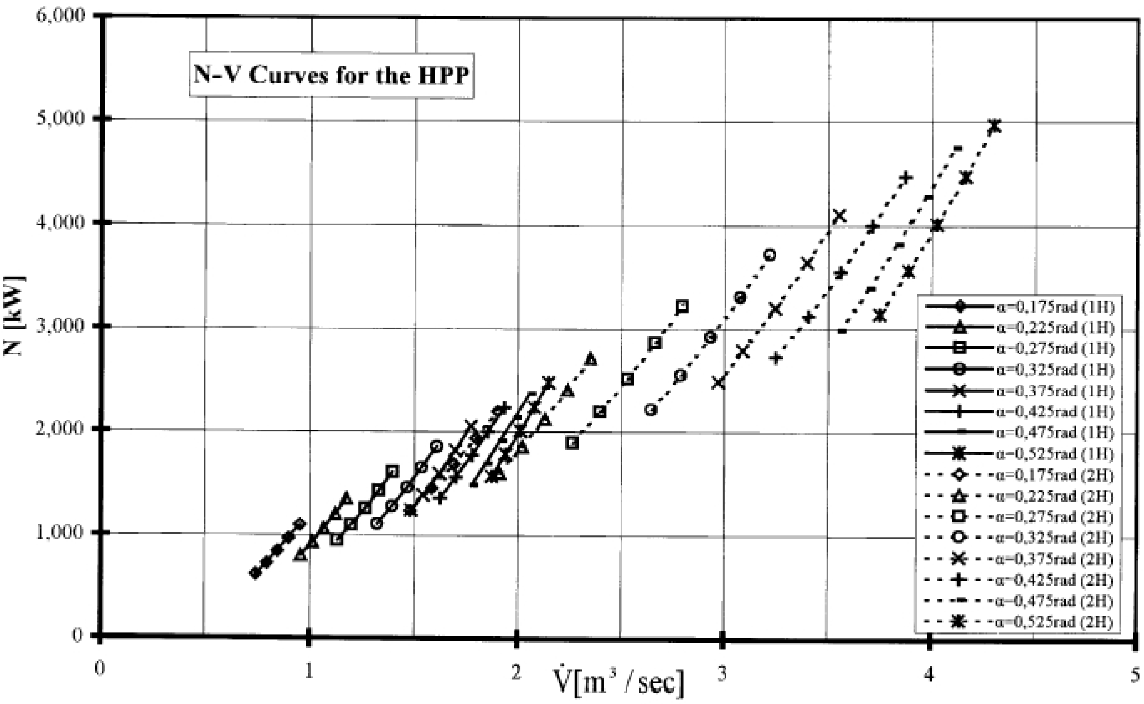


Figure 5.10: Operational (P-V) curves for the power hydro station

The peak power demand in the local grid is 4000kW that means it must be need a water turbine 5MW(or 2 x 2.5MW) in order to cover the future increasing demand. Using and combining the operational graphs of the power hydro station: 2 x 2.5MW water turbine with H = 117m and V = 2.5m^3 /sec.

$P_H = p * g * H * V * n_H * n_{el}$ $\quad$ $P_H = 1.8MW$

$P_H = 1.8 * 1.3 = 2.34$ MW

Final selection $\underline{P_H = 2.5 \text{ MW}}$

$p = 1000$ Kgr/m^3,

$g = 9.81$m/sec^2,

H = 117 m

V = 2.5 m^3/sec

n_H =0.8 the water turbine's efficiency,

n_{el} =0.8 the electric-generator's efficiency

5.3.4 Water pump station

The pump station, in conjunction with the reversible water-turbines operating as water pumps, is chosen to transfer water from the lower to the higher reservoir. It also absorbs the wind energy surplus of the combined power plant.

For increased reliability reason, it be selected a constant-speed water pump, its input power depends on the net hydraulic head H and the corresponding flow rate V.

$$P_p = p * g * H * V / * n_p * n_{el}$$

Where, p the density of water (Kgr/m^3)

g the free fall acceleration (m/sec^2)

H the head (m)

V the flow rate of the pump (m^3/sec),

n_p the water pump's efficiency (%),

n_{el} the efficiency of the water-pump's electric motor (%).

$P_p = p * g * H * V / * n_p * n_{el}$ $\qquad$ P_p = 4.48 MW

Final selection P_p =4.5 MW

p = 1000 Kgr/m^3,

g = 9.81m/sec^2,

H = 117 m

V = 2.5 m^3/sec

n_H =0.8 the water turbine's efficiency,

n_{el} =0.8 the electric-generator's efficiency

Conclusions

6.1 Analysis on Worksheets

An excel worksheet was built to simulate the operation of the overall power station. Precisely, parametric analysis is performed in order to estimate: i. the number and nominal power of wind turbines, ii. The nominal power of hydro station and the optimum size of the water reservoirs. iii. The number of hours without enough energy (power shortage) and the loss of the operation of this station.

The excel worksheet introduces the wind speed rates of each area; the number and the power of each pump, water and wind turbine type as well as the capacity of the upper reservoir.

The excel worksheet comprises of a ten-minute wind-speed distribution data-base, and the characteristic power curves for pumps wind and water turbines, which are selected from tables and graphs (operational characteristics of turbines). The calculations carried out are based on detailed measurements and real wind data.

Furthermore, table 6.1 presents a typical one-day period of operation of the combined wind/hydro power station in the area of Biannos. The wind speed distributions during a year and the monthly demand of Biannos –area have been provided by the Wind Energy Laboratory and PPC respectively. The wind energy supplied to the consumers in order to cover the demand is taking into account the number and the type of wind turbines and also the wind speed. When there is excessive amount of wind energy, this is diverted to the water pump station (for pumping), which is carrying water from a lower tank to a higher level and stores it. When the wind farm doesn't cover the consumer energy demands sufficiently, the hydro system produces energy utilizing the water stored in the upper reservoir (requirement power from water turbine). Finally the volume in the upper reservoir, the energy shortage due to the empty reservoir and the total losses of the power system are evaluated.

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	Wind Speed	Power	Total pow	Demanc	Wind Ensure Power	Left over of wind farm (on the top)	For Saving	For Pumping (power)	For saving (water)	Volume after the pumps	Required power from water turbine	For water turbine (water)	Volume after water turbine	Energ... short due em... tank	Losses
2/7/00 0:00 πμ/μμ	1.56	0	0	3800	0	0	0	0	0	0	3800	12904.3	0	3800	760
2/7/00 0:10 πμ/μμ	2.46	0	0	3800	0	0	0	0	0	0	3800	12904.3	0	3800	760
2/7/00 0:20 πμ/μμ	2.65	0	0	3800	0	0	0	0	0	0	3800	12904.3	0	3800	760
2/7/00 0:30 πμ/μμ	1.82	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 0:40 πμ/μμ	3.32	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 0:50 πμ/μμ	5	41.1	369.8	3800	369.8386	0.0	0.0	0.0	0.0	0.0	3430.2	8902.6	0.0	3430.2	686.0
2/7/00 1:00 πμ/μμ	3.13	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 1:10 πμ/μμ	6.14	105.5	949.6	3800	949.5582	0.0	0.0	0.0	0.0	0.0	2850.4	5862.7	0.0	2850.4	570.1
2/7/00 1:20 πμ/μμ	5.95	92.9	836.2	3800	836.163	0.0	0.0	0.0	0.0	0.0	2963.8	6153.6	0.0	2963.8	592.8
2/7/00 1:30 πμ/μμ	5.62	74.5	670.9	3800	670.8528	0.0	0.0	0.0	0.0	0.0	3129.1	6633.6	0.0	3129.1	625.8
2/7/00 1:40 πμ/μμ	6.24	112.5	1012.7	3800	1012.664	0.0	0.0	0.0	0.0	0.0	2787.3	5732.9	0.0	2787.3	557.5
2/7/00 1:50 πμ/μμ	6.29	116.0	1044.2	3800	1044.217	0.0	0.0	0.0	0.0	0.0	2755.8	5679.0	0.0	2755.8	551.2
2/7/00 2:00 πμ/μμ	6.26	113.9	1025.3	3800	1025.285	0.0	0.0	0.0	0.0	0.0	2774.7	5711.3	0.0	2774.7	554.9
2/7/00 2:10 πμ/μμ	5.95	92.9	836.2	3800	836.163	0.0	0.0	0.0	0.0	0.0	2963.8	6153.6	0.0	2963.8	592.8
2/7/00 2:20 πμ/μμ	5.88	89.0	801.1	3800	801.0972	0.0	0.0	0.0	0.0	0.0	2998.9	6243.6	0.0	2998.9	599.8
2/7/00 2:30 πμ/μμ	5.19	51.0	459.2	3800	459.2081	0.0	0.0	0.0	0.0	0.0	3340.8	8192.5	0.0	3340.8	668.2
2/7/00 2:40 πμ/μμ	4.86	36.2	325.9	3800	325.9391	0.0	0.0	0.0	0.0	0.0	3474.1	9127.8	0.0	3474.1	694.8
2/7/00 2:50 πμ/μμ	4.15	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 3:00 πμ/μμ	3.46	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 3:10 πμ/μμ	3.41	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 3:20 πμ/μμ	0.75	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 3:30 πμ/μμ	1.3	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 3:40 πμ/μμ	3.15	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 3:50 πμ/μμ	5.12	47.2	425.0	3800	424.9913	0.0	0.0	0.0	0.0	0.0	3375.0	8543.6	0.0	3375.0	675.0
2/7/00 4:00 πμ/μμ	5.27	55.4	498.3	3800	498.3131	0.0	0.0	0.0	0.0	0.0	3301.7	7791.2	0.0	3301.7	660.3
2/7/00 4:10 πμ/μμ	2.7	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 4:20 πμ/μμ	1.32	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 4:30 πμ/μμ	2.7	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 4:40 πμ/μμ	0.63	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 4:50 πμ/μμ	1.8	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 5:00 πμ/μμ	1.28	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 5:10 πμ/μμ	2.53	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	Wind Speed	Power	Total pow	Demanc	Wind Ensure Power	Left over of wind farm (on the top)	For Saving	For Pumping (power)	For saving (water)	Volume after the pumps	Required power from water turbine	For water turbine (water)	Volume after water turbine	Energy shortage due to empty tank	Losses
2/7/00 5:20 πμ/μμ	0.85	0.0	0.0	3800	0	0.0	0.0	0.0	0.0	0.0	3800.0	12904.3	0.0	3800.0	760.0
2/7/00 5:30 πμ/μμ	4.24	14.3	128.4	3800	128.3532	0.0	0.0	0.0	0.0	0.0	3671.6	11585.6	0.0	3671.6	734.3
2/7/00 5:40 πμ/μμ	4.96	39.7	357.3	3800	357.2959	0.0	0.0	0.0	0.0	0.0	3442.7	8966.9	0.0	3442.7	688.5
2/7/00 5:50 πμ/μμ	6.98	163.6	1472.6	3800	1472.629	0.0	0.0	0.0	0.0	0.0	2327.4	4883.3	0.0	2327.4	465.5
2/7/00 6:00 πμ/μμ	7.28	190.7	1716.5	3800	1716.509	0.0	0.0	0.0	0.0	0.0	2083.5	4167.5	0.0	2083.5	416.7
2/7/00 6:10 πμ/μμ	7.97	252.0	2268.4	3800	2268.378	0.0	0.0	0.0	0.0	0.0	1531.6	1440.8	0.0	1531.6	306.3
2/7/00 6:20 πμ/μμ	9.19	377.8	3400.4	3800	3400.395	0.0	0.0	0.0	0.0	0.0	399.6	1004.5	0.0	399.6	79.9
2/7/00 6:30 πμ/μμ	9.78	440.2	3961.8	3800	3800	161.8	161.8	161.8	59.9	59.9	0.0	0.0	59.9	0.0	32.4
2/7/00 6:40 πμ/μμ	10.14	480.0	4319.9	3800	3800	519.9	519.9	519.9	170.9	230.8	0.0	0.0	230.8	0.0	104.0
2/7/00 6:50 πμ/μμ	8.88	346.9	3121.9	3800	3121.91	0.0	0.0	0.0	0.0	230.8	678.1	1111.8	0.0	678.1	135.6
2/7/00 7:00 πμ/μμ	9.99	466.3	4196.3	3800	3800	396.3	396.3	396.3	181.1	181.1	0.0	0.0	181.1	0.0	79.3
2/7/00 7:10 πμ/μμ	13.03	647.0	5822.8	3800	3800	2022.8	2022.8	2022.8	701.8	882.9	0.0	0.0	882.9	0.0	404.6
2/7/00 7:20 πμ/μμ	13.56	652.4	5871.4	3800	3800	2071.4	2071.4	2071.4	722.6	1605.5	0.0	0.0	1605.5	0.0	414.3
2/7/00 7:30 πμ/μμ	11.96	610.9	5497.7	3800	3800	1697.7	1697.7	1697.7	508.4	2113.9	0.0	0.0	2113.9	0.0	339.5
2/7/00 7:40 πμ/μμ	10.68	525.8	4732.2	3800	3800	932.2	932.2	932.2	136.8	2250.7	0.0	0.0	2250.7	0.0	186.4
2/7/00 7:50 πμ/μμ	9.59	416.6	3749.6	3800	3749.638	0.0	0.0	0.0	0.0	2250.7	50.4	47.0	2203.7	0.0	10.1
2/7/00 8:00 πμ/μμ	9.21	379.6	3416.6	3800	3416.639	0.0	0.0	0.0	0.0	2203.7	383.4	998.2	1205.5	0.0	76.7
2/7/00 8:10 πμ/μμ	9.33	390.5	3514.1	3800	3514.103	0.0	0.0	0.0	0.0	1205.5	285.9	960.6	244.9	0.0	57.2
2/7/00 8:20 πμ/μμ	10.02	469.6	4226.4	3800	3800	426.4	426.4	426.4	178.6	423.5	0.0	0.0	423.5	0.0	85.3
2/7/00 8:30 πμ/μμ	9.8	442.7	3984.1	3800	3800	184.1	184.1	184.1	97.5	521.0	0.0	0.0	521.0	0.0	36.8
2/7/00 8:40 πμ/μμ	9.52	407.9	3671.5	3800	3671.467	0.0	0.0	0.0	0.0	521.0	128.5	282.6	238.4	0.0	25.7
2/7/00 8:50 πμ/μμ	11.47	585.7	5271.0	3800	3800	1471.0	1471.0	1471.0	341.8	580.1	0.0	0.0	580.1	0.0	294.2
2/7/00 9:00 πμ/μμ	11.32	574.9	5174.2	3800	3800	1374.2	1374.2	1374.2	196.8	777.0	0.0	0.0	777.0	0.0	274.8
2/7/00 9:10 πμ/μμ	10.66	524.2	4717.4	3800	3800	917.4	917.4	917.4	138.0	915.0	0.0	0.0	915.0	0.0	183.5
2/7/00 9:20 πμ/μμ	8.99	359.1	3232.2	3800	3232.232	0.0	0.0	0.0	0.0	915.0	567.8	1069.3	0.0	567.8	113.6
2/7/00 9:30 πμ/μμ	8.31	285.4	2568.5	3800	2568.54	0.0	0.0	0.0	0.0	0.0	1231.5	1325.1	0.0	1231.5	246.3
2/7/00 9:40 πμ/μμ	9.07	367.0	3302.9	3800	3302.93	0.0	0.0	0.0	0.0	0.0	497.1	1042.0	0.0	497.1	99.4
2/7/00 9:50 πμ/μμ	8.35	289.3	2604.1	3800	2604.083	0.0	0.0	0.0	0.0	0.0	1195.9	1311.4	0.0	1195.9	239.2
2/7/00 10:00 πμ/μμ	7.02	167.0	1503.4	3800	1503.382	0.0	0.0	0.0	0.0	0.0	2296.6	4804.4	0.0	2296.6	459.3
2/7/00 10:10 πμ/μμ	9.99	466.3	4196.3	3800	3800	396.3	396.3	396.3	181.1	181.1	0.0	0.0	181.1	0.0	79.3
2/7/00 10:20 πμ/μμ	11.73	599.3	5394.0	3800	3800	1594.0	1594.0	1594.0	464.1	645.2	0.0	0.0	645.2	0.0	318.8
2/7/00 10:30 πμ/μμ	13.18	648.4	5835.8	3800	3800	2035.8	2035.8	2035.8	707.3	1352.6	0.0	0.0	1352.6	0.0	407.2

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	Wind Speed	Power	Total pow	Demand	Wind Ensure Power	Left over of wind farm (on the top)	For Saving	For Pumping (power)	For saving (water)	Volume after the pumps	Required power from water turbine	For water turbine (water)	Volume after water turbine	Energy shortage due to empty tank	Losses
2/7/00 10:40 πμ/μμ	12.65	638.4	5745.2	3800	3800	1945.2	1945.2	1945.2	668.6	2021.2	0.0	0.0	2021.2	0.0	389.0
2/7/00 10:50 πμ/μμ	13.63	653.4	5880.2	3800	3800	2080.2	2080.2	2080.2	726.3	2747.5	0.0	0.0	2747.5	0.0	416.0
2/7/00 11:00 πμ/μμ	15.84	660.7	5946.5	3800	3800	2146.5	2146.5	2146.5	754.7	3502.2	0.0	0.0	3502.2	0.0	429.3
2/7/00 11:10 πμ/μμ	15.67	660.5	5944.6	3800	3800	2144.6	2144.6	2144.6	753.8	4256.0	0.0	0.0	4256.0	0.0	428.9
2/7/00 11:20 πμ/μμ	16.36	661.2	5950.6	3800	3800	2150.6	2150.6	2150.6	756.4	5012.4	0.0	0.0	5012.4	0.0	430.1
2/7/00 11:30 πμ/μμ	16.22	661.1	5949.6	3800	3800	2149.6	2149.6	2149.6	756.0	5768.4	0.0	0.0	5768.4	0.0	429.9
2/7/00 11:40 πμ/μμ	17.88	662.4	5961.2	3800	3800	2161.2	2161.2	2161.2	760.9	6529.4	0.0	0.0	6529.4	0.0	432.2
2/7/00 11:50 πμ/μμ	16.36	661.2	5950.6	3800	3800	2150.6	2150.6	2150.6	756.4	7285.8	0.0	0.0	7285.8	0.0	430.1
2/7/00 12:00 πμ/μμ	14.48	659.4	5934.8	3800	3800	2134.8	2134.8	2134.8	749.6	8035.4	0.0	0.0	8035.4	0.0	427.0
2/7/00 12:10 πμ/μμ	13.7	654.3	5889.1	3800	3800	2089.1	2089.1	2089.1	730.1	8765.5	0.0	0.0	8765.5	0.0	417.8
2/7/00 12:20 πμ/μμ	13.13	647.9	5831.5	3800	3800	2031.5	2031.5	2031.5	705.5	9471.0	0.0	0.0	9471.0	0.0	406.3
2/7/00 12:30 πμ/μμ	11.85	605.3	5448.1	3800	3800	1648.1	1648.1	1648.1	487.2	9958.2	0.0	0.0	9958.2	0.0	329.6
2/7/00 12:40 πμ/μμ	13.46	651.1	5860.0	3800	3800	2060.0	2060.0	2060.0	717.7	10675.9	0.0	0.0	10675.9	0.0	412.0
2/7/00 12:50 πμ/μμ	15.15	660.6	5945.7	3800	3800	2145.7	2145.7	2145.7	754.3	11430.3	0.0	0.0	11430.3	0.0	429.1
2/7/00 13:00 πμ/μμ	15.48	660.3	5942.4	3800	3800	2142.4	2142.4	2142.4	752.9	12183.2	0.0	0.0	12183.2	0.0	428.5
2/7/00 13:10 πμ/μμ	16.98	660.6	5945.6	3800	3800	2145.6	2145.6	2145.6	754.3	12937.4	0.0	0.0	12937.4	0.0	429.1
2/7/00 13:20 πμ/μμ	17.24	661.1	5949.8	3800	3800	2149.8	2149.8	2149.8	756.1	13693.5	0.0	0.0	13693.5	0.0	430.0
2/7/00 13:30 πμ/μμ	17.38	661.3	5952.1	3800	3800	2152.1	2152.1	2152.1	757.1	14450.6	0.0	0.0	14450.6	0.0	430.4
2/7/00 13:40 πμ/μμ	17.35	661.3	5951.6	3800	3800	2151.6	2151.6	2151.6	756.8	15207.4	0.0	0.0	15207.4	0.0	430.3
2/7/00 13:50 πμ/μμ	17.78	662.2	5959.4	3800	3800	2159.4	2159.4	2159.4	760.2	15967.6	0.0	0.0	15967.6	0.0	431.9
2/7/00 14:00 πμ/μμ	17.47	661.5	5953.6	3800	3800	2153.6	2153.6	2153.6	757.7	16725.3	0.0	0.0	16725.3	0.0	430.7
2/7/00 14:10 πμ/μμ	18.09	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	17486.4	0.0	0.0	17486.4	0.0	432.4
2/7/00 14:20 πμ/μμ	18.66	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	18247.5	0.0	0.0	18247.5	0.0	432.4
2/7/00 14:30 πμ/μμ	17.45	661.5	5953.2	3800	3800	2153.2	2153.2	2153.2	757.5	19005.0	0.0	0.0	19005.0	0.0	430.6
2/7/00 14:40 πμ/μμ	16.22	661.1	5949.6	3800	3800	2149.6	2149.6	2149.6	756.0	19761.0	0.0	0.0	19761.0	0.0	429.9
2/7/00 14:50 πμ/μμ	15.98	660.9	5948.0	3800	3800	2148.0	2148.0	2148.0	755.3	20516.3	0.0	0.0	20516.3	0.0	429.6
2/7/00 15:00 πμ/μμ	15.81	660.7	5946.1	3800	3800	2146.1	2146.1	2146.1	754.5	21270.8	0.0	0.0	21270.8	0.0	429.2
2/7/00 15:10 πμ/μμ	15.76	660.6	5945.6	3800	3800	2145.6	2145.6	2145.6	754.3	22025.1	0.0	0.0	22025.1	0.0	429.1
2/7/00 15:20 πμ/μμ	17.07	660.8	5947.0	3800	3800	2147.0	2147.0	2147.0	754.9	22779.9	0.0	0.0	22779.9	0.0	429.4
2/7/00 15:30 πμ/μμ	17.59	661.8	5955.8	3800	3800	2155.8	2155.8	2155.8	758.7	23538.6	0.0	0.0	23538.6	0.0	431.2
2/7/00 15:40 πμ/μμ	17.78	662.2	5959.4	3800	3800	2159.4	2159.4	2159.4	760.2	24298.8	0.0	0.0	24298.8	0.0	431.9
2/7/00 15:50 πμ/μμ	15.48	660.3	5942.4	3800	3800	2142.4	2142.4	2142.4	752.9	25051.7	0.0	0.0	25051.7	0.0	428.5

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	Wind Speed	Power	Total pow	Demanc	Wind Ensure Power	Left over of wind farm (on the top)	For Saving	For Pumping (power)	For saving (water)	Volume after the pumps	Required power from water turbine	For water turbine (water)	Volume after water turbine	Energy shortage due to empty tank	Losses
2/7/00 16:00 πμ/μμ	15.12	660.7	5946.2	3800	3800	2146.2	2146.2	2146.2	754.6	25806.3	0.0	0.0	25806.3	0.0	429.2
2/7/00 16:10 πμ/μμ	12.89	644.0	5795.8	3800	3800	1995.8	1995.8	1995.8	690.2	26496.5	0.0	0.0	26496.5	0.0	399.2
2/7/00 16:20 πμ/μμ	13.89	657.0	5913.0	3800	3800	2113.0	2113.0	2113.0	740.3	27236.8	0.0	0.0	27236.8	0.0	422.6
2/7/00 16:30 πμ/μμ	19.44	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	27997.9	0.0	0.0	27997.9	0.0	432.4
2/7/00 16:40 πμ/μμ	18.26	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	28759.0	0.0	0.0	28759.0	0.0	432.4
2/7/00 16:50 πμ/μμ	17.17	661.0	5948.7	3800	3800	2148.7	2148.7	2148.7	755.6	29514.6	0.0	0.0	29514.6	0.0	429.7
2/7/00 17:00 πμ/μμ	15.1	660.7	5946.6	3800	3800	2146.6	2146.6	2146.6	754.7	30269.3	0.0	0.0	30269.3	0.0	429.3
2/7/00 17:10 πμ/μμ	16.41	661.2	5950.9	3800	3800	2150.9	2150.9	2150.9	756.5	31025.9	0.0	0.0	31025.9	0.0	430.2
2/7/00 17:20 πμ/μμ	18.71	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	31786.9	0.0	0.0	31786.9	0.0	432.4
2/7/00 17:30 πμ/μμ	16.07	661.0	5948.6	3800	3800	2148.6	2148.6	2148.6	755.6	32542.5	0.0	0.0	32542.5	0.0	429.7
2/7/00 17:40 πμ/μμ	12.34	628.1	5652.8	3800	3800	1852.8	1852.8	1852.8	606.0	33148.5	0.0	0.0	33148.5	0.0	370.6
2/7/00 17:50 πμ/μμ	10.7	527.4	4747.0	3800	3800	947.0	947.0	947.0	135.5	33284.0	0.0	0.0	33284.0	0.0	189.4
2/7/00 18:00 πμ/μμ	11.28	572.0	5148.4	3800	3800	1348.4	1348.4	1348.4	174.8	33458.8	0.0	0.0	33458.8	0.0	269.7
2/7/00 18:10 πμ/μμ	11.73	599.3	5394.0	3800	3800	1594.0	1594.0	1594.0	464.1	33922.9	0.0	0.0	33922.9	0.0	318.8
2/7/00 18:20 πμ/μμ	11.58	591.8	5326.4	3800	3800	1526.4	1526.4	1526.4	435.2	34358.1	0.0	0.0	34358.1	0.0	305.3
2/7/00 18:30 πμ/μμ	15	660.9	5948.4	3800	3800	2148.4	2148.4	2148.4	755.5	35113.6	0.0	0.0	35113.6	0.0	429.7
2/7/00 18:40 πμ/μμ	14.91	661.1	5950.0	3800	3800	2150.0	2150.0	2150.0	756.2	35869.8	0.0	0.0	35869.8	0.0	430.0
2/7/00 18:50 πμ/μμ	15.45	660.2	5942.1	3800	3800	2142.1	2142.1	2142.1	752.8	36622.5	0.0	0.0	36622.5	0.0	428.4
2/7/00 19:00 πμ/μμ	17.47	661.5	5953.6	3800	3800	2153.6	2153.6	2153.6	757.7	37380.2	0.0	0.0	37380.2	0.0	430.7
2/7/00 19:10 πμ/μμ	21.32	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	38141.3	0.0	0.0	38141.3	0.0	432.4
2/7/00 19:20 πμ/μμ	20.99	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	38902.4	0.0	0.0	38902.4	0.0	432.4
2/7/00 19:30 πμ/μμ	17.95	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	39663.5	0.0	0.0	39663.5	0.0	432.4
2/7/00 19:40 πμ/μμ	14.84	660.8	5947.5	3800	3800	2147.5	2147.5	2147.5	755.1	40418.6	0.0	0.0	40418.6	0.0	429.5
2/7/00 19:50 πμ/μμ	14.98	661.0	5948.7	3800	3800	2148.7	2148.7	2148.7	755.6	41174.2	0.0	0.0	41174.2	0.0	429.7
2/7/00 20:00 πμ/μμ	15.1	660.7	5946.6	3800	3800	2146.6	2146.6	2146.6	754.7	41928.9	0.0	0.0	41928.9	0.0	429.3
2/7/00 20:10 πμ/μμ	13.67	653.9	5885.3	3800	3800	2085.3	2085.3	2085.3	728.5	42657.4	0.0	0.0	42657.4	0.0	417.1
2/7/00 20:20 πμ/μμ	14.93	661.1	5949.6	3800	3800	2149.6	2149.6	2149.6	756.0	43413.4	0.0	0.0	43413.4	0.0	429.9
2/7/00 20:30 πμ/μμ	16.5	661.1	5949.9	3800	3800	2149.9	2149.9	2149.9	756.1	44169.5	0.0	0.0	44169.5	0.0	430.0
2/7/00 20:40 πμ/μμ	16.71	660.8	5947.1	3800	3800	2147.1	2147.1	2147.1	754.9	44924.4	0.0	0.0	44924.4	0.0	429.4
2/7/00 20:50 πμ/μμ	15.55	660.4	5943.2	3800	3800	2143.2	2143.2	2143.2	753.3	45677.7	0.0	0.0	45677.7	0.0	428.6
2/7/00 21:00 πμ/μμ	14.13	658.7	5928.2	3800	3800	2128.2	2128.2	2128.2	746.8	46424.6	0.0	0.0	46424.6	0.0	425.6
2/7/00 21:10 πμ/μμ	13.08	647.5	5827.2	3800	3800	2027.2	2027.2	2027.2	703.6	47128.2	0.0	0.0	47128.2	0.0	405.4

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	Wind Speed	Power	Total pow	Demanc	Wind Ensure Power	Left over of wind farm (on the top)	For Saving	For Pumping (power)	For saving (water)	Volume after the pumps	Required power from water turbine	For water turbine (water)	Volume after water turbine	Energy shortage due to empty tank	Losses
2/7/00 21:20 πμ/μμ	13.67	653.9	5885.3	3800	3800	2085.3	2085.3	2085.3	728.5	47856.7	0.0	0.0	47856.7	0.0	417.1
2/7/00 21:30 πμ/μμ	14.17	658.8	5929.0	3800	3800	2129.0	2129.0	2129.0	747.2	48603.8	0.0	0.0	48603.8	0.0	425.8
2/7/00 21:40 πμ/μμ	16.29	661.1	5950.1	3800	3800	2150.1	2150.1	2150.1	756.2	49360.0	0.0	0.0	49360.0	0.0	430.0
2/7/00 21:50 πμ/μμ	16.93	660.5	5944.7	3800	3800	2144.7	2144.7	2144.7	753.9	50114.0	0.0	0.0	50114.0	0.0	428.9
2/7/00 22:00 πμ/μμ	16.5	661.1	5949.9	3800	3800	2149.9	2149.9	2149.9	756.1	50870.1	0.0	0.0	50870.1	0.0	430.0
2/7/00 22:10 πμ/μμ	16.12	661.0	5948.9	3800	3800	2148.9	2148.9	2148.9	755.7	51625.8	0.0	0.0	51625.8	0.0	429.8
2/7/00 22:20 πμ/μμ	15.41	660.2	5941.7	3800	3800	2141.7	2141.7	2141.7	752.6	52378.4	0.0	0.0	52378.4	0.0	428.3
2/7/00 22:30 πμ/μμ	14.58	659.8	5938.0	3800	3800	2138.0	2138.0	2138.0	751.0	53129.4	0.0	0.0	53129.4	0.0	427.6
2/7/00 22:40 πμ/μμ	15.36	660.2	5942.0	3800	3800	2142.0	2142.0	2142.0	752.7	53882.1	0.0	0.0	53882.1	0.0	428.4
2/7/00 22:50 πμ/μμ	14.41	659.3	5933.5	3800	3800	2133.5	2133.5	2133.5	749.1	54631.2	0.0	0.0	54631.2	0.0	426.7
2/7/00 23:00 πμ/μμ	14.2	658.8	5929.5	3800	3800	2129.5	2129.5	2129.5	747.4	55378.6	0.0	0.0	55378.6	0.0	425.9
2/7/00 23:10 πμ/μμ	14.6	659.9	5938.8	3800	3800	2138.8	2138.8	2138.8	751.4	56130.0	0.0	0.0	56130.0	0.0	427.8
2/7/00 23:20 πμ/μμ	17.69	662.0	5957.7	3800	3800	2157.7	2157.7	2157.7	759.4	56889.4	0.0	0.0	56889.4	0.0	431.5
2/7/00 23:30 πμ/μμ	18.04	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	57650.5	0.0	0.0	57650.5	0.0	432.4
2/7/00 23:40 πμ/μμ	18.57	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	58411.6	0.0	0.0	58411.6	0.0	432.4
2/7/00 23:50 πμ/μμ	18.14	662.4	5961.8	3800	3800	2161.8	2161.8	2161.8	761.1	59172.7	0.0	0.0	59172.7	0.0	432.4
3/7/00 0:00 πμ/μμ	17	660.7	5945.9	3800	3800	2145.9	2145.9	2145.9	754.4	59927.1	0.0	0.0	59927.1	0.0	429.2
3/7/00 0:10 πμ/μμ	16.86	660.6	5945.1	3800	3800	2145.1	2145.1	2145.1	754.1	60681.2	0.0	0.0	60681.2	0.0	429.0
3/7/00 0:20 πμ/μμ	15.31	660.3	5942.9	3800	3800	2142.9	2142.9	2142.9	753.1	61434.3	0.0	0.0	61434.3	0.0	428.6
3/7/00 0:30 πμ/μμ	17.02	660.7	5946.2	3800	3800	2146.2	2146.2	2146.2	754.5	62188.8	0.0	0.0	62188.8	0.0	429.2
3/7/00 0:40 πμ/μμ	16.95	660.6	5945.1	3800	3800	2145.1	2145.1	2145.1	754.0	62942.9	0.0	0.0	62942.9	0.0	429.0
3/7/00 0:50 πμ/μμ	14.86	660.9	5948.2	3800	3800	2148.2	2148.2	2148.2	755.4	63698.2	0.0	0.0	63698.2	0.0	429.6
3/7/00 1:00 πμ/μμ	12.25	624.0	5616.4	3800	3800	1816.4	1816.4	1816.4	574.9	64273.1	0.0	0.0	64273.1	0.0	363.3
3/7/00 1:10 πμ/μμ	9.57	414.1	3727.3	3800	3727.303	0.0	0.0	0.0	0.0	64273.1	72.7	128.5	64144.6	0.0	14.5
3/7/00 1:20 πμ/μμ	8.69	325.7	2931.4	3800	2931.354	0.0	0.0	0.0	0.0	64144.6	868.6	1185.2	62959.4	0.0	173.7
3/7/00 1:30 πμ/μμ	8.57	312.3	2811.0	3800	2811.003	0.0	0.0	0.0	0.0	62959.4	989.0	1231.6	61727.7	0.0	197.8
3/7/00 1:40 πμ/μμ	8.99	359.1	3232.2	3800	3232.232	0.0	0.0	0.0	0.0	61727.7	567.8	1069.3	60658.4	0.0	113.6
3/7/00 1:50 πμ/μμ	7.69	227.4	2046.9	3800	2046.87	0.0	0.0	0.0	0.0	60658.4	1753.1	3047.9	57610.6	0.0	350.6
3/7/00 2:00 πμ/μμ	9.57	414.1	3727.3	3800	3727.303	0.0	0.0	0.0	0.0	57610.6	72.7	128.5	57482.0	0.0	14.5
3/7/00 2:10 πμ/μμ	10.68	525.8	4732.2	3800	3800	932.2	932.2	932.2	136.8	57618.8	0.0	0.0	57618.8	0.0	186.4
3/7/00 2:20 πμ/μμ	12.15	619.6	5576.0	3800	3800	1776.0	1776.0	1776.0	541.9	58160.7	0.0	0.0	58160.7	0.0	355.2
3/7/00 2:30 πμ/μμ	13.2	648.6	5837.5	3800	3800	2037.5	2037.5	2037.5	708.1	58868.8	0.0	0.0	58868.8	0.0	407.5

Table 6.1: One-day operation of the combined wind/hydro power system

Figures 6.1 and 6.2 present the annual power shortage during the operation of the combined power system. It is obvious that during the first 3 months the value of the power shortage is very low. This occurs due to the approximately low energy demand manifested during the winter period. Moreover, the average wind speed at the same period is high thus covering the energy demand efficiently. On the other hand in the summer months, the assessment of the power shortage is high due to the extremely high demand and the value of the wind speed during the summer period. For the period between October to December the power shortage is actually usual. This is considered logical, because at this time both the average wind speed and energy demand are going on the middle level.

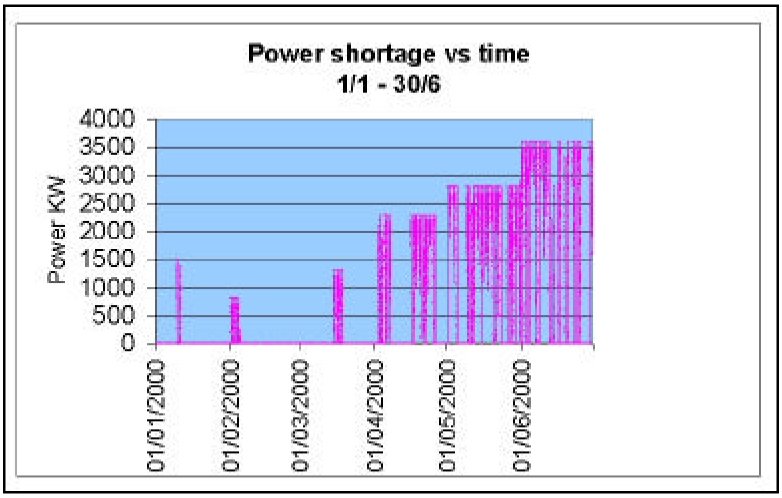


Figure 6.1: Power shortage during the operation of power plant 1/1 – 30/6

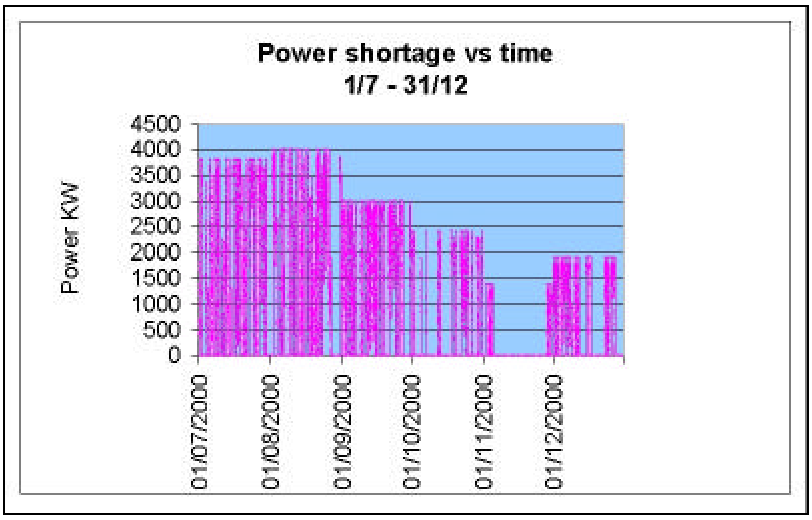


Figure 6.2: Power shortage during the operation of power plant 1/7 – 31/12

More precisely, figure 6.3 illustrates the number of hours per month during the period of a year, when the combined wind/hydro power plant doesn't cover the energy demand competently.

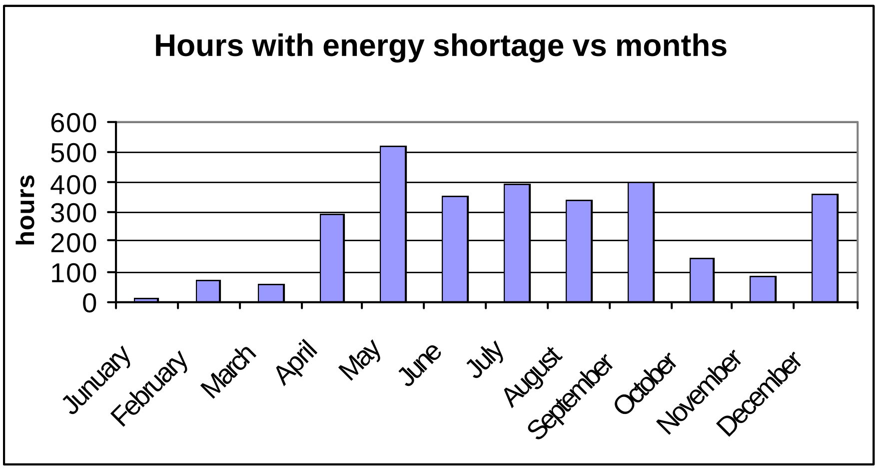


Figure 6.3: Hours with energy shortage during the annual operation of the combined power station

It is obvious that the period of May this power system has the largest amount of energy shortage. Furthermore, the longest continuous period (120.5 hours) of energy shortage comes up at the same period of time in May. Apart from this, the whole period of the summer takes place the lack of energy. It would be solved this problem with many different ways: to use a bigger power plant, to decrease the power demand, to use new conventional or renewable power station, but the cheapest solution is the use of the existing autonomous thermal power station APS. Particularly, a suitable alternative is the utilization of the solar power due to the extremely high sunlight especially during the summer period in Crete.

Finally, figures 6.4 and 6.5 present the penetration of wind and hydro in energy balance in a winter and a summer month. It must be emphasized that during the winter month (January) the energy demand is lower than during the summer month (August) when the demand peak of the year occurs.

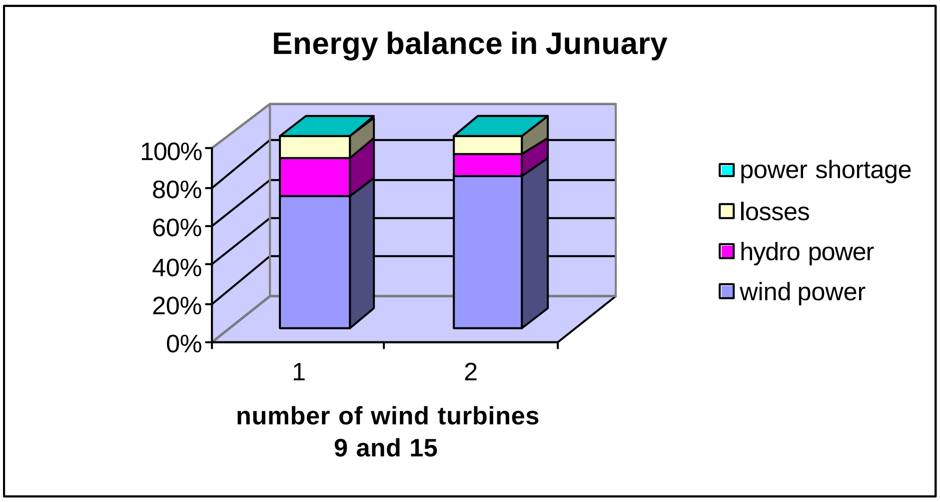


Figure 6.4: Energy balance in January

The higher percentage of wind power contributed to the total energy balance is taking place in August using the minimum number of wind turbines, operating in the high wind speed and satisfying the maximum energy demand.

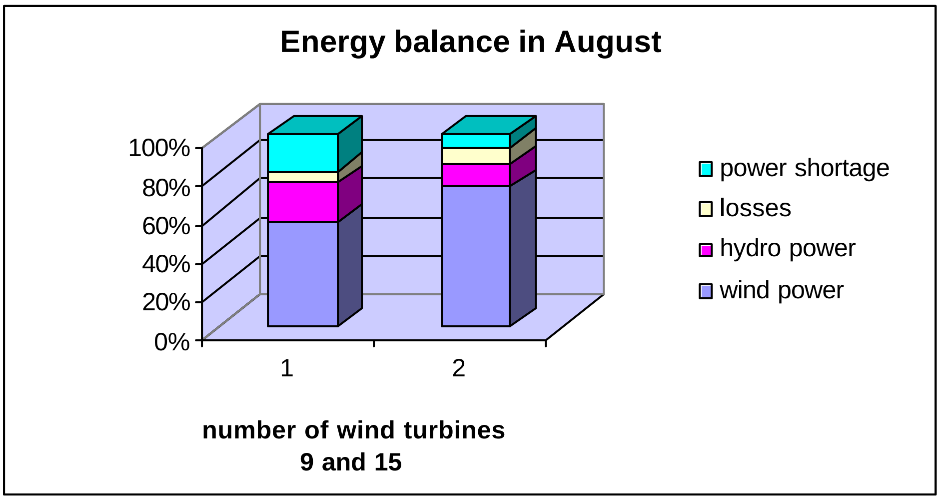


Figure 6.5: Energy balance in August

6.2 Financial evaluation

In order to comment on the feasibility of a combined wind/hydro power station in Biannos it is necessary to estimate the capital cost of the particular investment and the electricity supply to the area. The cost analysis consists of computing both capital cost and the operating cost of a combined wind/hydro power station. An assumption that the combined wind/hydro power station falls to the RES technology schemes is implying a 40% allowance provided by the European Union.

The capital cost components include:

- a wind park of 9 x 660kW wind turbines
- a hydropower plant (HPP), which consists of water turbines 2 x 2.5 MW
- a water pump station of total power 4.5 MW
- water reservoirs of capacity 285.000m^3
- Control and energy management system & SCADA
- Supervision & co-ordination

In the following table the capital cost components of the case study are presented.

Item	Parameters	Cost (Euro)
Wind farm	9 x 660 kw	5,940,000
Hydropower plant	2 x 2.5 MW	3,435,000
Water pump station	4.5 MW	1,316,000
Capacity of reservoirs	285.000 m3	2,175,000
Control and energy management system & SCADA	-	580,000
Supervisor & Co-ordination	-	970,000
Total		**14,416,000**

Table 6.2: The capital cost of investment

In order to calculate the cost of electricity supply (in euro per KWh) of the combined wind/hydro power station the 20-year repayment period and an interest rate of return 8% have been taken into account.

Initially the annual repayment is calculated:

$A = C * i (1+i)^n / [(1+i)^n - 1]$

C = 0.6 * 14,416,000 = 8,649,600 euro (40% subsidy)

i = 8%

n = 20 years

<u>A = 880,980 euro</u>

The electricity cost supply of the combined wind/hydro power station is:

c = (A +O) / E

where, A = 880,980 euro, the annual repayment

O = 200,000 euro, operating costs of the power station

E = 21,334,000 kWh, annul energy production of the power station

c = 0.05 euro/kwh

The profit from the operation of the combined wind/hydro power system is estimated more accurately taking into account the reduction of electricity supply cost in relation to the previous situation (APS station) in Biannos-area. According to the data from PPC the electricity cost for the conventional station for 2000 was 0.080 euro/kWh. Correspondingly the electricity cost for the combined wind/hydro power station is estimated at 0.05 euro/kWh. This means a relative profit of 0.03 euro/kwh.

Finally, the sensitivity analysis of the relative profit per kWh against the annual wind production, the interest rate of return and the annual operating costs is illustrated in figure 6.6.

It is obvious that the relative profit per kWh is significantly increased as the annual wind production is increased. On the other hand, the relative profit per kWh is reduced as the interest rate of return and the annual operating costs are increased.

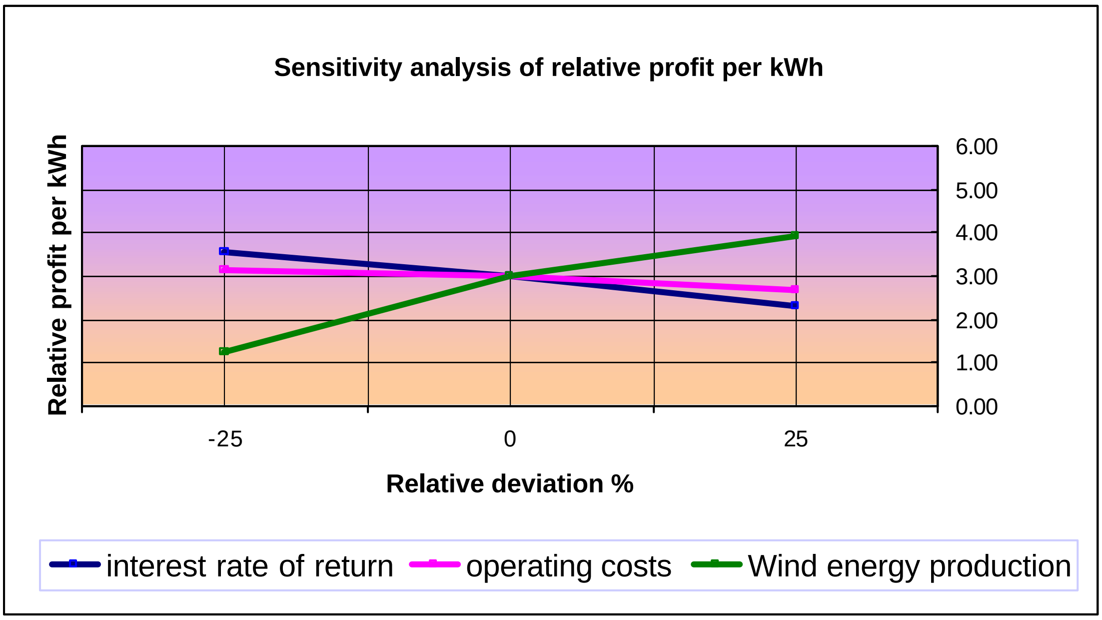


Figure 6.6: Sensitivity analysis of relative profit per kWh

6.3 Discussion

We examine with success the feasibility study of a combined wind/hydro power plant in Crete (a remote island). In order to investigate further a combined wind/hydro power plant is necessary to experiment with different case studies so we realize the complicate way of its operation. There is a list of factors that influence on effective operation or not of a combined power plant. The main factors are: the annual wind speed, the annual rainfall, the size and the stability of the grid. Apart from this there are also many other factors such as the number of days of continuing low wind speed, the size of wind and hydro plant the energy demand. It is very difficult to produce some general rules that they could be applied anywhere (any case study) due to the specific demands of each project thus it has some common characteristics. We try to examine the behavior and capability of this renewable power system.

Especially, we aim to give a response to three main questions. i) how much affect the size of the wind and hydro plant the efficient operation of the power system. ii) how much should be the wind power so the island's grid operating without problems if there is a hydro plant. iii) Finally, if a combined wind/hydro power plant should be a reliable solution for a remote island.

It is necessary to make clear that the results came from the examination of many case studies but most of them referred for remote islands and for small scale combined wind/hydro plants.

In order to find out the degree of affection of the size of the wind and hydro plants to the efficient operation of a combined power system, a wide-range of the different proportion of wind and hydro power has been used. The results of these combinations are presented in the following figures.

Initially, figure 6.7 illustrates the energy shortage and loss (during the operation of power plant) against the size of wind plant.

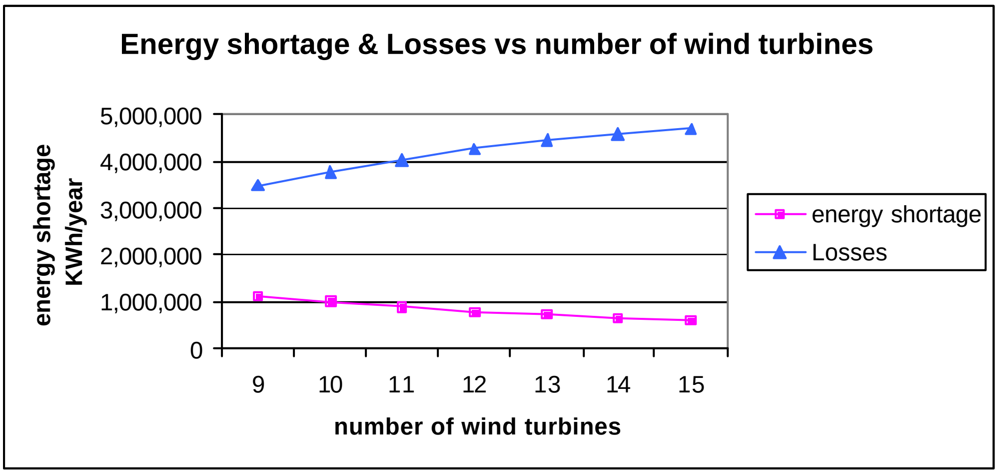


Figure 6.7: Energy shortage and losses vs size of wind farm

Moreover, the following figure 6.8 shows the number of hours in the year when the power plant doesn't produce enough energy and it doesn't cover productively the energy demand. In addition, the way of affection of the number of wind turbines (size of wind farm) to the total number of hours with energy shortage.

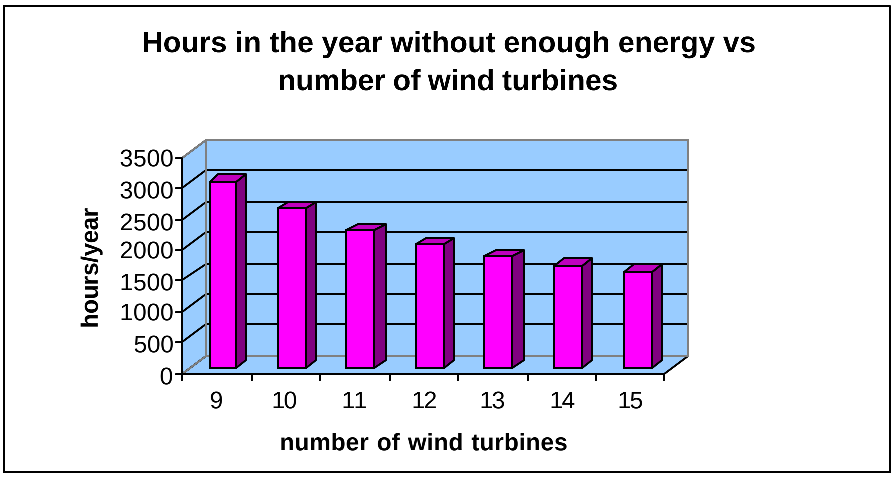


Figure 6.8: The number of hours without enough energy against to the number of wind turbines (size of wind farm)

The affection of the size of hydro to operation of the combined power plant is shown in figures 6.9 and 6.10. More precisely, they present the energy shortage during the operation of three different power plants and the best combination of (the lower power shortage) wind and hydro according to the size of hydro plant.

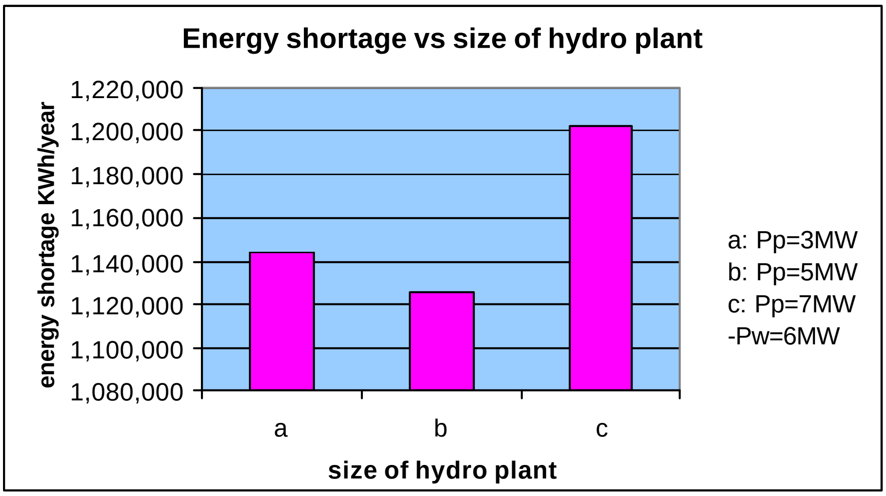


Figure 6.9: The relationship between the energy shortage and the size of hydro plant

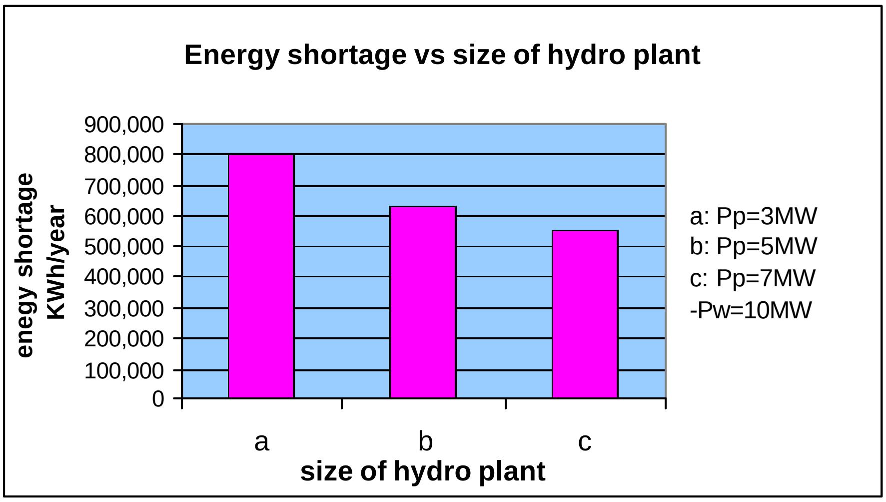


Figure 6.10: The relationship between the energy shortage and the size of hydro plant

According to the above figures the best combination of wind and hydro is the third case of the figure 6.10 that mean a wind park of 10MW and a hydro of 7MW.

It is obvious that the size of wind and hydro affects on the proper operation of a combined power plant. Apart from this, there is a list of many factors that has effects on a wind/hydro power plant. It would be an interesting project for further investigation.

A lot of combinations of wind and hydro could be used effectively but there is a range of values where the operation of a combined power plant is much more productive. According to the results of this thesis, it could be introduced the wind power of 20-40% greater than the hydro power in a remote island. It could be suggested as a general rule that could be applied in any remote island without operating problems.

Finally, a combined wind/hydro power plant could be a reliable solution for a remote island. It could not be provided 100% autonomy and the cheapest solution but using renewables as the main energy sources and the APS as the auxiliary source it would be a trustworthy solution with numerous of environmental and economical benefits.

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