INTEGRATION OF WIND AND HYDROPOWER GENERATION IN SELECTED SMALL ISOLATED ISLAND POWER GRID SYSTEM IN THE PHILIPPINES

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
HYDROELECTRIC SYSTEM ENGINEERING & MANAGEMENT

By

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CANDIDATE'S DECLARATION

I hereby declare that the dissertation, "**INTEGRATION OF WIND AND HYDROPOWER GENERATION IN SELECTED SMALL ISOLATED ISLAND GRID POWER SYSTEM IN THE PHILIPPINES**", being submitted by me in partial fulfillment of the requirement for the award of the degree of **MASTER OF TECHNOLOGY IN HYDROELECTRIC SYSTEM ENGINEERING AND MANAGEMENT** at the Water Resources Development Training Centre, Indian Institute of Technology – Roorkee, is an authentic record of my own work carried out during the period August 2, 2003 to May 30, 2004 under the supervision of Prof. Devadutta Das, Professor, WRDTC, Indian Institute of Technology – Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

Dated: June [illegible] 2004 **(RACHEL BOMBON GABUYA)**

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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RACHEL BOMBON GABUYA

ABSTRACT

The Philippine Archipelago in the Southeast Asia, due to its geography, has problems of linking its entire islands into one power grid. Some isolated and small islands have autonomous small power grid system in their locality, which are interconnected by power transmission from city to other nearby municipalities. About a hundred of these power generating plants depends on diesel or bunker oil C as its fuel. Although the diesel power plants have low front capital cost for new installation and provides steady power as base load plants, it however has several economic and environmental disadvantages such as unstable operating fuel and maintenance oil costs due to effect of volatility of crude oil price in the world market and the greenhouse gases (GHG) such as CO_2 that the fuel combustion emits. Consumer electricity prices in these islands are highly subsidized by the consumers in the main island of Luzon and the current operations are incurring losses due also to operational inefficiency of some of these old fossil fuel fired generators.

Some of these isolated island grids have sustainable alternative renewable energy resources that can provide substantial contribution to power generation in the island to meet its annually increasing electricity demand. This dissertation studies the potential application and integration of wind and hydro power system (WHPS) to selected small power grid system in Mindoro and Palawan Islands. Techno-economic analysis of the proposed system was performed using **HOMER** software to find the optimum size of each part of the wind and hydro power system such as the nominal power of the wind turbines, the hydropower contributions, remaining contribution of the grid, excess combined renewable energy production that can be utilized as deferrable load to pump water to higher reservoir and the amount of greenhouse gas (CO_2) reduced by the proposed system.

The study concludes that the proposed grid-integrated wind and hydro power system with deferrable load can contribute substantially to the present power system and is most likely to be cost effective and very attractive investment project for small isolated islands in the Philippines.

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INTRODUCTION

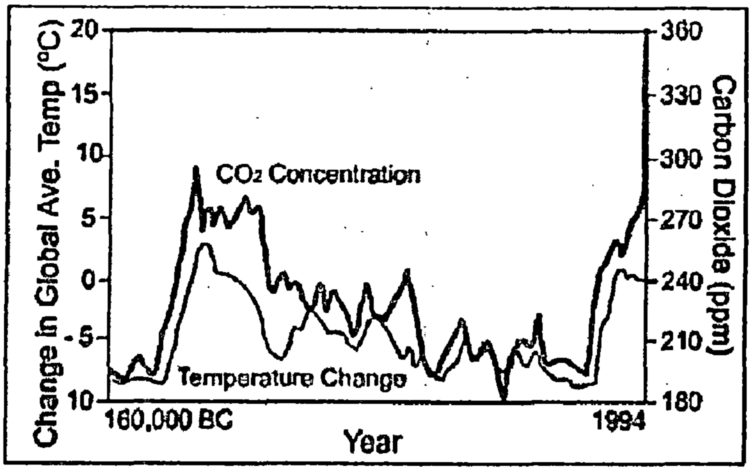
1.1 Background

According to one the most influential person and greatest physicist in the 20th century, Albert Einstein, "The world is a dangerous place to live; not because of the people who are evil, but because of the people who don't do anything about it."

NASA's Mariner 2, the first spacecraft to venture on a visit to another planet, took the first human-engineered peek at secretive Venus in 1962. In the four decades since then, the findings of 40 Venus missions – U.S. and Russian flybys, probes, landers and orbiters – have confirmed that Venus and Earth have nothing in common. In fact, our closest planet-neighbor has turned out to be the deadliest, broiling hot with sizzling temperatures, trapped in toxic concentration of carbon dioxide, devoid of water.

Magellan, the 1989 Venus Orbiting Radar Mission systematically radar-mapped the Venusian surface – with a 300-ft resolution from a polar orbit – before plunging, according to the plan, into its atmosphere. The Soviet's Venera missions measured the planet's chemical composition. Collating the data, it was found that with a surface pressure 92 times that of Earth's, Venus was choking on high levels of carbon dioxide, caused by an extreme greenhouse effect that was trapping so much heat that normal Venusian temperature ranges between 850 and 900 degrees Fahrenheit – far higher than Mercury's, the planet closest to the Sun.

Maybe it is now time to go for introspection. Will the Earth go the way of Venus? It is indeed a very frightening thought. Since the industrial revolution, civilizations have been emitting huge amounts of carbon dioxide, mostly through burning fossil fuel. Issues of climate change aggravating by pollution and eco-unfriendly practices are being debated upon. The Earth's closest neighbor is already a hothouse, inhospitable to life.[1] **Figure1-1** shows the change in global average temperature based on the level of carbon dioxide in the atmosphere until the end of 1994.

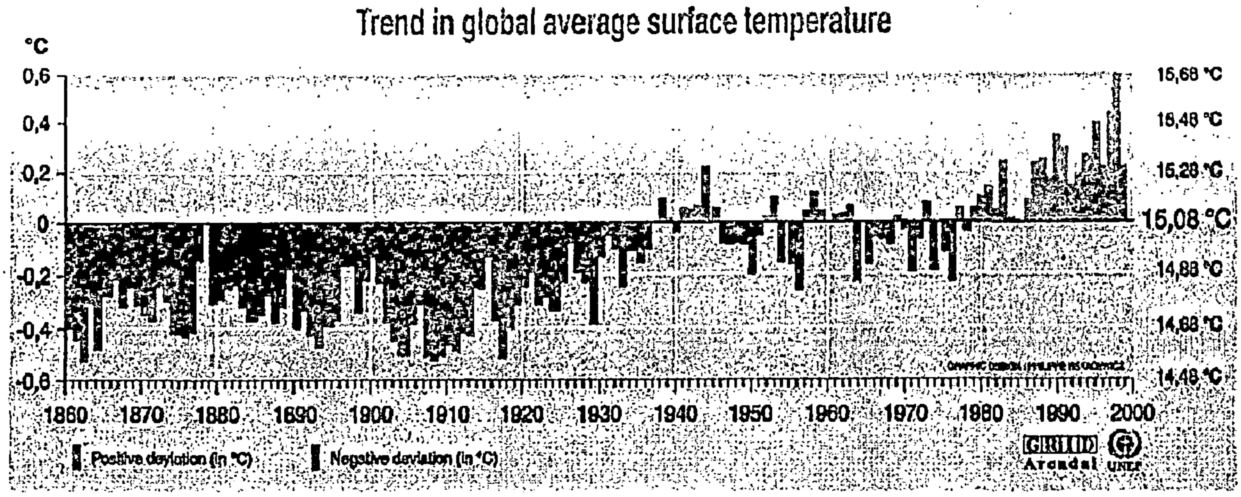


Global Temperatures and CO2 Levels. From World Watch, 1994.

Figure 1-1: Global Temperatures and CO_2 Levels

In January and February 2001, the Intergovernmental Panel on Climate Change (IPCC) met to discuss and approve the latest snapshot of Earth's climate. The role of the IPCC is to assess scientific, technical and socio-economic data in order to better understand climate change. In the summary of their findings, satellite data indicates that snow and ice cover is decreasing over the surface of the planet. The biggest reductions are occurring in the northern hemisphere, and it is likely that there has been a 40 percent decrease in the thickness of Arctic sea ice since the 1950s. As the planet warms, ice melts and water expands, causing the level of the oceans to rise. During last century, global average sea levels rose between 10 and 20 centimeters.

According to the IPCC report, emissions of greenhouse gases due to human activities continue to alter the atmosphere in ways that are expected to affect the climate. Concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), have all increased markedly during the last 200 years as a result of human activities. Ice core samples show that the atmospheric concentration of CO_2 has increased by 31 percent since 1750. Three-quarters of this increase in the past 20 years has been a result of burning fossil fuels like coal, oil and gas. It is the greatest observed increase in CO_2 for at least 420,000 years. The current trend forecasts continual growth of greenhouse gas concentrations, which will further accelerate the 'heating' of the planet.



Source: School of environmental sciences, climatic research unit, university of East Anglia, Norwich, United Kingdom, 1999.

Figure 1-2: Global Average Surface Temperature from 1860 up to 2000

Because of the negative environmental impacts of fossil fuel use, it is necessary to find ways to economically utilize non-polluting sources of energy. Worldwide, fossil fuel consumption is the largest cause of anthropogenic air pollutants such as carbon dioxide, sulfur and nitrogen oxides. These pollutants are threatening not only to those in the immediate vicinity of their generation, but also to the health of the global ecosystem. In an attempt to limit such emissions, thirty-nine countries have agreed to a combined 5.2 percent reduction of global greenhouse gas emissions by 2008-2012 in what has become known as the Kyoto Protocol (U.N. 1997). This international agreement lays the groundwork for development of environmentally sound alternatives to fossil fuel use.[2]

Rising pollution levels and worrying changes in climate, arising in great part from energy-producing process, demand the reduction of ever-increasing environmentally damaging emissions. Generating electricity utilizing renewable resources allows attainment of notable reductions. Thereby, in addition to the hydropower, a matured renewable energy technology used worldwide, the immense potentials of solar and wind energy assumes great importance. Their promise is, however, subject to time-dependent processes of nature.

The worldwide potential of wind power means that its contribution to electricity production can be of significant proportions. In many countries, the potential for wind energy production exceeds by far the local consumptions of electricity. Good prospects and economically attractive expectations for the use of wind power are, however, indivisibly linked to the incorporation of this weather dependent power source into existing distribution structures.

kWh

However, at present, large-scale wind power as an embedded generation is seen almost exclusively as producing energy (KWh) and making no contribution to other function of the power system such as voltage control, network reliability, and generation reserve of capacity.[3] For water, gas or steam turbines, and for diesel driven power stations the delivery energy can be regulated and adjusted to the needs of the end users. In contrast, the converter of a wind turbine is subject to external forces. The delivery of energy can be affected by changes in wind speed, or by machine-dependent factors such as disruption of the airstream around the tower, or grid weaknesses caused by load variations.[4]

Developing countries cannot improve their standards of living without increasing energy consumption. Using the same energy mix as is used in developed countries today, a worldwide equalization of per capita energy consumption levels to that of the United States would increase worldwide carbon dioxide emissions more than five-fold. As power capacity expands in the developing world, therefore, it is important that cleaner sources be used to address this future demand. Wind is an abundant resource that produces energy at low cost, with virtually no emissions, and is therefore likely to be an important component of future power generation in the Philippines.

The vast majority of wind power development to date has occurred in developed rather than developing countries. Some developing countries such as India and China are rapidly increasing wind capacity, but in the poorest countries there is a marked absence of utility-scale wind power development. [2]

When using renewables to power an isolated system such as an offgrid house, or an island without connection to the mainland, electricity storage is essential: the wind or sun cannot be guaranteed to do its bit when electricity is needed, and so batteries or alternative power storage systems are required. However, when renewables are integrated within a larger network the situation is very different. If renewables are to be used on a large scale then electricity storage will be required, or at least that costly adaptations to operating procedures will be inevitable. [4] This study focuses on the feasibility of integrating and hybrid development of large-scale wind power potentials with matured renewable energy technology such as hydropower on isolated small island mini-grid systems in the Philippines whose major electricity sources are fossil fuel-based generators.

Integrated operation of large-scale wind power plants with existing hydropower plants can provide significant technical and economic benefits for both technologies.[6] Analysis of the study on the evaluation of technical issues and cost impacts associated with integrating a large amount of windpower on the grid and the potential value from operating the wind plants in conjunction with the largely hydro-based power system showed there are no major technical nor cost constraints to preclude wind power from having a large share in an electric system.[7] There is a synergistic relationship between wind and hydro power. In a case study approach to assess the reliability as well as economic viability of a simple wind-hydro system using a variety of forecast configuration, the results indicate that there is a considerable synergy between the two renewable assets used in the study, as well as a considerable economic benefit to increasing short-term wind energy forecast accuracy.[8]

In Europe, several studies had been done on integration of renewable energy technologies in isolated islands, which is not connected to the mainland power grid network. Two case studies on problems concerning wind power and weak grids in Madeira, Portugal and County Donegal, Ireland revealed that sometimes the least cost and most attractive option is change in the operating strategy of the of the power system. The least cost option for the feeder studied is either grid reinforcement or a power control system based on a pumped storage if rather large amounts of wind energy are to be absorbed by the power system. The cost estimates for the two options are in the same range.[9]

Investigation indicates a possible development of a combined wind/hydro power system in Crete, a remote island of Greece, which has a great wind potential but the existing installed windpower capacity cannot be absorbed by the island's autonomous grid and the electricity cost is high. The study, which aims to produce low cost electricity and increase the penetration of the renewable energies (RES) in the grid system, concludes that the combined wind/hydro power system in Crete is an absolutely profitable investment.[10],[11],[12],[13] Studies on non-dynamic simulation of each subsystem's of a hybrid power system using medium–term pump–storage as energy storage for excess wind capacity in the islands of Ikeria and Kythos in the Aegean Sea which aim to find the optimum size of each subsystem at the lowest electricity cost conclude also that the wind/pump-storage hydro hybrid system is an absolutely profitable investment.[14],[15]. The works to develop the combined wind-hydro power station (WHPS), an innovative concept in hybrid of renewable energy technologies, which will allow the island of El Hierro (Canary Islands), Spain to be self-sufficient in renewable energy in the succeeding years, have already started. The feasibility study on the concept of WHPS reveals that with the implementation of the said project, it will be possible to cover 75% of the island's electricity demand and achieve a 30% direct wind penetration into the grid.[16]

Using life-cycle assessment, metrics for the calculation of input energy requirements and greenhouse gas emissions from utility energy storage systems have been developed and applied to three storage technologies: pumped hydro storage (PHS), compressed air energy storage (CAES), and advanced battery energy storage systems (BESS). The study revealed that change in EPR and emissions rate is relatively small when PHS is used, but is significant when CAES or BESS is utilized. CAES produces substantial emissions from the combustion of natural gas during operation, while BESS systems are highly energy intensive in the construction phase. Coupling storage and renewable energy systems can increase the per unit GHG emission rate by a factor of 2-5 times over the base rate. Even so, this emission rate is still substantially lower than fossil fuel derived electricity sources.[17]. An analysis of the performance and economic attributes of different storage systems (batteries, flywheel, SMES, ultra-capacitor, hydraulic, compressed air, hydrogen, regenerative fuel cell, mini pump storage hydro and pumped storage hydro) for wind energy integration in the grid network shows that for medium and long term energy storage systems as wind power load leveling application for local wind fluctuation and high wind capacity credit with daily or seasonal wind power variations, respectively, mini pump storage hydro from 10 kW – 50 MW and pumped storage hydroelectric from 500 – 1,500 MW have the highest efficiency of 0.87.[18],[19].

In a lesser scale study, integration micro and small hydro with other renewable energy technologies (RETs) such as wind and solar makes the hybrid power system more efficient and cost effective by eliminating some disadvantages of individual RET. However, an optimal mix of these technologies may become a complex problem of decision-making process. A concept and the rationale was proposed in this study which are necessary for developing a method for investigating the performance of hydro based renewable hybrid power system.[20]

The Philippines, due to its geography, has problems of linking all of its islands together into one grid and ensuring availability of electric power to the remaining 9,708 villages without electricity within the main island of Luzon as well as isolated small islands in the south. About 100 power generating plants of the small island power grids in the Philippines with installed capacities varying from 54 kW to 32,000 kW, depending on the islands' peak demand, and energy production ranging from 15 kWh/day to 106,000 kWh/day are owned and operated by the Strategic Power Utility Group (SPUG) of the National Power Corporation (NPC), the government's power utility agency under Department of Energy. These power plants are mostly fossil-fuel based generators and the islands' grid power systems are under missionary electrification program of the NPC-SPUG and are incurring losses due to high electricity production cost.

Small island power grids in the Philippines have been too dependent on these conventional diesel power generating sets for supply of electricity. Most of their electricity supply comes from either land-based diesel power plants or from power barges with diesel generating units. Energy planners usually recommend either land based diesel modular power plants or the flexible power barges for additional capacity build-up for island grids. However, much of these power units' fuel requirements comes from the main island of Luzon and had to be transported and stored at the local area where the small island power plants are located. This becomes too costly and fuel and oil lubrication consumptions accounts for a substantial portion of the operational cost for power generation in small island grids, thus NPC-SPUG has been incurring financial losses in their operation of small island power grids. Thus, the price of electricity for island consumers has to be subsidized by the main island grid systems consumers so as to make their price affordable to the residential consumers who are the majority users of electricity in the small island grid.

A wind resource analysis and mapping study for the Philippine archipelago was conducted and recently completed by the National Renewable Energy Laboratory (NREL) –U.S.A. to identify potential wind resource areas and to quantify the value of that resource within those areas. The wind mapping results show many areas of good-to-excellent wind resource for utility-scale applications or excellent wind resource for village power applications. More than 10,000 km^2 of windy land areas are estimated to exist with good-to-excellent wind resource potential which could support more than 70,000 MW of potential utility-scale type installed capacity of power using a conservative assumption of about 7 MW per km^2).[21] Also preliminary assessments of micro-hydro potential have been conducted in the Philippines by NREL-USA based on a few in situ measurement programs. The results indicate that a rich and well-distributed micro-hydro resource can exist, particularly in the more mountainous region of the Philippines. However, the assessment defines the total potential energy based on the flow of the entire stream, whereas in fact a micro-hydro facility will make use of only a small fraction of this energy and a future assessment had been recommended by the study group to address this issue during the workshop reviewing the result of this assessment which was conducted at the Philippine Department of Energy on October 26 – 27, 2000.[22]

An analysis of the feasibility study to estimate the potential fuel and cost savings that might be achieved by retroffiting hybrid power systems in existing diesel power plants in isolated islands in the Philippines conducted by the National Renewable Energy Laboratory (NREL) shows that wind retrofits to the existing isolated power plants in the Philippines most likely to be cost-effective for the plants providing 24-hour service, for wind speed 5.5 m/s and greater, and for fuel prices above about US$0.20 to US$0.25/liter, with some trade-off between the minimum wind speed and the minimum fuel price.[23] However, the possibility of deferrable loads, also known as productive dump loads such water pumping for energy storage which can enhance the economic advantage of a hybrid power system by utilizing the excess wind energy that is occasionally available in the system, was not considered in the study and this can be given a subsequent study and analysis.

This study will discuss the Philippines's wind and hydro energy resources potentials integration to the existing small island mini-grid systems in order to assist its future power development, especially in the isolated islands. To this end, this paper first provides overview information about world's energy and the renewable energy's contribution to power generation in Chapter 2. Chapter 3 will discuss the Philippine energy policy in relation to its development program in renewable energy and its contribution to power development in the Philippines. Chapter 4 and 5 will discuss the renewable energy technologies for wind energy and hydropower. The issues on the energy storage and its technologies will be taken up in Chapter 6. Review on wind-hydro power system (WHPS) concept model will be presented on Chapter 7. Information about the study areas are given in Chapter 8, with a description of the area's geography, demographics, wind and hydro energy potential of the sites as well as its electricity demand. Chapter 9 will provide the analysis of the results optimization process for the wind-hydro power system (WHPS) of the study area as well as the conclusion of the study.

thesi

1.2 Aims of this Study

The study on the integration and/or combined wind and hydropower generation in selected isolated small island mini-grid systems in the Philippines with specific emphasis on the possible **wind-hydro power system (WHPS)** [10],[16] hybrid concept as an alternative for power generation aims:

1. To provide the concept and develop a systematic approach for evaluating the option for diesel mini-grids with hybrids of matured renewable technologies such as wind and hydro.

2. To maximize the available identified sustainable renewable energy potentials of the study islands for integration of these in their power generation so as to augment the current electricity demand of their specific mini-grids.

3. To provide some view on the operational constraints, economic benefits and the maximum penetration of the **WHPS** concept in small and medium sized island power grid systems in the Philippines.

4. To contribute to the reduction of the **greenhouse gases (GHGs)** caused by the combustion of fossil fuels in power generation.

1.3 Wind-Hydro Power System (WHPS) Concept Study Model

The typical study model of the WHPS concept, which will be used in the study areas, can be summarized in **Figure 1-3**.

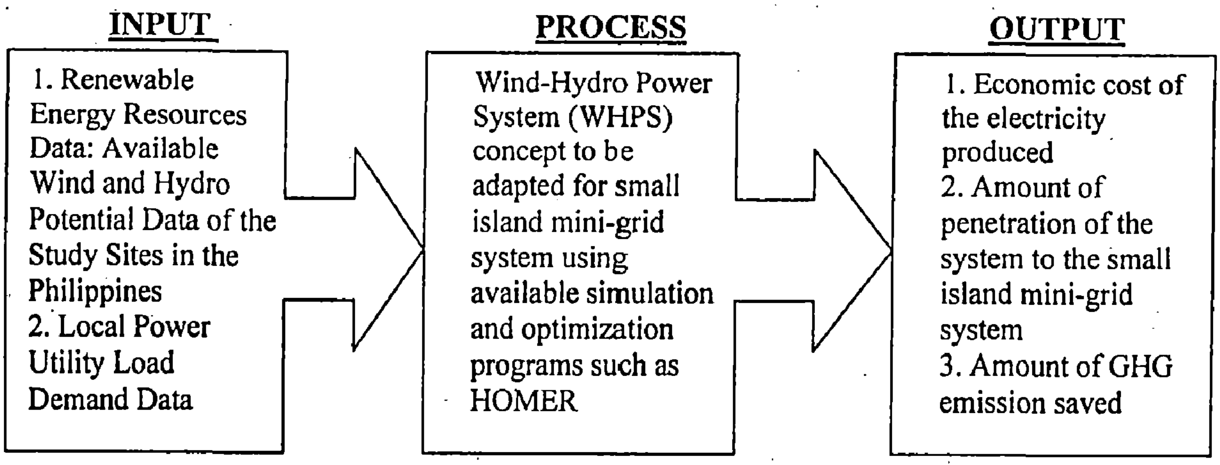


Figure 1-3: Study Model of Wind-Hydro Power System Concept

The basis for the input of the model will be the available renewable energy resources data of the study sites such as the feasibility studies of the hydropower potential capacities, streamflow data of rivers within the basin area, and the current wind speed data as provided by Department of Energy's National Power Corporation-Small Power Utility Group (NPC-SPUG), GIS technology based offshore wind speed data provided by NREL of USA in HOMER website, available data in the currently published Department of Energy's Wind Resource Atlas of the Philippines and the Assessment of the Micro-Hydro Resources in the Philippines. The data for the monthly and annual historical load demand of the study sites were provided by National Electrification Administration

(NEA) based on the Rural Electric Cooperatives monthly engineering report of electricity supply and demand.

The model's process will be the Wind-Hydro Power system (WHPS) concept. The different available hourly as well mean monthly power available from the different renewable energy resources will be simulated with the historical as well as future hourly stochastic load demand data of the study sites using HOMER software as well as Excel spreadsheets.

The model's output will be the economic cost of the different hybrid units' capacity of the system that will be committed to the small island min-grid system which has the lowest cost of energy. This will also provide the percentage of penetration of renewable energy to the mini-grid system. The output of the optimization will also assess the amount of equivalent fossil fuel saved based on converted tons of emitted CO_2 saved.

1.4 Methodology

To assess and develop the feasibility of WHPS concept for small island mini-grids in the Philippines, the study will comprises the following areas;

A. Development and analysis of the innovative concept of an alternative power generation system options, that of wind generating turbines or wind farm combining with a pump-storage hydropower as well as run-of-river hydropower system. In order to analyze this option, existing wind turbines, power generation system operation and load flow must be modified and developed to adopt it to the resources of the study areas in the Philippines.

B. Stochastic simulation of the innovative concept on the study areas with sufficient and sustainable wind and hydropower resources using HOMER and the available data for these resources for which the current grid system is currently generated 100% by diesel or bunker C fuel oil power generating system.

C. Development of the technical and economic feasibility of the innovative system for the study areas.

D. Analysis of the operation of the proposed innovative system to compare its energy production cost as against the production cost of the existing purely diesel or bunker C fuel oil power plants operating at the study area using hybrid system computer models software available for renewable resources, HOMER (Hybrid Optimization Model for Electric Renewable) [24] and the basic Excel spreadsheets.

GLOBAL ENERGY AND THE RENEWABLE ENERGY

2.1 Global Energy Overview

Energy is inseparable from matter- all material phenomena are associated with energy changes. Energy is also essential to life and human society cannot survive without a continuous supply of energy. So important is energy to human society that the magnitude of energy consumed per capita became one of the indicators of a country's "modernization". Energy is an essential component for any economic and social development of every country in the world.

Modern societies, and in particular industrial societies, are now totally dependent upon the use of large quantities of energy, most of it in the form of fossil fuels, for virtually all aspects of life. The global patterns of energy use also create problems to the modern societies. The "oil shocks" of late 1973 and 1979 awakened people and governments to the problems of continuing energy supply expansion.[27]

Two decades on, there are series of important shifts in the pattern of energy consumption and supply. Natural gas is overtaking coal as a source of energy around the world. Trade in both oil and gas as a proportion of total energy consumption is growing, and the geographical pattern of that trade is changing as economic growth, particularly in China, leads to an increase in the requirement for energy imports. The continuing development of Russian energy resources is steadily increasing production and opening up the potential for new trading links. So, too, is the development of the energy resources in the Caspian region. The growth in natural gas consumption is contributing to the shift to a lower carbon fuel mix as well as providing a further important element of security in an energy market where the sources of supply are more diversely spread than at any time over the last century. These are the trends that will shape the world's energy market over the decades ahead. [28]

Today the energy-related problems that hit the headlines most often are environmental ones. Twenty years ago it was sustainability problems; concerns that supplies of fuel such as oil and coal would run out. These concerns, of course, are still with us.

These trends indicate that, in order to comply with the necessary conditions for the three dimensions of sustainability (economic, environmental and social) with respect to energy production and consumption, a decoupling of economic activity from fossil primary energy consumption should be achieved. New and Renewable Energy Technologies (RETs) with low impact on the environment will need to play a greater role in the future energy mix in order to achieve low-carbon intensive energy systems.[29]

2.2 Global Energy Supply and Demand

In the year 2000 alone, about eighty percent of the world's energy supplies are provided by fossil fuels, with the associated emissions causing local, regional and global environmental problems. Most energy projections show that current and expected future global energy demand patterns are not sustainable.[30] Even when assuming massive improvements in energy intensity, total energy demand is also expected to increase. Long-term projections indicate that the world energy demand may increase dramatically, with most of this increase taking place in developing countries.

The main findings of the World Energy Council's 2001 Survey of Energy Resources confirm that conventional commercial fossil fuels, encompassing coal, oil and natural gas, remain in adequate supply, with a substantial resource base. Compared to the 1998 Survey, coal and natural gas reserves increased somewhat, while those of oil declined slightly. Within the total coal reserves, both sub-bituminous coal and lignite reserves declined from the previously reported levels by 15% and 3% respectively, but bituminous coal reserves increased by 2%.

Based also on the Survey, hydropower accounts for 19% of the world electricity supply, utilizing one third of its economically exploitable potential. Hydro projects have the advantage of avoiding emissions of greenhouse gases, SO_2 and particulates. Their social impacts, such as land transformation, displacement of people, and impacts on fauna, flora, sedimentation and water quality can be mitigated by taking appropriate steps early in the planning process. Whilst a question remains over the advantage of smaller hydro schemes over larger ones (owing to the former's greater total reservoir area requirement), it is believed that generally hydropower is competitive, when all factors are taken into account.

The Survey also reported a steady growth in the size and output of Wind turbines, now available with capacities of up to 3 MW for offshore machines. The support provided by national governments influences development patterns: for example, wind farms in the USA and the United Kingdom and single machines (or clusters of two or three) in Denmark and Germany. Environmental issues surrounding wind energy pertain to noise, television and radio interference, danger to birds, and visual effects, but in many cases, sensitive siting can solve these problems. Many utility studies have indicated that wind can be readily absorbed in an integrated power network until its share reaches 20% of maximum demand. It is expected that due to the rapid capacity growth in many countries and regions, global installed wind capacity may reach 150 GW by 2010, depending on political support, both nationally and internationally, and further improvements in performance and costs.

The 2001 Survey continues to report the adequacy of the world's total energy resource base and highlights the implications of environmental concerns, especially those over carbon dioxide and other greenhouse gas emissions, for each fuel. The global trend of increased energy sector competition, promoted by regulatory reforms such as privatization of public energy services, is becoming an important factor in the choice of preferred fuel in many countries and regions. [31]

Global energy consumption has more than doubled over the past four decades and, despite improvements in energy efficiency, population growth in the developing countries is expected to maintain an upward pressure on demand. World consumption of primary energy increased by 2.6% in 2002, well ahead of the 10-year growth trend of 1.4% per annum. Reported growth in energy demand of almost 20% in China was behind much of this relative strength: energy consumption in the world, excluding China, grew by less than 1% during the year, reflecting a second year of below-trend economic growth.

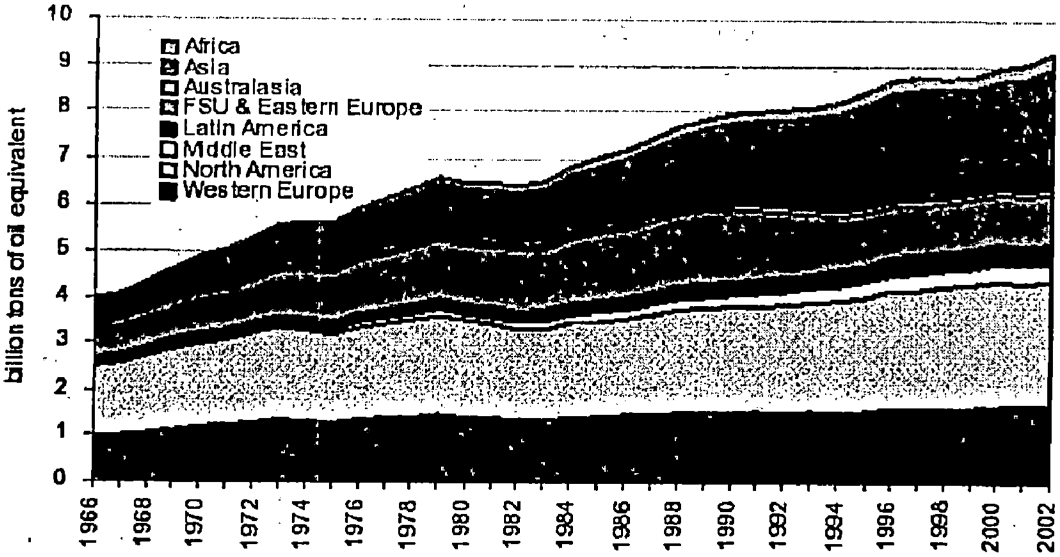


Figure 2-1: World Primary Energy Consumption by Region from 1966 to 2002
Source: BP Statistical Review of World Energy June 2003

Coal was the fastest-growing fuel in 2002 on the back of a huge 28% reported rise in Chinese consumption. World coal consumption increased by almost 7%, well ahead of the 10-year annual trend rate of less than 1%. Natural gas consumption recovered strongly to grow by 2.8% in 2002, while oil consumption was broadly flat for the second year running. Nuclear and hydroelectricity grew by 1.5% and 1.3% respectively.

By region, energy demand was especially weak in Europe and Japan, where consumption fell by 1%, and in South & Central America, where consumption was flat compared with 2001. Economic conditions explain much of this weakness. Apart from South & Central America, energy consumption growth in the emerging economies was relatively robust in 2002. Non-OECD Asia Pacific (excluding Japan, South Korea and Australasia) experienced growth of almost 11.5%, reflecting very strong growth of 19.7% in China, while Africa and the Middle East saw rises of 2.2% and 1.6% respectively.[32]

According to the *International Energy Outlook 2004 (IEO2004)* reference case of Energy Information Administration (EIA), world energy consumption is projected to increase by 54 percent over the 24-year forecast horizon from 2001 to 2025. Worldwide, total energy use is projected to grow from 404 quadrillion British thermal units (Btu) in 2001 to 623 quadrillion Btu in 2025 (**Figure 2-2**).

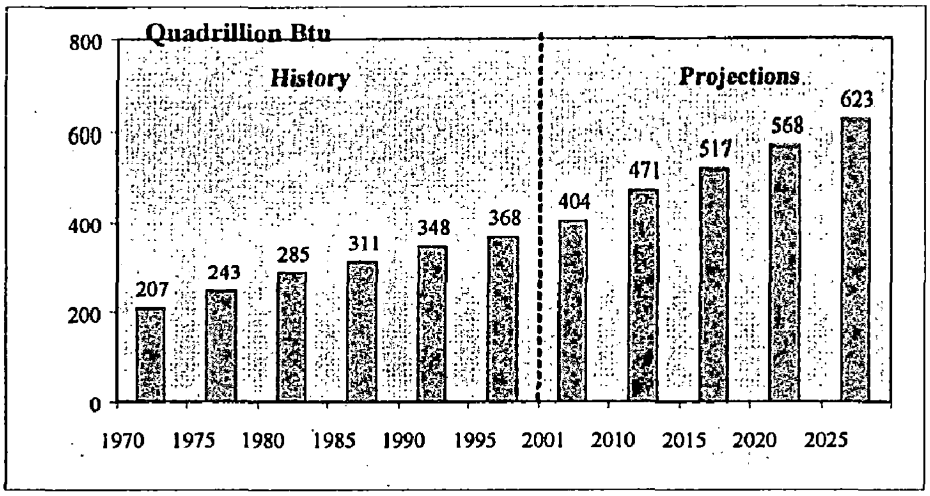


Figure 2-2: World Marketed Energy Consumption 1970-2025
Source: EIA – IEO2004

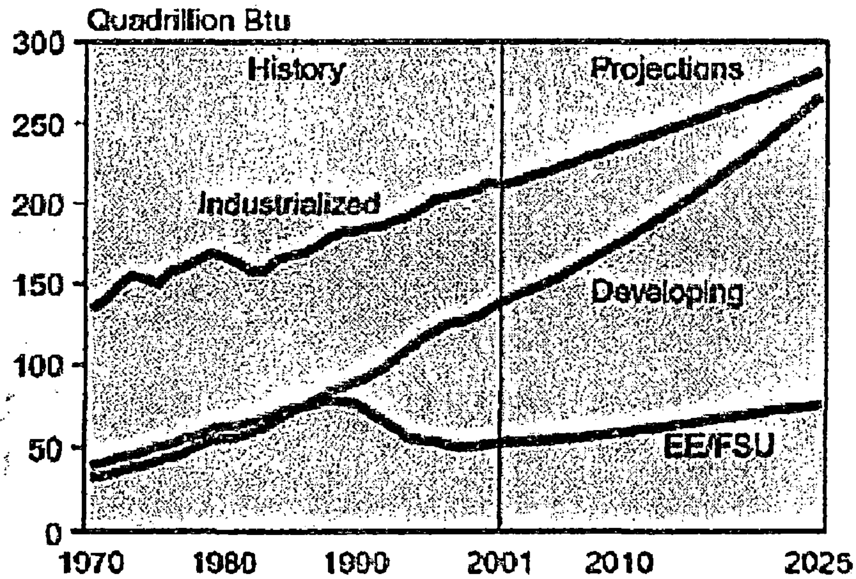


Figure 2-3: World Marketed Energy Consumption by Region 1970-2025
Source: EIA- IEO2004

The *IEO2004* reference case outlook shows strongest growth in energy consumption among the developing nations of the world (**Figure 2-3**). The fastest growth is projected for the nations of developing Asia, including China and India, where robust economic growth accompanies the increase in energy consumption over the forecast period. Gross domestic product (GDP) in developing Asia is expected to expand at an average annual rate of 5.1 percent, compared with 3.0 percent per year for the world as a whole. With such strong growth in GDP, demand for energy in developing Asia doubles over the forecast, accounting for 40 percent of the total projected increment in world energy consumption and 70 percent of the increment for the developing world alone. [33]

In contrast to the developing world, slower growth in energy demand is projected for the industrialized world, averaging 1.2 percent per year over the forecast period. Generally, the nations of the industrialized world can be characterized as mature energy consumers with comparatively slow population growth. Gains in energy efficiency and movement away from energy-intensive manufacturing to service industries result in the lower growth in energy consumption. In the transitional economies of Eastern Europe and the former Soviet Union (EE/FSU) energy demand is projected to grow by 1.5 percent per year in the *IEO2004* reference case. Slow or declining population growth in this region, combined with strong projected gains in energy efficiency as old, inefficient equipment is replaced, leads to the projection of more modest growth in energy use than in the developing world.

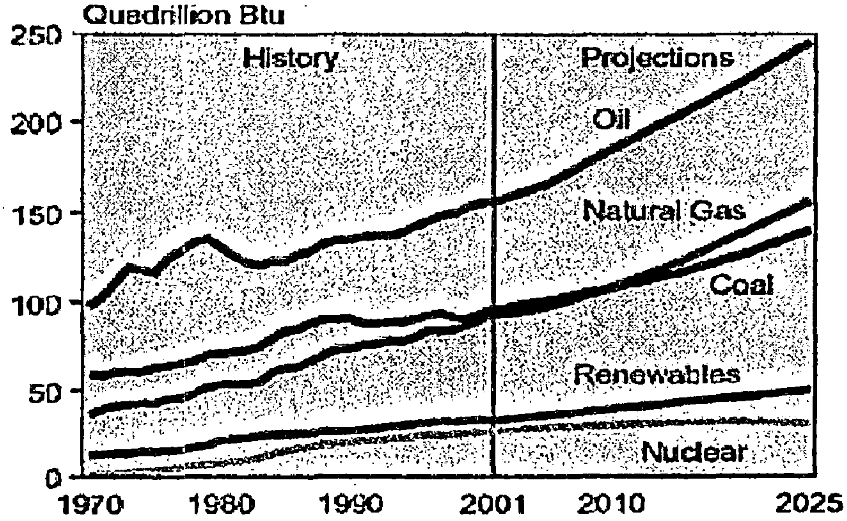


Figure 2-4: World Marketed Energy Consumption by Energy Source 1970-2025
Source: EIA- IEO2004

The *IEO2004* reference case projects increased consumption of all primary energy sources over the 2001-2025 period (**Figure 2-4**). Fossil fuel prices for electricity production are projected to remain low relative to the costs of nuclear power and renewable energy sources; as a result, non-fossil fuels are not expected to be economically competitive with fossil fuels over the forecast. The outlook for fossil fuels could, however, be altered by government policies or programs, such as environmental laws aimed at limiting or reducing pollutants from the combustion of fossil fuel consumption and encouraging the use of non-fossil fuels. In the absence of such laws, consumption of oil, natural gas, and coal is expected to supply most of the primary energy needed to meet the projected demand for end-use consumption.

Oil is expected to remain the dominant energy source worldwide through 2025. Future world oil consumption is a matter of much debate. In the *IEO2004* reference case, world oil demand increases by 1.9 percent annually over the 24-year projection period, from 77 million barrels per day in 2001 to 121 million barrels per day in 2025. Much of the increase in oil demand is projected to occur in the United States and in developing Asia. The United States, China, and the other nations of developing Asia account for nearly 60 percent of the increment in world oil demand in the IEO2004 reference case.

The projected increment in worldwide oil use would require an increment to world productive capacity of more than 44 million barrels per day over current levels. Although OPEC producers are expected to be the major suppliers of increased production requirements, non-OPEC supply is expected to remain competitive, with major increments in supply coming from offshore resources, especially in the Caspian Basin, Latin America, and deepwater West Africa. But some doubt that the Middle East can actually increase its production to meet such demand. Mr A. M. S.Bakhtiari, the senior corporate planner of the National Iranian Oil Co has stated: “OPEC simply cannot produce such amounts of crude, whatever the circumstances or the price of oil.”

Oil and gas currently account for almost 56% of energy consumption (**Figure 2-5**), with the demand for natural gas growing at a greater rate than oil, in both developed and developing countries. This trend is enhanced by the environmental benefits of gas as a cleaner-burning fuel, in a world increasingly concerned about air pollution and climate change. According to the International Energy Agency (IEA), gas consumption is expected to nearly double over the 2001-2025 period. [34]

The BP Statistical Review of World Energy reveals that the level of proved world oil reserves amounts to 1037.6x10^9 barrels, while 1997 world consumption reached

71.67×10^6 barrels per day (26177×10^6 BBL/year), and that the world oil consumption increased 2.0% from 1996 to 1997. This entirely means that the world oil reserves will end in 39.6 years (year 2037) if there is no consumption increase above 1997 levels. The oil reserves at the present tendency of 2% consumption increase per year will end in 29 years (year 2026). But if instead of increasing, as is happening now, the world consumption would be decreased by, say 2%, the same oil reserves will last for a period of 80 years. This change from 'increase' to 'decrease' consumption by a modest 2% rate would extend the oil availability from 29 to 80 years, a time gain of 51 years, equivalent to 2 generations! This extra available time should allow for a full transition of the present oil based energetic technology to renewable sources and to a just/sustainable socio-economic energy distribution.

2.3 Renewable Energy

The term 'renewable energy' can be defined in several ways:

- Energy flows which are replenished at the same rate as they are "used", adding the term renewable energy may be taken to include, more broadly, the usage of any storage reservoir which is being "refilled" at rates comparable to that of extraction.[36]

- Energy obtained from the continuous or repetitive currents of energy recurring in the natural environment.[37]

- Renewable energy are those energy flows that occur naturally and repeatedly in the environment and can be harnessed for human benefit. The ultimate sources of most of this energy are the sun, gravity and the earth's rotation. [38]

The term "renewable" is generally applied to those energy resources and technologies whose common characteristic is that they are non-depletable or naturally replenishable. [32]

Most renewable energy sources (renewables) are derived from solar radiation, including the direct use of solar energy for heating or electricity generation, indirect forms such as energy from the wind, waves and running water, and from plants and animals (wood, straw, dung and other plant wastes). Tidal sources of energy results from the gravitational pull of the moon and sun, and geothermal comes from the heat generated within the earth.

Renewable energy is very diverse, multi-faceted and in reality a number of disparate energy sources artificially brought together. The wider scope of the renewable energy utilization includes heating (domestic and commercial), power and commercial electricity production – so called primary energy. Renewables currently represents approximately 14% of the world's primary energy consumption and is growing steadily.

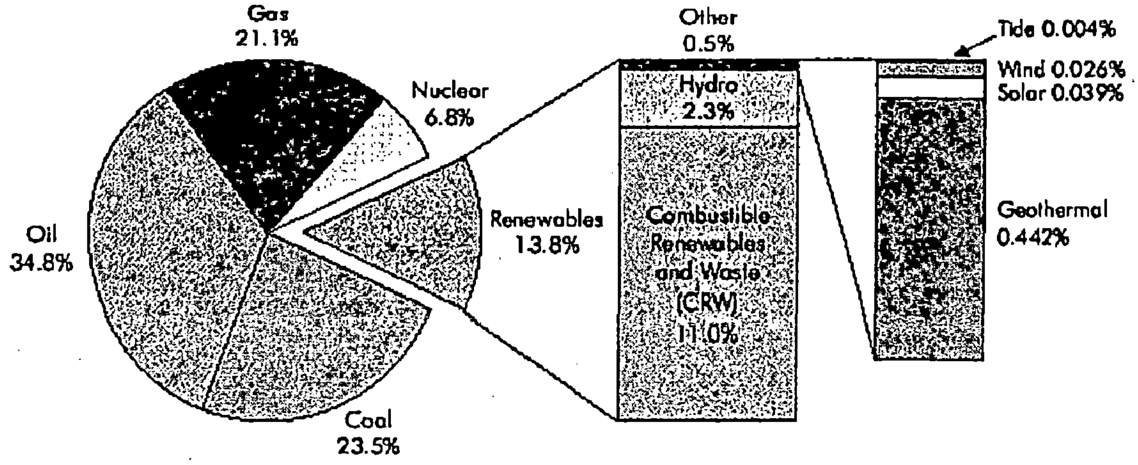


Figure 2-5: Fuel Shares of World Total Primary Energy Supply 2000
Source: IEA Energy Statistics

The figure above is based on data taken from IEA. This shows that in 2000, renewable energy took a 13.8% share of the total world primary energy supply. The figures include both commercial and non-commercial energy. The above figures show that the main component in the renewable energy share of the world total primary energy supply is combustible renewables and waste, accounting for 80% of the 13.8% renewables total. Hydroelectric power (principally large-scale) is the second largest element. Other renewable sources combine to give 0.5% of the total energy supply, with geothermal being the main segment. Although the 'other' grouping is by far the smallest component of the world energy supply, it is without doubt the fastest growing. Offshore wind renewables are growing from a small base which helps explain their tremendously high growth rate – as this base increases as new projects are brought online, the annual growth rate will begin to reduce, even though installation will remain high.

With the above statistics from the IEA it is important to note that the definition of 'primary energy supply' is wide ranging (rather than just primary electrical generation) and includes, for example, fuel for cooking and heating. Electricity generation is a major user of energy in the world. Presently electrical power generation accounts for 35% of primary energy use. It is in the area of commercial electrical power generation that renewable energy will have the most direct impact over the next five years.

2.4 Renewable Energy Sources

Renewable energy increases diversity of energy supplies and can replace diminishing fossil fuel resources over the long run. Most renewable energies use indigenous resources enhancing a country's independence from external supplies of primary fuels. Renewable energies could be a key element in providing electricity to the rural poor. Their use in place of fossil fuels can substantially reduce greenhouse gases and other pollutants.

The key growth area for the renewable energy is not within the wide definition of primary energy but within the tighter definition of commercial electrical power generation. The renewable energy sources such as biomass, hydro, geothermal, solar, and wind are forecast over the next five years to grow their annual installed capacity at a combined rate of over 25% p.a., considerably faster than the conventional energy sources of hydrocarbons and nuclear fuel. Over the period 2003-2007 total capacity additions of over 185 GW of new capacity are forecast; more than double that in the previous five-year period. The growth is more noticeable when the distorting factors of large-scale hydroelectric schemes are ignored.

Throughout the world, renewable energy is increasingly being seen as the power source of choice. Whilst it is easy to state that market mechanisms are distorting the advantages of renewables by offering incentives to encourage take-up compared with conventional hydrocarbon power generation, the reality is that in an increasing number of situations renewable energy is able to compete without subsidy. It could therefore be argued that we are starting to see a true large-scale industrial sector develop that has substantial direct and indirect benefits.

2.4.1 Biomass

The term ‘biomass’ means any plant-derived organic matter available on a renewable basis, including dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants and animal wastes. The organic carbon-based material reacts with oxygen in combustion and in natural metabolic processes to release heat. Plant or animal residues may be transformed by chemical and/or biological processes to produce intermediate biofuels such as methane gas, ethanol or charcoal.

The use of biomass energy can be separated into two categories, namely modern biomass and traditional biomass. Modern biomass usually involves large-scale uses and aims to substitute for conventional fossil fuel energy sources. It includes forest wood and agricultural residues; urban wastes; and biogas and energy crops. Traditional biomass is generally confined to developing countries and small-scale uses. It includes fuel wood and charcoal for domestic use, rice husks, other plant residues, and animal dung.

2.4.2 Geothermal

The interior of the earth is very much hotter than its surface, with estimated temperatures of several thousand degrees Celsius. The high temperature was originally cause by the gravitational contraction of the earth when it was formed, but this has been enhanced by the heat from the decay of the small quantities of radioactive materials contained within the earth’s core. There are some places where the hot rock is very near or actually on the earth’s surface and heats water in the underground aquifers. Such places have provided hot water or steams for centuries. Water or steam extracted from geothermal reservoirs can be used for geothermal heat pumps, water heating, or electricity generation. Over 20 countries in the world, such as USA, Philippines, Italy, use geothermal steam to produce electricity.

Geothermal resources are not strictly renewable in the sense that geothermal activity occurs on a much larger time scale than human lifetimes. However, they are renewable if the rate of extraction of the energy is less than the rate of replenishment of the resource. The natural recharge rates of geothermal reserves vary from a few to over 1,000MW of thermal energy. However, in current practice, all installations are exceeding the recharge rates of the resources. The geothermal resources are therefore being used in a non-sustainable manner, and are effectively being 'mined' as fossil fuels are.

2.4.3 Hydro

The most familiar renewable energy resource is hydroelectric energy, which is derived from the solar energy by means of the evaporation of water that is subsequently returned to the earth either as rainfall or snow. Hydropower is energy that comes from the force of moving water. The fall and flow of water is part of a continuous natural cycle of the earth called hydrologic cycle. The sun draws up moisture from the oceans and rivers, and the moisture then condenses into clouds in the atmosphere. The moisture falls as rain or snow, replenishing the oceans and rivers. Gravity drives the water, moving it from high ground to low ground. The force of the moving water can be extremely powerful.

Hydro-electricity is either produced by converting potential energy stored (storage dam) water held at height to kinetic energy (or the energy used in movement) by releasing it through a conveying system then to water turbine in a powerhouse at the lower part of the reservoir or storage or diverting (run-of-river) the streamflow with substantial drop of elevation or height that occurs over a distance of the river in turning a turbine in a powerhouse at the lower part of the river to produce electricity.

2.4.4 Solar

Our sun is an enormous source of energy. Solar radiation can be converted into useful energy directly using various technologies. It can be absorbed in solar 'collectors' to provide solar space or water heating at relatively low temperatures. Solar radiation can be concentrated by parabolic mirrors to provide heat at up to several thousand degrees Celsius, and these high temperatures may then be used either for heating purposes or to generate electricity. Solar thermal power stations are in commercial operation in USA. Solar radiation can also be converted directly into electrical energy using photovoltaic devices called solar cells.

2.4.5 Tidal

The gravitational forces between the earth and the moon cause them to rotate around one another in a 28-day cycle. Another result of those forces is a tidal "bulge" in the sea facing the moon, and another tidal "bulge" on the opposite side of the earth, due to the centrifugal force generated by the mutual rotation. The approach in harnessing tidal energy is to dam the estuary using a tidal barrage and use turbine to extract the ebb and/or flow of the tides. In principle, extracting tidal energy increases the friction of the rotation of the earth, and so would tend to slow its rotation over time. In practice, the amount of tidal energy which could be recovered is so small compared to the overall resource that this effect is negligible.

2.4.6 Wave

Energy produced from the motion of waves is generated by the motion of wind across stretches of water surface. The precise mechanisms involved in the interaction between the wind and the surface of the sea are complex. Because the wind is originally derived from solar energy, the energy in the ocean waves may be considered to be a stored, moderately high-density, form of solar energy.

In order to capture energy from the sea waves, it is necessary to intercept the waves with a structure which can respond in an appropriate manner to the forces applied to it by the waves. If the structure is fixed to the sea bed or sea shore then it is easy to see that some part of the structure may be allowed to move with respect to the fixed structure and hence convert the wave energy into mechanical energy, which is usually then converted into electricity. The physical size of the structure of a wave energy converter is a critical factor in determining its performance.

2.4.7 Wind

Winds are caused by differential heating of the earth's surface by the sun. The wind is indirect form of solar energy, and is therefore "renewable", that is, it is always being replenished by the sun. Every location on the planet experiences wind, but the absolute amount of wind in any one area is highly variable.

Like water flowing in a river, wind motion contains kinetic energy that can be converted to mechanical energy for driving pumps, mills, and electric power generators using wind energy conversion systems (WECS) or commonly known as wind turbines. The amount of electricity that wind turbines produce depends upon the amount of energy in the wind passing through the area swept by the wind turbine blades in a unit of time. This energy flow is referred to as the wind power density.

2.5 Power Supply and Demand

The world's electrical generation capacity has shown a steady increase from 14,388 TWH in 1998 and this is expected to continue its growth to 17,676 TWH in 2007. The main forms of power generation are oil, gas, coal, nuclear and hydroelectric. Gas has become the generation plants of choice amongst conventional power generation. In relative terms, on the other hand, the share of 'modern' renewables (excluding elements such as domestic wood burning of biomass), including large hydro, in the total primary energy supply has remained around 4% (see **Figure 2-6**).

Renewables are the second largest contributor to global electricity production. They accounted for 19% of production in 2000, after coal (39%) but ahead of nuclear (17%), natural gas (17%) and oil (8%). Most of the electricity generated from renewables comes from hydro power plants (92%) followed by combustible renewables and waste (5%). Although fast growing, geothermal, solar and wind accounted for less than 3% in 2000.

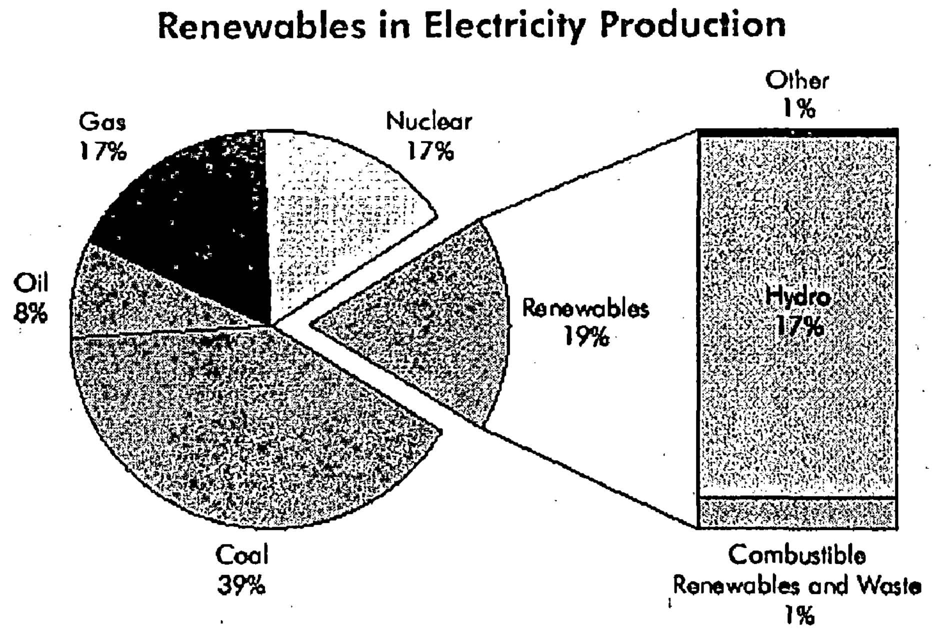


Figure 2-6: Breakdown of Renewables' Share in World Electricity Production in 2000
Source: IEA Energy Statistics

Total renewables supply experienced an annual growth of 2% over the last 30 years, almost identical to the annual growth in total primary energy supply (TPES) (see **Figure 2-7**). However, the 'other' category in the chart above (also referred to as "new" renewables and including geothermal, solar, wind, etc.) recorded a much higher annual growth of 9%. Due to a very low base in 1971 and to recent fast growing development, wind experienced the highest increase (+52% p.a.) followed by solar (+32% p.a.).[39]

Due to the high share of biomass in total renewables, non-OECD regions like Asia, Latin America and Africa emerge as the main renewables users. The bulk of the consumption occurs in the residential sector for cooking and heating purposes. When looking at hydro and other (or "new") renewables (solar, wind), OECD accounts for most of the use with, respectively, 50% and 70% in 2000. World electricity demand will almost double by 2025, growing 3.5 percent a year in developing countries from newly purchased home appliances and air conditioning.

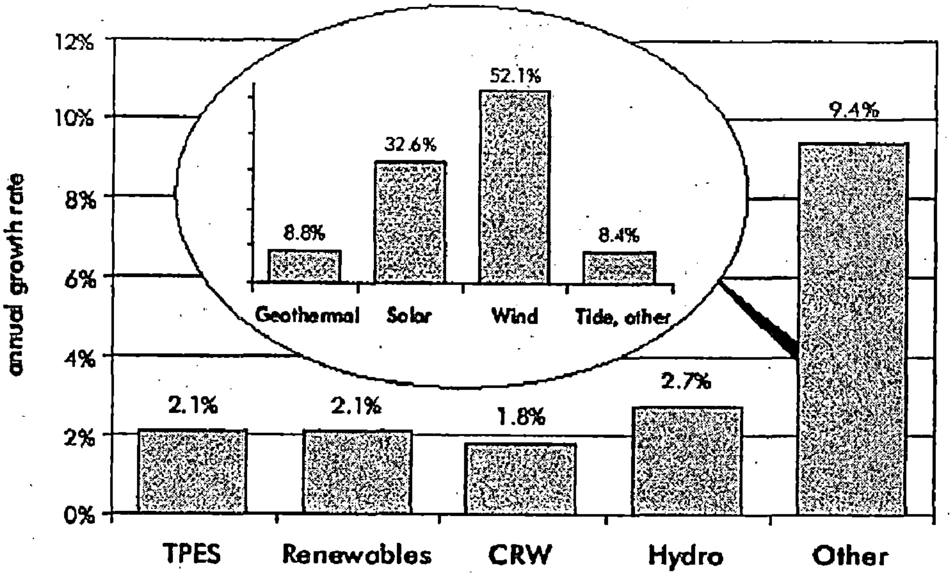


Figure 2-7: Annual Growth of Renewables Supply from 1971 to 2000
Source: IEA Energy Statistics

Power generation costs are variable depending both on project, location and externally acting factors. In the table below, a typical cost range for each power source is given, as well as an average cost for that source. Whilst traditional power sources continue to have the lowest generation costs (barring large hydro), some renewable sectors are beginning to draw close. Onshore wind is of a comparable cost to oil, coal and natural gas and, in time, we foresee offshore wind as being equally as competitive due to the economies of scale employable on these large projects utilizing multi-megawatt turbines.

Type	*Sector*	*Cost Range (Cents/kWh)*	*Average (Cents/kWh)*
Nuclear	Nuclear	1.5 - 3	2
Fossil Fuel	Coal	2 - 5	3.5
	Oil	3 - 5	4
	Natural Gas	2 - 5	3
Renewable	Onshore Wind	2.5 - 7	4
	Offshore Wind	3 - 8	5.5
	Solar	20 - 40	26
	Tidal & Current	7 - 10	8
	Wave	3 - 12	9
	Geothermal	7 - 9	8
	Biomass	2.9 - 8	6
	Small Hydro	5 - 10	7
	Large Hydro	0.5 - 2	1

Table 2-1: Typical Power Generation Costs
Source: Douglas-Westwood

Large hydro has very low generation costs, because of its huge capacity and low operational costs, but this must be balanced out against the negative environmental and sometimes humanitarian consequences of such major projects. The production costs of large-scale hydro are mainly associated with the dam construction costs.

2.6 Energy Supply Security and Sustainability Issues

World demand for all forms of energy is expected to grow by 54 percent over the next two decades, with oil consumption alone jumping by 40 million barrels a day. The strongest growth in energy use will come from developing countries, especially China and India, where buoyant economies will boost demand. Energy use in developing countries is forecast to soar by 91 percent over the next two decades, while rising 33 percent in industrialized nations.

World oil demand is forecast to rise from 81 million barrels per day (bpd) 2004 to 121 million bpd in 2025, with the United States, China, and the rest of developing Asia soaking up almost 60 percent of those extra barrels. Over the past several decades, oil has been the world's foremost source of primary energy consumption, and it is expected to remain in that position. To meet that demand, global oil production capacity would have to rise by 44 million bpd over current levels. OPEC is expected to be the major supplier of the extra oil, with the cartel's production at 56 million bpd in 2025 compared to 27 million bpd this year. Additional non-OPEC barrels will also come from offshore wells in the Caspian Sea, Latin America, and West Africa.

In the time since the 'oil shocks' in 1973 and 1979 and the recent September 11, 2001, the importance of a diversified energy base has been brought into sharper focus for most governments, as it is perceived that limited-source energy supply is inappropriate in the face of newly emerging world dangers. Whilst renewables currently only make up a small amount of world energy, their more widespread adoption could offer some peace of mind to those who normally rely so heavily upon traditional sources of energy. In August 2003 a massive power shortage on the US eastern seaboard gave prominence to the issue.

Four broad avenues are potentially open to supply the energy the world needs sustainably and affordably:

1. ***Renewable energies*** (in particular, wind, solar, wave, geothermal, modern biomass and hydrogen from non-fossil fuel sources) generally have low or no emissions and are potentially well suited for meeting the energy needs of rural populations. They are, however, typically diffuse, intermittent and relatively expensive energy sources. Considerable technological advance in collection and storage technologies is needed, as is their harnessing in hybrid systems with conventional fuels.
2. ***Conservation and energy efficiency*** are not strictly energy sources but represent substantial potential for the same task to be achieved with either less energy or to produce the needed energy with less fuel. Either way emissions can be reduced, provided that demand for the service doesn't expand because it now costs less. Energy pricing policies and public information has a critical role to play.
3. ***Cleaner fossil fuels systems*** enable us to use fossil fuels with less environmental impact. Fossil fuels currently dominate the market, because they are cheap and convenient to use. Moreover, reserves will last for a long time to come. If we can use these fuels cleanly, they can play an immensely valuable role in a sustainable energy future. Greater fuel efficiency has already led to significant emissions reductions for a given energy output. This work needs to continue, but the ultimate prize is carbon sequestration. Technological breakthroughs are needed.
4. ***Nuclear energy*** is one of the few options currently available for bulk electricity supply without greenhouse gas emissions and it is supported by ample uranium resources worldwide.

2.7 Renewable Energy Installed Capacity

The six key renewable energy sources are forecasted to grow their annual installed capacity at a combined rate of over 25% p.a. (Figure 2-10), considerably faster than the conventional energy sources of hydrocarbons and nuclear fuel. Over the period 2003-2007 a total of over 185 GW of new capacity is forecast, more than double the previous five-year period. The growth is more noticeable when the distorting factors of large-scale hydroelectric schemes are ignored.

In **Figure 2-8**, hydroelectric and onshore wind power represent 44% and 34% respectively of the bulk of new capacity being installed throughout the period 2003-2007. The marine sector is amongst the fastest growing by virtue of its emergence from virtually zero in the previous five years. A lack of currently identifiable projects, because of the nature of the young industry (many devices with high potential are only at a prototype stage), should not be taken as a sign of low potential.

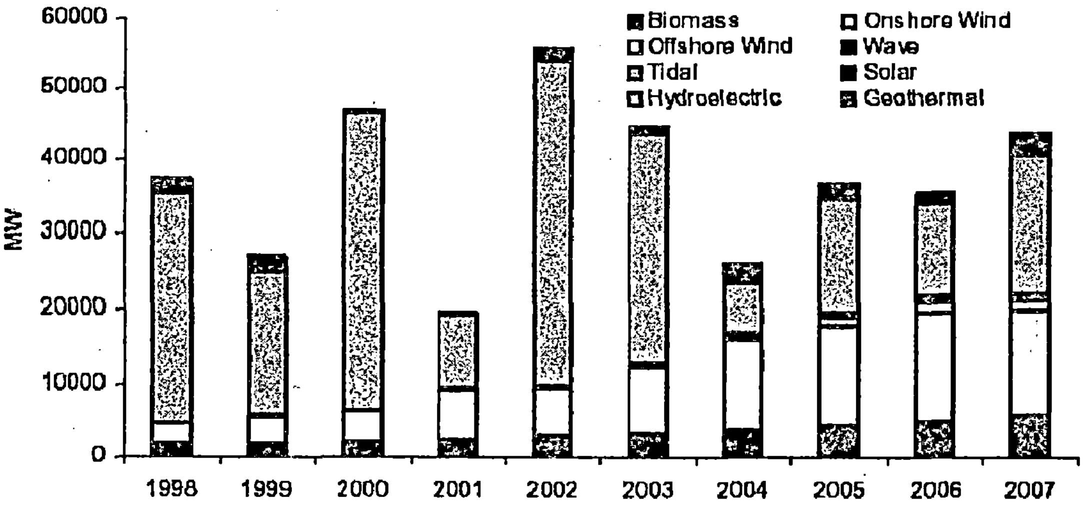


Figure 2-8: Global Annual Installed Capacity by Energy Source, 1998 - 2007

MW	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	03-07
Biomass	1,740	1,924	2,171	2,432	2,758	3,073	4,001	4,366	4,817	5,776	22,032
Onshore Wind	2,854	3,532	4,133	6,846	6,686	9,222	12,008	13,390	14,488	14,202	63,310
Offshore Wind			4	61	163	279	413	1,247	1,638	1,261	4,838
Wave	0.1		1.5		0.2	3.1	8.5	3.8	6.5	0.7	23
Tidal					0.4	0.9	1.3	12.5	0.3	12.3	27
Solar	182	124	192	271	314	393	492	576	700	972	3,134
Hydroelectric	30,373	19,595	40,128	9,504	44,060	30,376	6,501	14,840	12,308	18,418	82,444
Geothermal	2,120	1,766	77	168	1,591	1,256	2,562	1,993	1,100	2,989	9,899
Total	37,269	26,941	46,706	19,281	55,573	44,604	25,987	36,427	35,058	43,630	185,706

Table 2-2: Global Annual Installed Capacity by Energy Source, 1998 - 2007

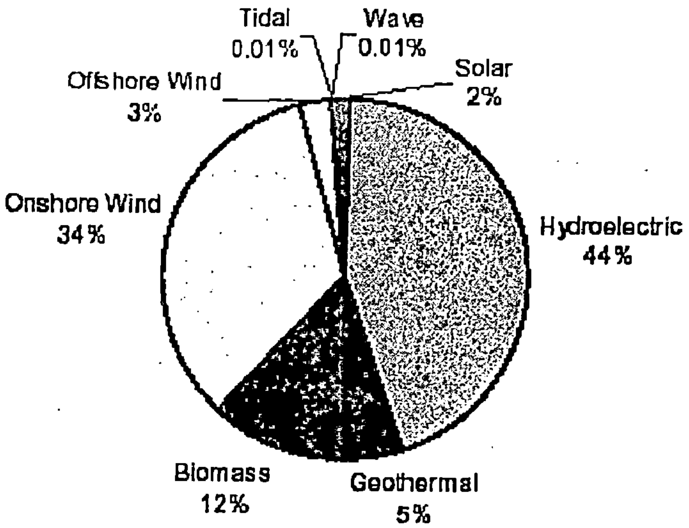


Figure 2-9: Global Installed Capacity by Energy Source 2003-2007

2.8 Greenhouse Gas (GHG) and the Kyoto Protocol

Dr. Gregg Marland of Environmental Science Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, in his seminar at US Global Change Research Program in September 16, 1996 described the history and pattern of CO_2 emissions, where they come from in the economy, and where they come from in the world. The atmospheric concentration of the greenhouse gas carbon dioxide (CO_2) is increasing, and it is increasing now largely because of the combustion of fossil fuels. Since the beginning of the fossil fuel era, over 250 billion metric tons of carbon (C) from fossil fuels had been released to the atmosphere as CO_2, and the rate of release now exceeds 6 billion tons of C per year. Prior to the fossil fuel era, the atmosphere contained about 600 billion tons of C as CO_2. From 1950 to 1990, global per capita emissions of CO_2 from fossil fuels increased by a factor of 1.8 while global population increased by a factor of 2.1. These two factors caused annual CO_2 emissions to go up by a factor of 3.7.

The USGCRP seminar provided four primary conclusions: (1) Anthropogenic emissions, dominantly from the burning of fossil fuels, are responsible for the increasing concentration of CO_2 in the atmosphere; (2) current emissions are dominantly from a small number of developed and/or large, populous countries; (3) there are wide disparities in per capita emissions rates around the world; and (4) growth rates of emissions and the potential for growth in emissions are very large in some developing parts of the world.[41]

The US Department of Energy's Energy Information Agency (US-EIA) recently released its log-term energy forecast that highlight among others that carbon dioxide emissions will rise from 23.9 billion metric tonnes in 2001 to 27.7 billion tons in 2010 and 37.1 billion tons in 2025. The developing world will account for 61 percent of the increase because of reliance on coal and other fossil fuels.

The United Nations Framework Convention on Climate Change (UNFCC, 1992) was adopted to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The Kyoto Protocol (1997) to the UNFCC establishes legally binding emission reduction targets for developed countries. They are to be reached in the period between 2008 and 2012, known as the 'first commitment period.'

Agreement on emission reductions was made conditional on the inclusion of additional instruments, commonly referred to as 'Kyoto Mechanisms'. They aim at easing the economic burden of emissions reductions by providing the means to achieve targets at lower cost. These mechanisms comprise International Emission Trading (ET), Joint Implementation (JI), and a Clean Development Mechanism (CDM).

Overall, the targets adopted at Kyoto commit industrialized nations (Annex B Parties) to reduce their emissions of a basket of greenhouse gases (GHGs), evaluated in CO_2 equivalent , by around 5 percent between 2008 to 2012 as compared to the 1990 levels. The Kyoto Protocol allows the Annex B Parties to implement their commitments by entering into a formal agreement to undertake their obligations jointly (Article 4), to transfer emission reduction units from projects within Annex B (Article 6), which corresponds to Joint Implementation (JI), or to engage in emissions trading (ET) (Article 17). In addition, a form of joint implementation between Annex B and non-Annex B Parties using the CDM was defined in the Protocol (Article 12) through which emission reductions can be earned within a non-Annex B Party and used towards meeting the Annex B Party's commitments.

Reducing emissions can be undertaken through various measures, including increasing the efficiency in the provision and end-use of energy, and a switch towards carbon-free (renewable) and less carbon intensive (e.g., natural gas) resources. Often the cheapest option with significant impact on emissions is fuel switching. The move to gas, however, has, in many cases, already been undertaken through the ongoing liberalization of energy markets. New pathways need to be sought. These may include the increase use of renewable energy. [1]

The Intergovernmental Panel on Climate Change (IPCC) has suggested that renewable energy can play an important role in meeting the ultimate goal of replacing large parts of fossil fuels, noting that "in the longer term, renewable energy sources could meet a major part of the world's demand for energy" (IPCC). This would be an accelerated 'de-carbonization' of the world's energy systems over the next century, and would require a dramatic reversal of the trend in global emissions during the last decades.

New and renewable energy sources have become attractive national energy options because of their environmental benefits as well as a means of increasing energy access in areas in the developing world that could not be served by the electricity networks. New and renewable energy technologies have occupied significant market shares in Asia since the early 1980s. In fact, some Asian countries have implemented these technologies at equivalent or higher level than developed Western countries. Most have already formulated policies for the development and promotion of new and renewable energy technologies or are in the process of doing so. China and India, for example, have designed ambitious plans and programs to strengthen the contribution of these technologies to their total energy supply. Developments in renewable energy, however, have been largely as a result of direct and indirect government intervention. **Table 2-3** presents the GHG, SO_2, NO_X and particulate matter emissions of different electricity generation options.[41]

Electricity generation option	GHG emissions (kt eq. CO_2/TWh)	SO_2 emissions (t SO_2/TWh)	NO_x emissions (t NOx/TWh)	Particulate matter emissions (t/TWh)
Hydropower with reservoir	2-48	5-60	3-42	5
Diesel	555-883	84-1,550	316+-12,300	122-213+
Modern coal power plant: bituminous coal	790-1,182	700-32,321+	700-5,273+	30-663+
Old coal power plant: lignite	1,147-1,272+	600-31,941+	704-4,146+	100-618
Oil thermal w/o scrubbing	686-726+	8,013-9,595+	1,386+	
Nuclear	2-59	3-50	2-100	2
Natural gas CC	389-511	4-15,000+	13+-1,500	1-10+
Biomass: energy plantation	17-118	26-160	1,110-2,540	190-212
Wind power	7-124	21-87	14-50	5-35
Solar PV	13-731	24-490	16-340	12-190

Source: Adapted from IEA (2000), p. 8.

Table 2-3: Environmental Emissions of Electricity Options

If the science of global warming has become a little firmer, how the world's nations will decide to respond to it has not. In March 2001, the US withdrew from the Kyoto Protocol, throwing into further doubt a mechanism, which already looked problematic. There are thus still no binding international commitments to reduce emissions. It should be remembered, however, that the parent treaty - the UN International Framework Convention on Climate Change of 1994 - still stands and commits the signatories to stabilize concentrations of atmospheric greenhouse gases "at a level that would prevent dangerous anthropogenic interference with the climate system". Thus, with or without the Kyoto Protocol, the expanded demand for energy services noted above will need to be met in ways that does not add to global greenhouse gas emissions, let alone exacerbate the various forms of localized pollution resulting from today's energy use.[42]

The World Summit on Sustainable Development (WSSD) held in Johannesburg in August 2002 considered the introduction of a global renewable energy target. The concept originated from the Brazilian Energy Initiative, which proposed an increase in the use of renewable energy to 10% of total primary energy supply by 2010. After intense negotiations, no agreement was reached to support the proposed targets. Given the complexity and costs of negotiating, enforcing and monitoring any global targets, the WSSD agreed to:

"Diversify energy supply by developing advanced, cleaner, more efficient, affordable and cost-effective energy technologies, including fossil fuel technologies and renewable energy technologies, hydro included, and their transfer to developing countries on concessional terms as mutually agreed. With a sense of urgency, substantially increase the global share of renewable energy sources with the objective of increasing its contribution to total energy supply, recognizing the role of national and voluntary regional targets as well as initiatives, where they exist, and ensuring that energy policies are supportive to developing countries' efforts to eradicate poverty, and regularly evaluate available data to review progress to this end".[43]

PHILIPPINE ENERGY POLICY AND POWER SYSTEM

3.1 Country Background

The Philippine archipelago, a tropical country in the region of Southeast Asia with a total land area of 300,000 square kilometers or 115,830 square miles, comprises more than 7,100 islands, which is divided into three major island groups. The Luzon group (106,000 square kilometers), including Palawan and Mindoro, is the largest, representing 35% land area of the country. The Mindanao group (96,000 square kilometers) in the south is the second largest and the Visayas islands in the middle part of the country is the third major island group. Some 2,800 islands are inhabited.

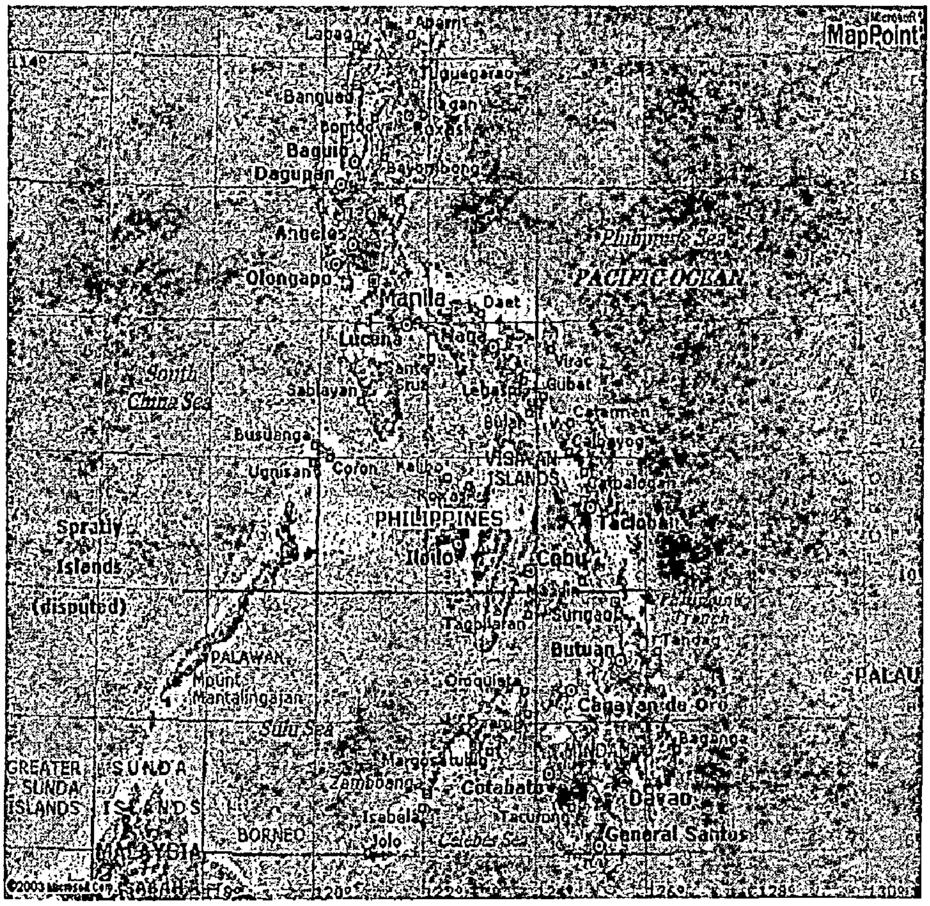


Figure 3-1: The Map of the Philippine Archipelago

Philippines has a population of 76.5 million based on 2000 national census with an estimated interim population of 84.2 million in 2004 for a population density of 281 persons per square kilometer on an average annual population growth of 2.32%. The urban to rural population distribution ratio is 40:60.

Around 25 % of the land area is flat and reasonably well-suited for agriculture. More than half of the land mass has a slope of more than 15 %. The Philippine climate is maritime-tropical with great variation in annual rainfall. In the rainy season (June-December), typhoons with wind velocities up to 250 km/h occur regularly in the northern and eastern part of the country. Rain forests (still) cover some 10,000 km2. Fishery resources (1,800,000 km2 of sea) are still abundant but declining due to poor fishing practices and over-fishing.

The annual per capita poverty threshold in 2002 was PhP 11,906 or $ 230 (based on PhP 51.67 per $1 exchange rate in 2002). The real gross domestic product (GDP) growth in 2003 was 4.5 and gross national product (GNP) growth was 5.5%. Gross domestic product in 2002 is $78.0 billion with a total external debt of $ 53.7 billion. The inflation rate in the last few years has been between 8 % and 10 %. After an extended period of stagnant or even negative growth, the last five years indicate a robust recovery with expected annual GDP growth rates of around 7 %. With 50 % of the workforce working in agriculture, forestry and fishery, which together contribute no more than 22 % to GDP, further industrialization is to be expected.

3.2 Philippine General Energy Policy

It is a declared policy of the Philippine to ensure a continuous, adequate, and economic supply of energy to ultimately achieve self-reliance with respect to the country's energy requirements. This policy is to be achieved through intensive as well as extensive exploration, production, management and development of the country's indigenous energy sources, and judicious conservation, renewal, and efficient utilization of the energy to keep pace with the country's economic development. The active participation of the private sector has been sought in the various areas of energy resource development. It is also a goal to integrate and coordinate the various programs of the

Government towards self-sufficiently and enhanced productivity in power and energy without sacrificing environmental values.

The government body that is primarily responsible for the formulation of policies in the energy sector is the Department of Energy (DOE). It is mandated by law to prepare, integrate, coordinate, supervise, and control all plans, programs, projects, and activities of the Government relative to energy exploration, development, utilization, distribution, and conservation. The DOE is endeavors to ensure that "energy must be adequate, reliable and affordable: to industries to enable them to provide continuous employment and low cost goods and services; and to the ordinary citizen to enable them to achieve a descent lifestyle. The energy should be produced and used in a manner that will promote sustainable development and utilization of the Philippine's natural resources but at the same time maintain its overall economic competitiveness.

"Economic growth with social equity." This is the thrust that underpins the Philippine energy sector's developmental blueprint. Through the years, the eradication of poverty remains a daunting challenge for the Philippine Government. To achieve the overarching objective of poverty alleviation, the DOE has formulated a well-crafted Philippine Energy Plan (PEP) 2004-2013 wherein the government's medium term plan is anchored on economic growth with social equity, including bridging the urban/rural divide. This is the energy sector's contribution to poverty alleviation and the DOE shares this vision by believing that provision of electricity is a basic ingredient in national development

Specifically the DOE's rural electrification program will provide the major impetus for the socio-economic development of rural communities in areas that still lack electricity. It is a vital component to the national government's program to reduce absolute poverty and spur economic growth. To pursue the electrification program's objective of attaining a 100 percent electrification level by 2006, the DOE will carry on with its policies and strategies as part of the PEP. These include the development and utilization of the New and Renewable Energy (NRE) sources for power and electrification and enhancing the private sector participation in all energy activities.

To meet this daunting challenge of achieving the targets set for rural power sector, the government has been proactive in seeking support from the donors and private sector. To implement the programs and projects under the PEP, a total investment of close to P2 billion will be poured into the industry in the next two decades. Bulk or 90 percent of the investment requirement will be sourced from the private sector.

3.3 Philippine Energy Supply and Demand

Philippine energy supplies come from a diversified mix of energy sources, conventional as well as new and renewable energy (NRE). Renewable energy accounted for 31% of the 45.5% or 113 MMBFOE indigenous energy provided for the actual total energy mix in 2001 excluding hydro and geothermal.

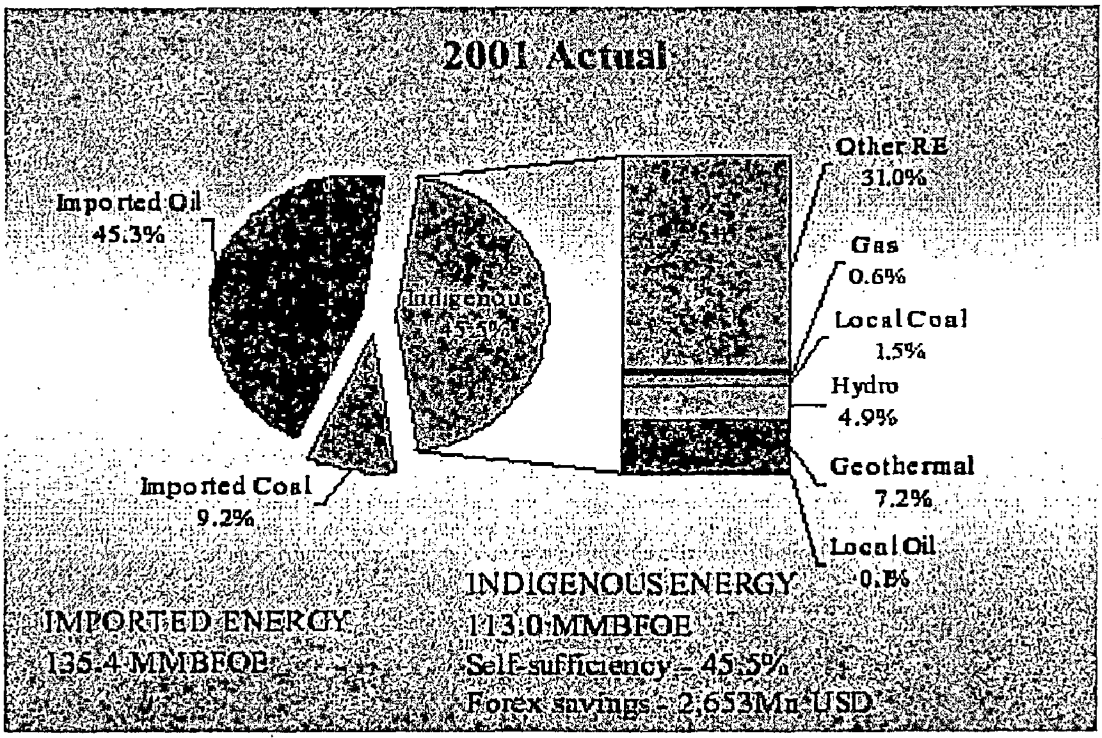
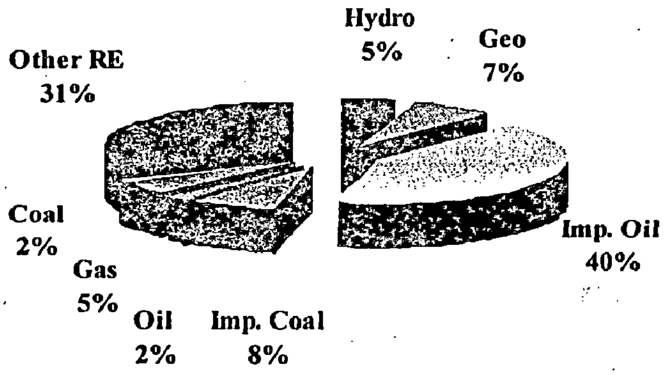


Figure 3-2: Actual Total Primary Energy Mix - 2001, in MMBFOE

However, from its 2002 and 2003 total primary energy mix of 250.8 MMBFOE and 268.16 MMBFOE, the Philippine was able to maintain a constant renewable energy level of 43% respectively. Figure 3-4 shows the primary energy mix in 2002 and 2003.


Philippine Primary Energy Mix, 2002

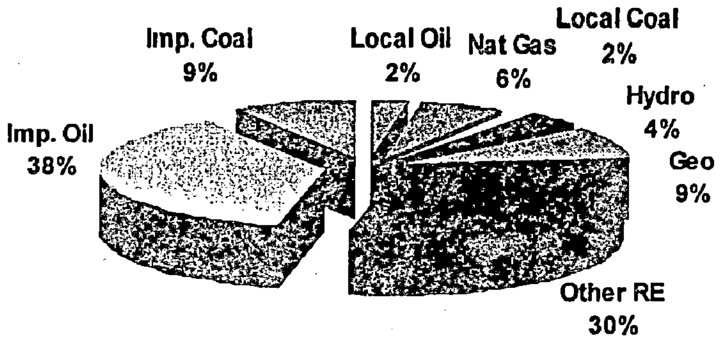

Philippine Primary Energy Mix, 2003

Figure 3-3: Philippine Primary Energy Mix in 2002 and 2003

Gross energy demand is projected to increase from 220 million barrels of fuel oil equivalent (MBFOE) in 1996 to 550 MBFOE in 2010, mainly driven by increase in fuel requirements for power generation, currently 28 %, but projected to grow to 48 % by 2010. Notwithstanding recent finds of oil and gas in Philippine territory, the Philippines will remain a net energy importer. Imported fuels, mainly oil and coal, will continue to meet the bulk of the generation requirements. The current oil dependency is forecasted to continue to decline. New and renewable energy sources (NRES) are expected to play an increasingly important role in the energy mix with a major role for geothermal, hydro and biomass (woodwastes, biogas, coconut, rice residues, animal wastes, and municipal solid wastes).

3.4 Philippine's Renewable Energy

There exist bright prospects and greater opportunities for new and renewable energy (NRE) development, utilization and commercialization in the Philippines being an archipelagic country with abundant agricultural and renewable resources and considering the fast technological developments locally and internationally. Considering the population of more than 76.5 million people in which about 50% are living in the rural areas, there exist a large potential for vast opportunities for trade and investment in the country. In addition, it has been identified that indigenous resources are largely utilized by the rural populace especially in the household sector.

Demand for environment-friendly new and renewable energy sources such solar, wind, micro-hydro and biomass is seen to go up from 72.114 MMBFOE in 2000 to 92.3 MMBFOE in 2009. This corresponds to an annual growth rate 0f 2.8%. The attractiveness of NRE for commercial and industrial application is usually weighed against the cost of using conventional fuel including the cost of delivery, equipment operation and maintenance, and the construction of waste disposal system.

3.4.1 Renewable Energy Policy

The Department of Energy issued the Philippine Renewable Energy Policy Framework last May 9, 2003. The Philippine renewable energy policy framework gears towards to;

- Diversify energy mix development and utilization in favor of or bias to indigenous renewable energy resources
- Promote wide-scale use of renewable energy as alternative fuels and technologies
- Encourage greater private sector investments and participation in renewable energy development through market-based incentives and

provide renewable energy projects “priority’ for special incentives by the Board of Investments

- Establish responsive market mechanisms for regenerated power
- Encourage to continue the use renewable energy in rural development and off-grid electrification

The rationale for the use of new and renewable energy is that this contribute to the strengthening the Philippines’ energy self-sufficiency program. Renewable energy is widely used in the government’s rural electrification program. Renewable energy also complements the government’s thrust of increased environmental awareness. The Philippine Senate in October 2003 ratified the Kyoto Protocol.

The long-term objectives of the Philippine renewable energy policy framework are;

- Increase in renewable energy-based capacity by 100% by 2012
- Increase non-power contribution of renewable energy to the energy mix by 10 MMBFOE within the next ten years
- Be the No.1 geothermal energy producer in the world
- Be the No. 1 wind energy producer in Southeast Asia
- Double the hydro capacity by 2012
- New contribution of biomass, solar and ocean by 100 MW

3.4.2 Renewable Energy Potentials

The Philippines, being an agricultural country where major crops grown are rice, coconut and sugarcane, could generate substantial volumes of residues that could be utilized as energy fuel. Data and statistics on these available NRE resources obtained from various government agencies give an optimistic picture of NRE in the future. Based on the projections of the Department of Agriculture and the Department of Environment and Natural Resources, the aggregate biomass supply potential in 2000 is equivalent to 253.8 Million Barrels of Fuel Oil Equivalent (MMBFOE) and still is expected to exhibit a modest growth of 301.5 MMBFOE in 2008. Contributors to this aggregate biomass supply potential are woodwastes, bagasse, coconut and rice residues, animal wastes and municipal solid wastes.

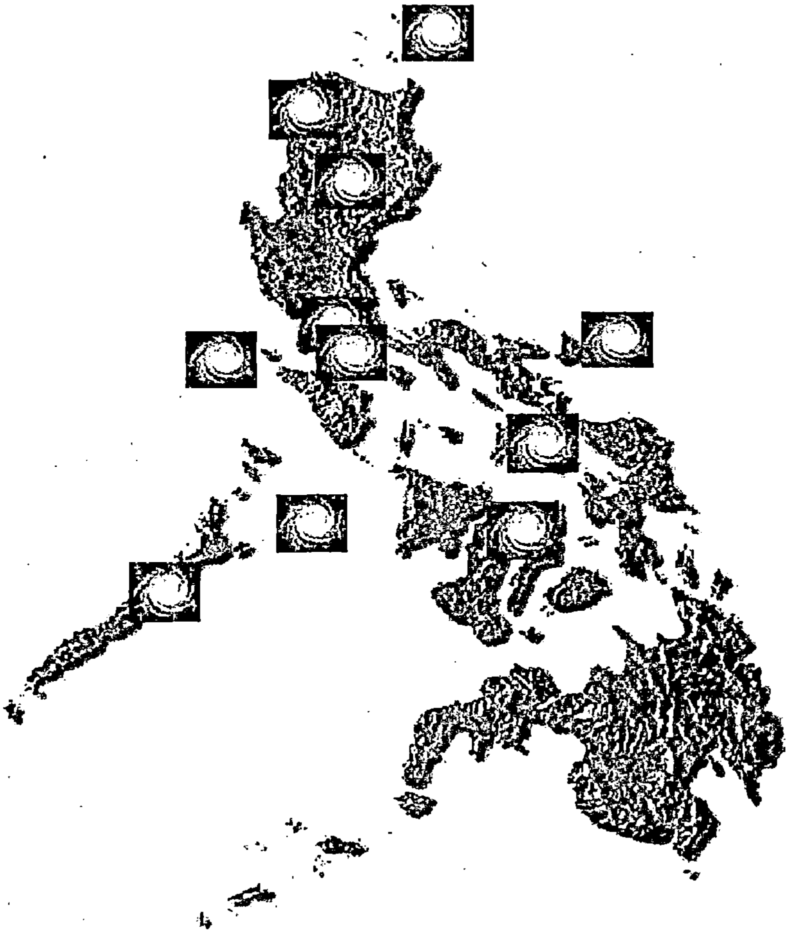


Figure 3-4: Wind Energy Potential Areas in the Philippines

The country, which is situated on the fringes of the Asia Pacific moonsoonal belt, exhibits a good potential for wind energy. The Philippine Atmospheric, Geophysical, Astronomical Services Administration (PAG-ASA) data showed that the national average mean wind power density is about 31 watts per square meter (W/m2). Moreover, the data indicated that Region I has the highest potential for wind energy applications with an annual wind power density of 88 W/m2. Other regions with good wind regimes are Regions VI, CAR, V and III. More specifically, the sites that have been identified as areas with high potential for wind energy utilization are Ilocos; Mt. Province; Cuyo Island; Basco, Batanes; Catanduanes; Tagaytay City, Lubang and Cabra Islands off the Northwestern coast of Mindoro, western portions of Batangas, Guimaras, Masbate, northeast coast of Negros Occidental and Palawan.

Being located just above the equator, the Philippines likewise has a vast potential for various solar energy applications. The country's average daily insolation is around 5 kilowatt hour per square meter per day (kwh/m^2-d). Estimated also from PAG-ASA's weather data, the country's average solar radiation based on sunshine duration is 161.7 W/m2 with a range of 128-203 W/m^2.

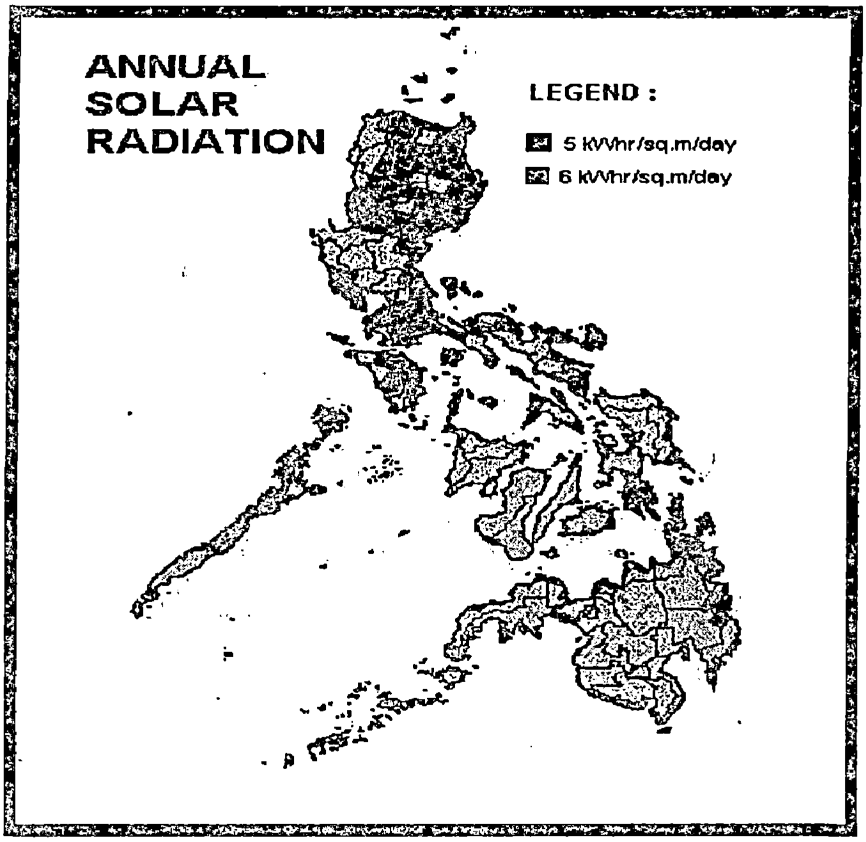


Figure 3-5: Annual Solar Energy Resources Areas in the Philippines

The country has an aggregate micro-hydro power potential of about 28 MW located in various areas of the country. Based on the regional profile of micro-hydro potential, Regions V and VIII show good prospects.

The country's ocean resource area is 1,000 square kilometers, which is attributed mainly on its archipelagic nature. Based from a study, the potential capacity for this resource is theoretically estimated to be about 170,000 MW. Although, there is very little information available on the potential of ocean energy, navigational experiences hypothesize that these systems are significant resource options. Initial ocean energy potential sites identified are Hinatuan Passage, Camarines, Northeastern Samar, Surigao, Batan Island, Catanduanes, Tacloban, San Bernardino Strait, Babuyan Island, Ilocos Norte, Siargao Island and Davao Oriental.

3.5 Philippine Power System

The Philippine power system consists of three major island grids, namely Luzon, Visayas and Mindanao; there are also several small island grids. The Luzon grid is the largest, accounting for 76.5% of total generation in 2001 and 78.5% of the installed capacity. The Visayas grid comprises the islands of Cebu, Leyte, Negros, Panay, Samar and (soon) Bohol. Together they amount to around 9.4% of total generation and installed capacity. The Mindanao grid accounts for about 13.1% of total generation and installed capacity. The small island grid accounts only for 1% of the total generation in 2001.

Luzon, which includes the capital Manila, has about 75% of national electricity demand. Prices are such that industrial and commercial customers subsidize residential customers, and the Luzon grid subsidizes those of the Visayas and Mindanao.

The Philippine power industry is divided into three major sectors: generation, transmission and distribution. Under the present power industry structure, the government-owned National Power Corporation (NPC) generates its own electricity and buys electricity from independent power producers (IPPs). However, one of the major reforms of the recently enacted power reform law, EPIRA or the Electric Power Industry Reform Act of 2001 (R.A. 9136) under Chapter 2 Section 5, the electric power industry calls for the separation of the different components of the power sectors namely, generation, transmission, distribution and supply.

Prior to 1987, electricity production was solely the responsibility and monopoly of the government-owned National Power Corporation (NPC) until the issuance of Presidential Executive Order No. 215, which opened the generation sector to private investors. Although the NPC remains the principal generator, a significant portion of generating capacity is now being operated by independent power producers (IPPs). In 1999, IPP installed capacity stood at almost 50% of total generating capacity, accounting for 50% of the total of around 40 TWh of electricity produced. As a consequence of the Asian economic crisis in 1997, projected load growth did not materialize. The result was that NPC plants are now under-utilized, with the spare capacity margin being about 50% of demand on average.

Another major reform that embodied in R.A. 9136 is the privatization of the National Power Corporation (NPC). This involves the sale of the state-owned power firm's generation and transmission assets (e.g., power plants and transmission facilities) to private investors. This reform is aimed at encouraging greater competition and at attracting more private-sector investments in the power industry. A more competitive industry will in turn result in lower power rates and a more efficient delivery of electricity supply to the end-users.

Up until 2002, responsibility for transmission still remains with the NPC. Since 1995, the NPC has allowed "open access" over the high voltage transmission system, allowing IPPs to sell directly to distributors and large industrial customers. With the passing into law of the Electric Power Industry Reform Act of 2001 also known as EPIRA, the National Transmission Corporation or TRANSCO was created which assume the electrical transmission function of the NPC. The TRANSCO assumes the authority and responsibility of the NPC for the planning, construction and centralized operation and maintenance of its high voltage transmission facilities, including grid interconnections and auxiliary services. The TRANSCO is wholly owned by the Power Sector Assets and Liabilities Management Corporation (PSALM Corp.).

Grid interconnections between the main Visayas group of islands were completed by end of 2000. The main island of Luzon is interconnected to the Visayas grid through a double circuit 350 kV DC link which now allows transport of about 480 MWe of geothermal energy from the Visayas. Another submarine HVDC link with a capacity of 500 MWe is planned to be in place by 2004 between the Visayas and the hydro-dominated Mindanao grid. Total length of power transmission line is 20,773 circuit kilometers. In addition, there are also small isolated island grids, predominantly located in the Visayas region, which are served by small diesel generators. (see **Figure 3-6**)

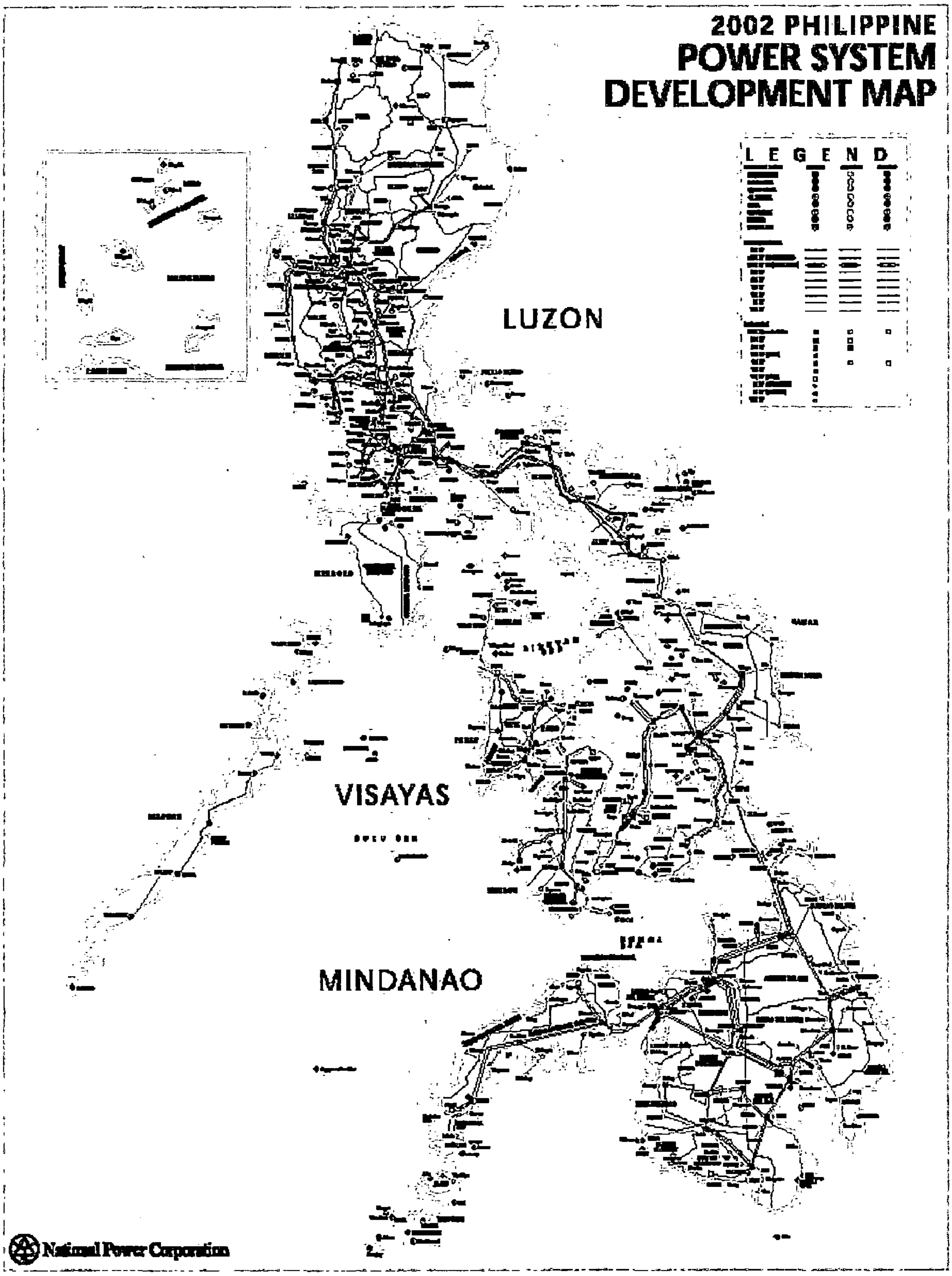


Figure 3-6: Philippine Power System Development Map - 2002

Distribution is performed by 20 private and local government owned utilities, and also by 119 rural electricity cooperatives. The largest privately owned distribution company by far is the Manila Electric Company, which distributes more than 75% of national sales. As of February 2004, about 90% of villages are electrified and connected to the main grids, and the government aims to extend electrification to all villages by 2006.

The supply sector in Chapter 2 Section 29 in the current power reform law is described as a business affected with public interest. Except for distribution utilities and electric cooperatives with respect to their existing franchise areas, all suppliers of electricity to the contestable market shall require a license from the Energy Regulatory Commission (ERC). The prices to be charged by suppliers for the supply of electricity to the contestable market shall not be subject to regulation by the ERC. However, electricity suppliers will be subject to the rules and regulations concerning abuse of market power, cartelization, and other anti-competitive behavior to be promulgated by the ERC.

3.6.1 Philippine Power Supply and Demand

The Philippine power supply system has a total installed generating capacity of 15,123 MW with a dependable capacity of 13, 262 MW and total peak load demand of 8,509 MW. The main Luzon grid has 78.5% of the total installed capacity with the highest peak load demand. Fifty percent of the installed generating powers are mostly oil and coal-based power plants with natural gas power plants contributing 18% and hydro and geothermal plants generating the rest at 19% and 13% respectively. **Table 3-1** summarizes the installed capacity by grid and plant type.

Based on the current electricity generation mix by the energy sources from 1999 to November of 2003, coal, geothermal and hydro continues to dominate the power sector with 31%, 25.23% and 20.07% respectively. **Table 3-2** provides the detail of the energy sources mix in electricity generation.

Grid	Installed Capacity (MW)	Dependable Capacity (MW)	Peak Demand (MW)
Luzon	11,871	10,519	6,454
Visayas	1,579	1,423	1,006
Mindanao	1,673	1,320	1,049
Total	15,123	13,262	8,509

Plant Type	Installed (MW)	% Share
Oil-based	3,607	24
Hydro	2,885	19
Geothermal	1,910	13
Coal	3,958	26
Natural Gas	2,763	18
Total	15,123	100

Table 3-1: Philippine Power Installed Generating Capacity and Plant Type (as of December 31, 2003)
Source: DOE-NPC

Philippines	1999		2000		2001		2002		2003	
	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%
Hydro	7617	19	7.49	18	7035	16	6530	17	7812.35	20.07
Oil Thermal	5392	14	2550	6	3527	8	941	2	4718.05	12.12
Coal Thermal	11276	29	15607	39	16881	39	14018	37	12067.33	31
Diesel	2270	6	1976	5	3397	8	2497	7	-	-
Geothermal	10638	27	11331	28	10458	24	9974	26	9822.44	25.23
Gas Turbine	52	0	36	0	64	0	37	0	4505.05	11.57
Combined Cycle	2083	5	1521	4	1801	4	3709	10	-	-
Total NPC & IPP	39328		40370		43163		37706		38925.82	
IPP	18532	47	20141	50	22885	53	21345	57		

Table 3-2: Philippine Electricity Generation Mix 1999 – November 2003
Source: DOE, NPC, TransCo

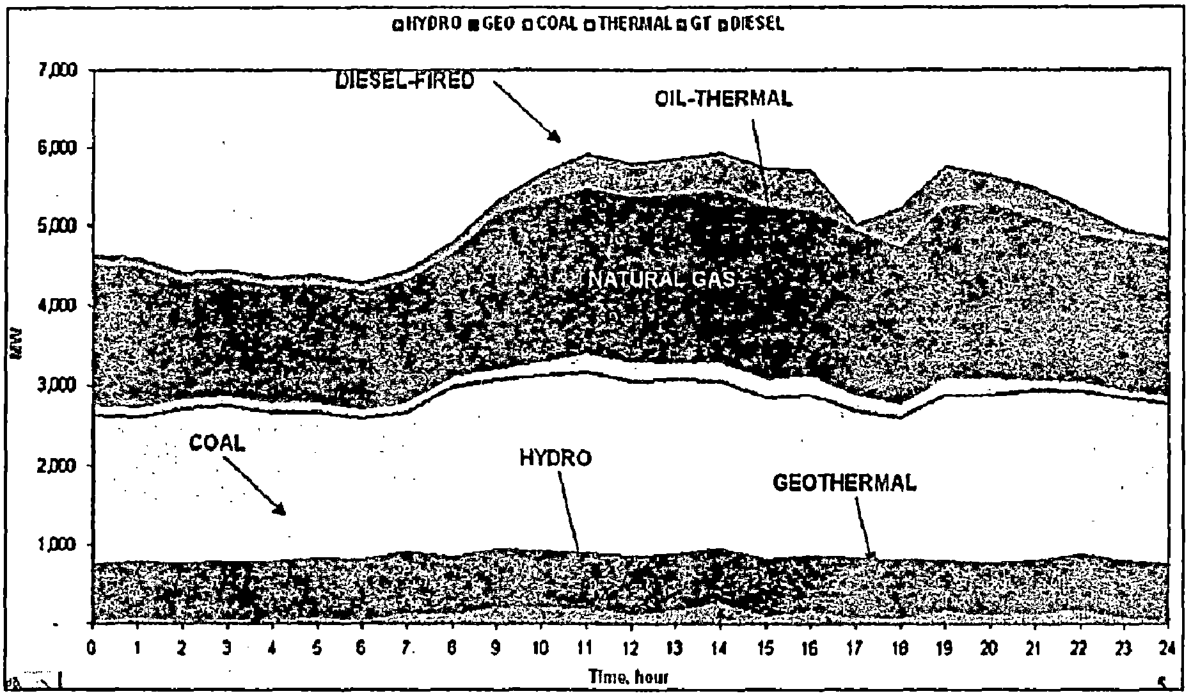


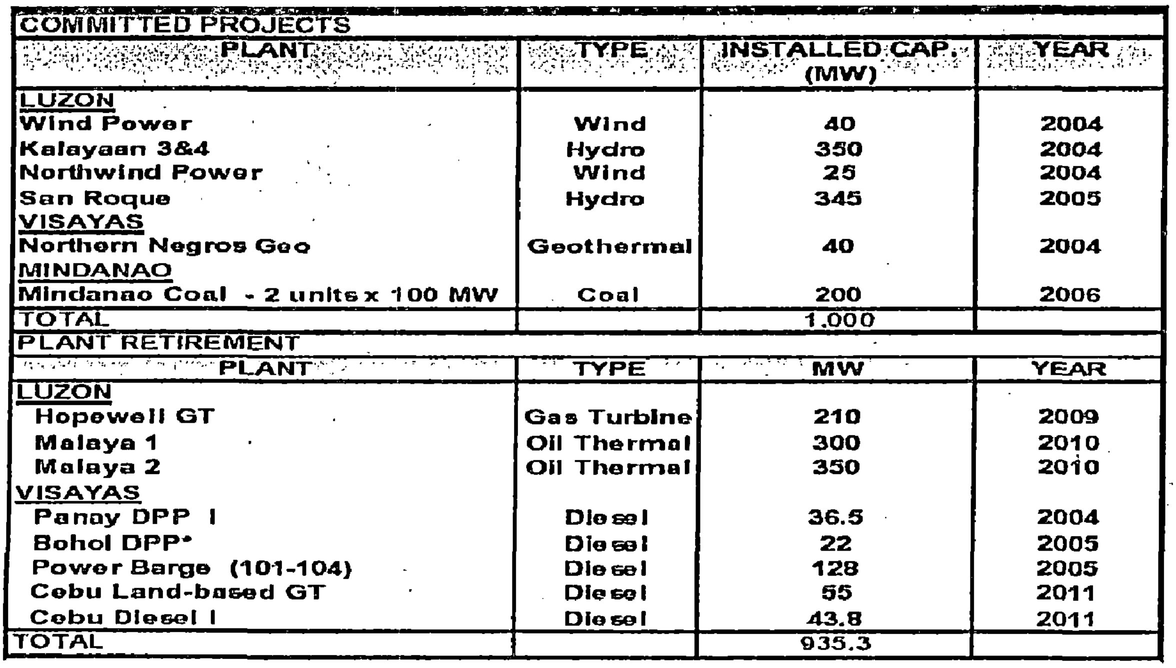
Figure 3-7: Typical Philippine Luzon Grid Power Daily Load Curve
Source: DOE-NPC, Transco

Based on the 5.4 percent growth rate set by the National Economic and Development Authority (NEDA), the country's demand for electricity will correspondingly increase by around 7.6 percent a year. Increasing penetration of electrical appliances in Philippine households, rising population and expansion of economic activities will propel a strong growth in the electricity consumption. Growth rates will remain high in the Visayas and in the Mindanao considering the high economic growth potentials in these areas while Luzon will continue to account for the highest levels in absolute values in the view of its high demand base.

The Philippines has a large gas field some 500 km off-shore from Luzon. Gas-fuelled generating plants are under construction, and a gas pipeline from the Malampaya gas field in Palawan island is expected to be operational by 2002. By about 2003, good fuel diversity is expected to be achieved between hydro, coal, gas, oil and other sources (e.g. geothermal, wind, etc.). The Philippines is the world's second largest producer of geothermal power, after the USA.

Year	Total	Residential	Commercial	Industrial	Transport	Others	Utilities/ Own Use	Power Losses
1991	25,649	6,249	4,847	9,339	-	952	1,086	3,176
1992	25,870	6,053	4,910	8,859	-	823	1,154	4,071
1993	26,579	6,368	4,725	9,395	-	721	1,132	4,238
1994	30,459	7,282	5,865	10,684	-	762	1,132	4,734
1995	33,554	8,223	6,353	10,950	-	1,067	1,226	5,735
1996	36,708	9,150	7,072	11,851	-	1,167	1,340	6,128
1997	39,796	10,477	7,984	12,531	-	1,296	1,471	6,037
1998	41,577	11,936	8,725	12,543	-	934	1,590	5,849
1999	41,431	11,875	8,901	12,444	-	921	1,536	5,754
2000	45,289	12,894	9,512	13,191	-	957	2,390	6,345
2001	47,048	13,547	10,098	14,452	-	1,042	2,196	5,713
2002	48,468	13,715	10,109	13,628	63	1,110	3,873	7,915

Table 3-3: Electric Energy Consumption by Sector, 1991 - 2002 (in million kilowatt-hours)



COMMITTED PROJECTS			
PLANT	TYPE	INSTALLED CAP. (MW)	YEAR
LUZON			
Wind Power	Wind	40	2004
Kalayaan 3&4	Hydro	350	2004
Northwind Power	Wind	25	2004
San Roque	Hydro	345	2005
VISAYAS			
Northern Negros Geo	Geothermal	40	2004
MINDANAO			
Mindanao Coal - 2 units x 100 MW	Coal	200	2006
TOTAL		1,000	
PLANT RETIREMENT			
PLANT	TYPE	MW	YEAR
LUZON			
Hopewell GT	Gas Turbine	210	2009
Malaya 1	Oil Thermal	300	2010
Malaya 2	Oil Thermal	350	2010
VISAYAS			
Panay DPP I	Diesel	36.5	2004
Bohol DPP*	Diesel	22	2005
Power Barge (101-104)	Diesel	128	2005
Cebu Land-based GT	Diesel	55	2011
Cebu Diesel I	Diesel	43.8	2011
TOTAL		935.3	

Table 3-4: Philippine Committed Power Projects and Plants for Retirements

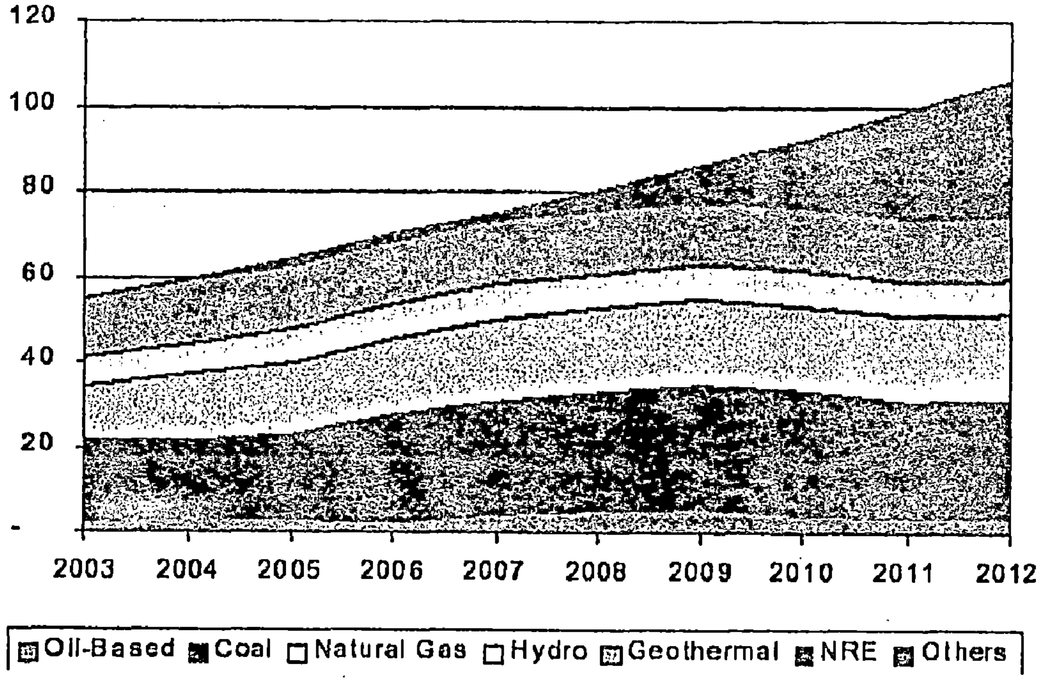


Figure 3-8: Total Philippine Power Generation Forecast, in TWh

Since most of the new demand will come from Luzon, the Philippine Energy Plan (PEP) assumes that 5,190 MW must be added to the Luzon grid. The Visayas and Mindanao will need 990 MW and 970 MW, respectively. The PEP identifies at least six projects in different stages of implementation that will generate an additional 1,000 MW for the Luzon grid. These include a 25-MW wind power plant of Northwind Development Corp., the subsidiaries of state-owned Philippine National Oil Co., and 345-MW San Roque hydro power plant in Pangasinan. In the Visayas and Mindanao, committed projects within the next three years include: the 40-MW Northern Negros geothermal power plant in Negros Occidental and a 200-MW coal-fired plant in Northern Mindanao.

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WINDPOWER

4.1 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. The sun warms the Earth's surface by variable amounts at different locations, thereby creating differential pressures which initiate air motions. Thus, wind is a manifestation of solar energy. Heating is greatest at the equator, and, in the upper layers of the atmosphere, air flows away from the equator. In the northern hemisphere, the *Coriolis Effect* continuously forces air to the right of its current motion (the opposite is true in the southern hemisphere).

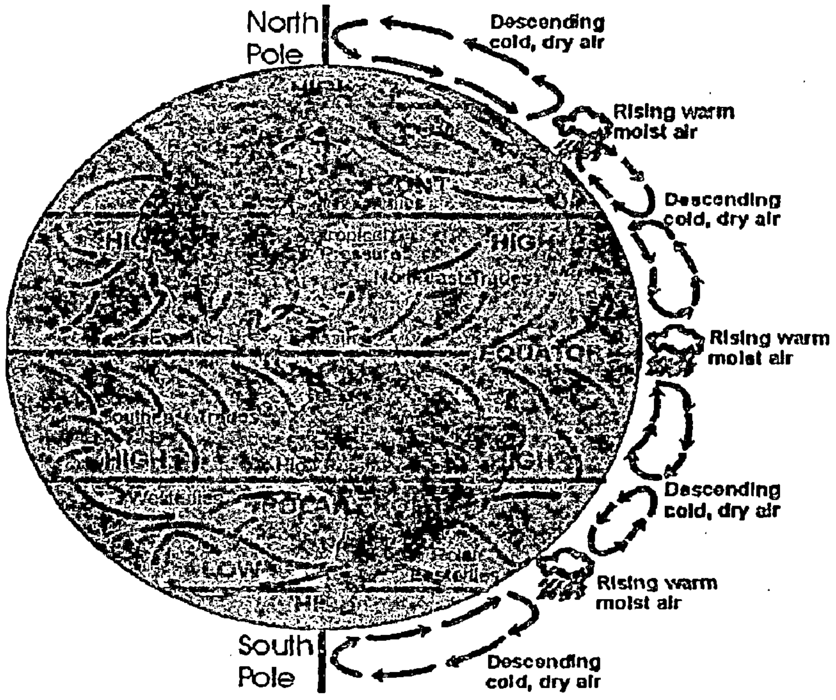

Figure 4-1: Simplified Representation of Global Wind Circulation

At about 30° latitude, the air moving northward from the equator in the upper atmosphere descends to the lower levels and forms a zonal latitude region of high surface air pressure. There are other large-scale circulation structures between 30° and the poles as shown in **Figure 4-1**. These high-altitude airflows above about 1-3 km are not affected by frictional forces induced by interactions at the Earth's surface.

Surface winds (below about 1-3 km) are very much influenced by the Earth's surface roughness and obstacles. Mountains, valleys and other topographic features can concentrate and increase wind velocities. Mountain-valley winds are created when cool mountain air warms up in the morning and, as it becomes lighter, begins to rise: cool air from the valley below then moves up the slope to replace it. During the night the flow reverses, will cool mountain air sinking into the valley. At a seacoast during the day, air expands and rises over hotter land surfaces and flows out to sea in the upper atmosphere, and air at lower levels moves from the sea to the land, producing a cool "sea breeze." At night, the flow reverses, and the prevailing shore winds near the surface blow from land to the sea.

Humanity arguably has more cumulative experience with wind power than any other energy source. Wind energy is one of the first non-animal sources of energy to be exploited by early civilization. For millennia prior to the invention of external and internal combustion engines and electricity, wind power was the only viable form of power for ocean going vessels, and the only source of energy for large mills and water pumps in many parts of the world. Despite the vagaries of wind - its unpredictability and the occasional violent storm – its energy was harnessed for sail and other applications and made sufficiently dependable and economical, so that empires were built upon the results. A base of knowledge and expertise, and near perfection in the application of it to marine propulsion, made it commercially competitive against steam and diesel marine propulsion well into the 20th century.

Wind energy offers the potential to generate substantial amounts of electricity without the pollution problems of most conventional forms of electricity generation. Wind energy power generation harness the energy in wind to drive electric power generators. This is done using some form of windmill or a wind turbine, or any of the several other types of devices that are essentially similar in operating concept. The advantages of wind generation are: there is no fuel charge; it is non-polluting; units are modular with a fairly linear power vs. cost relationship for large-scale installation, and unlike solar conversion, it is potentially a 24-hour per day source of energy. The disadvantages are high initial cost, unpredictability of energy production, no viable thermal storage system such as solar thermal, and environmental impacts generally considered to be greater than solar power's.

4.2 Wind Energy

Wind is simply air in motion. Air's invincibility and omnipresence tend to make many people overlook its very considerable potential power. This is the kinetic energy of air in motion, equal to one-half (½) its mass times its velocity squared. Wind moving at 11.8 meters per second (26 mph) carries 1 kW (one and one-third horsepower) of energy per square meter of cross-section.

The energy contained in wind is proportional to the cube of wind speed. The wind's kinetic energy varies as the square of its speed (i.e., energy = $\frac{1}{2}mv^2$), and the mass of air passing any point is proportional to wind speed, so the mass doubles as wind speed doubles. Therefore, in total, if wind speed doubles, the energy increases by a factor of eight. Thus, wind at 5.9 meters per second (13 mph) carries only one-eight the energy of wind at 11.8 meters per second (26 mph), or only 125 watts per square meter.

Wind energy conversion systems removes energy from the wind by literally slowing it down, collecting the difference in "before and after" kinetic energy. Wind is an elastic fluid. Slowing it completely would be self-defeating for any wind turbine, sail, or other energy conversion medium. It would mean no mass was in motion past the turbine rotor blades, and that the energy collected was zero. Thus, energy is extracted from the wind when it is slowed, but not stopped. The maximum energy is extracted when it is slowed to 1/3 of its speed, which robs the wind of 59% its energy.

One difficulty in harnessing wind energy conversion is that the wind speed is not completely predictable, making it impossible to depend upon it entirely, or to commit to a production schedule or firm power sales contract. As a result, wind energy is often labeled as a "non-dispatchable" resource: utility owner has to take whatever power is available, when available.

4.3 Power Extracted from Wind Energy

The power in the wind can be computed using the concept of kinetics. Power is the energy delivered per unit time. The available energy is the kinetic energy of wind in motion. Based in previous section, the kinetic energy (K.E.) of any particle is one-half of the product of its mass (M) and velocity (v) squared.

$$\text{K.E.} = \frac{1}{2}M(v)^2$$

Mass, M can be replaced by the product of density ρ and volume (Vol). The volume in turn, can be replaced by the distance covered by a vertical layer of wind and its cross-sectional area. If we assume 'dist' to be the thickness of the layer of wind passing through the WTG,

$$\text{K.E.} = \frac{1}{2}\rho(\text{Vol})(v)^2 = \frac{1}{2}(\text{dist})(\text{area})(v)^2 \ldots\ldots 4.1$$

$$\text{K.E. for blade area A} = \frac{1}{2}\rho A(\text{dist})(v)^2 \ldots\ldots 4.2$$

$$\text{Power, } P_W = \frac{\text{K.E.}}{\text{Time}} = \frac{1}{2}\rho\left(\frac{\text{dist}}{T}\right)A(v)^2 = \frac{1}{2}\rho A(v)^3 \ \textit{watts} \ldots\ldots 4.3$$

Here we consider the velocity v to be the distance covered in time T.

Where,

$\rho = 1.2$ kg/m^3 (density of air)

A = wind turbine blade sweep area in m^2

v = wind speed in m/sec

Since, we have already found an expression for power available in the wind (egn. 4.3). Now we would like to know how much of the energy in the wind can be extracted by an ideal WTG. After deriving several equations on the energy extracted, W_T from the wind, which is the difference between the kinetic energies in the wind upstream and downstream, the maximum extractable power can be summarized as,

$$P_{max} = \left(\frac{1}{4}\right)\rho A\left(\frac{4}{3}v\right)\left(\frac{8}{9}v^2\right) = \frac{8}{27}\rho Av^3 \quad \text{.......... 4.4}$$

P_{max} is a quantity which varies with the speed of the incoming wind.

But based on equation 4.3,

Power in wind for area (A), $P_a = ½\rho Av^3$

Therefore, according to Albert Betz, the maximum wind turbine output is

$$P_{max} = \left(\frac{16}{27}\right)\left(\frac{1}{2}\rho Av^3\right) = \frac{16}{27}P_a = 0.593P_a \quad \text{.......... 4.5}$$

Alternatively,

$$P_{max} = \left(\frac{1}{2}\right)(C_p)(\rho Av^3) \quad \text{.......... 4.6}$$

This quantity, 0.593, is known as the ***Betz constant***. This constant is generally represented as C_p, the coefficient of performance. It implies that, under ideal conditions, when the WTG is lossless up to 59.3% of the available power can be extracted from the wind. The ratio of the power, P_w absorbed by the turbine to that of the moving air mass

$$P_0 = A_R \frac{\rho}{2} \upsilon^3 \quad \text{.......... 4.7}$$

under smooth flow conditions at the turbine defines the dimensionless performance coefficient

$$C_P = \frac{P_w}{P_0} \quad \text{.......... 4.8}$$

Where,

P_w = wind turbine power, watts
ρ = 1.2 kg/m^3 (density of air)
A_R = wind turbine blade sweep area in m^2
υ = wind speed in m/sec

The coefficient of performance C_p, which has a maximum value of 59.3%, depends on the mechanical design of the wind turbine. Wind tunnel tests have shown that ideal horizontal-axis two-bladed, propeller type rotors normally have power coefficients of 0.42, which is 71% of the maximum efficiency attainable, WMO (1981). Two major factors which characterize the design of a particular wind turbine are: (i) tip-speed ratio and (ii) blade pitch angle.

The ideal conditions assumed in the development of equation 4.4 can never be achieved. Moreover, there are certain practical considerations, which will limit the level of power production from an electromechanical device like the WTG. Some of the important ones are the following:

1. Blade tip loss;
2. Friction loss; and
3. Electrical loss.

The tip of the blade is usually rounded because test results indicate that a rounded blade tip increases energy capture by reducing the cut-in wind speed. For example, in the design of MOD-O WTG, it has been possible to reduce the cut-in wind speed from 5.7 m/s to 4.7 m/s, and increase the peak aerodynamic efficiency from 0.34 to 0.38 [EPRI, 1983] using the rounded blade tip. The "blade tip loss" is caused by the fact that, the usually round shape of the tip of the blade, designed to minimize the frictional losses, is unable to capture all of the power available to that part of the blade. Also, some of the diffused wind creeps to the back side of the blade and neutralizes some of the energy captured by the wind turbine. The friction losses are due to the rotational motion of the turbine. These come from the wind turbine, gear mechanism and mechanical couplings. The electrical losses come from the generator, and the related electrical power transmission system.

Figure 4-2 shows the power available from the wind and the power extractable by a wind turbine. Only the mechanical losses are reflected in this diagram. The following three speed characteristics are defined with reference to **Figure 4-2**.

WATER RESOURCES DEVELOPMENT TRAINING CENTRE
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Dated : July 05 ,2004

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Assistant Registrar(ACADEMIC)
Indian Institute of Technology,
Roorkee

Subject : Grade Award Sheet for dissertation – M.Tech (Hydroelecrtric System Engineering & Management)

Enclosed please find the grade award sheet in respect of dissertation submitted by **Mr. Rachel B. Gabuya (Enrolment No. 028104)** for the award of M. Tech degree in Hydroelectric System Engineering and Management in a sealed envelope alomg with one copy of the dissertation.

(Devadutta Das)
Professor

Please acknowledge receipt.

Encl:1. Sealed envelope as above
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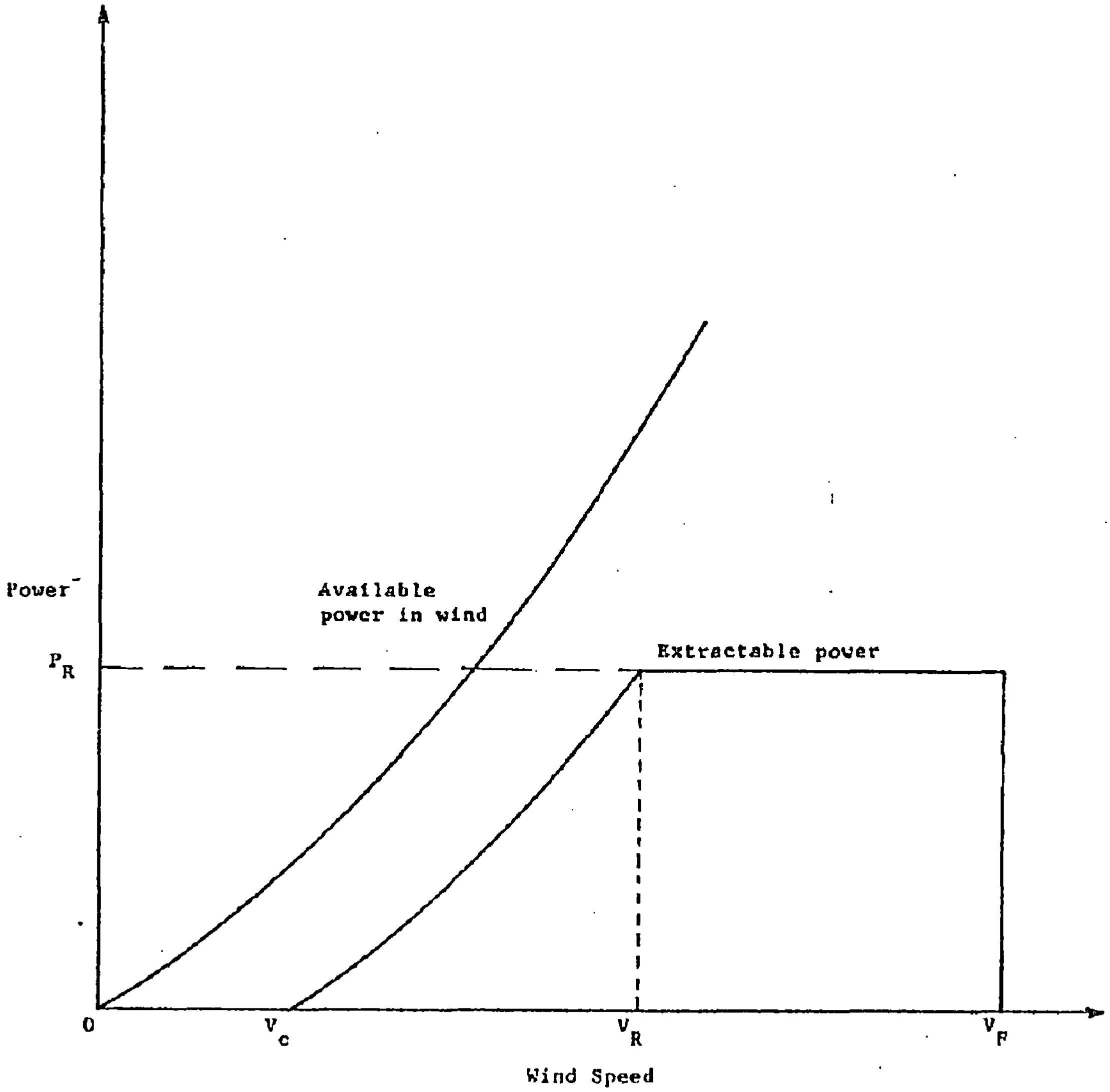


Figure 4-2: Extractable Power from a Wind Turbine as a function of Wind Speed

V_C = cut-in speed, wind speed at which the WTG starts producing electricity.
V_R = rated speed, wind speed at which the WTG starts producing rated power.
V_F = furling speed, wind speed at which the WTG stops producing power.

A certain amount of wind speed is necessary for the WTG to overcome the mechanical inertia and provide enough rotational motion for the generator to start producing electrical power. This is known as the cut-in speed and can be as low as 3 meters/sec for small WTG's. The WTG produces variable power between cut-in and rated speeds. When the rated wind speed is attained, the WTG produces full power as it reaches its design rotational speed. Any speed higher than the design rotational speed resulting from a wind speed higher than V_R may cause damage to the mechanical couplings, gearboxes and the electrical generator. Thus, as the wind speed exceeds V_R, a constant blade rotational speed is maintained by changing the pitch angle of the blade. There is, however, an upper limit on the ability of the pitch control mechanism to maintain a fixed rotational speed of the wind turbine as the wind speed keeps on increasing. When that limit is reached (as the wind speed reaches the furling speed) the WTG is turned off. For many machines this speed can be as high as 30 meters/sec. Failure to stop the WTG under high wind speeds will cause mechanical as well as electrical damage to the machinery.

4.3 Wind Power Technologies

4.3.1 Wind Energy Conversion System (WECS)

Modern windmills are usually referred to as ***wind turbines*** or ***wind energy conversion systems*** to distinguish them from their traditional forebears. The majority of modern wind turbines are electricity-generating devices. They range from small turbines that produce a few tens or hundreds of watts of power to relatively large turbines that produce 1 MW or more.

There are two basic configurations of modern wind turbines: ***horizontal axis turbines*** and ***vertical axis turbines***. Depending on the way in which energy is extracted from the wind, wide variations are discernible between converters, depending on whether they use the drag developed at the surface of the moving parts or the lift exerted on the wings or blades. Wind power machines for generating electricity are produced with horizontal and with vertical axes. The turbines are so constructed that they can use lifting power. Lift originates in the flow of air past the rotor blade, which causes an overpressure on the underside of the blade and an underpressure on the top. The tangential component of the lifting power causes the rotor blade to rotate.

According to Albert Betz, a lifting rotor can only extract approximately 60% (16/27) of the energy / power from an airstream (see **eqn. 4.5**). The remaining 40% must remain in the air flowing past. Complete braking of the moving air mass to $V_3 = 0$ would result in air backing up at the turbine: the inflow of air would be halted and energy extraction would no longer be possible. In practice, after conversion losses, lower levels on the order of 45% are aimed at. For wind turbines, therefore, in contrast with, for example, water-driven turbines, no efficiency levels are given – rather the performance coefficient C_p is used. For operating machines, this figure gives the ratio of the power taken from the wind to that contained by it.

The ***horizontal axis wind turbines*** (HAWTs) generally have 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 by solid blades, and are ***high-solidity*** devices. These include the multi-blade wind turbines used for water pumping on farms. In contrast, the swept area of wind turbines with few blades is largely void and only a very small fraction appears to be solid and referred to as ***low-solidity*** devices.

All grid-connected commercial wind turbines today as shown in **Figure 4-3** are low-solidify devices built with a propeller-type rotor on a horizontal axis (i.e. a horizontal main shaft). They are almost universally used to generate electricity. The purpose of the rotor, of course, is to convert the linear motion of the wind into rotational energy that can be used to drive a generator. The same basic principle is used in a modern water turbine, where the flow of water is parallel to the rotational axis of the turbine blades. The blades have a clean, streamlined appearance, due to wind turbine designer's improved understanding of aerodynamics, derived largely from the developments in aircraft wing and propeller design.

The ***vertical axis wind turbines*** (VAWTs) have an axis of rotation that is vertical and they can harness wind from any direction without the need to reposition the rotor when the wind direction changes. The only vertical axis turbine shown in **Figure 4-3** which has ever been manufactured commercially at any volume is the Darrieus machine, named after the French engineer Georges Darrieus who patented the design in 1931. It was manufactured by the U.S. company FloWind which went bankrupt in 1997. The Darrieus machine is characterized by its C-shaped rotor blades which make it look a bit like an eggbeater. It is normally built with two or three blades.

The blades of a Darrieus VAWT take the form of a 'troposkien' (the curved shape taken by a spinning skipping rope). This shape is a structurally efficient one, well suited to coping with relatively high centrifugal forces acting on VAWT blades. However, the shape causes difficulties in the manufacture, transportation and installation of the curved blades.

The basic theoretical advantages of a vertical axis machine are:

1) The generator, gearbox etc. can be placed on the ground, and may not need a tower for the machine.

2) No need for a yaw mechanism to turn the rotor against the wind.

The basic disadvantages are:

1) Wind speeds are very low close to ground level, so although one may save a tower structure, wind speed will be very low on the lower part of the rotor.
2) The overall efficiency of the vertical axis machines is not impressive.
3) The machine is not self-starting (e.g. a Darrieus machine will need a "push" before it starts. This is only a minor inconvenience for a grid-connected turbine, however, since one may use the generator as a motor drawing current from the grid to start the machin).
4) The machine may need guy wires to hold it up, but guy wires are impractical in heavily farmed areas.
5) Replacing the main bearing for the rotor necessitates removing the rotor on both a horizontal and a vertical axis machine. In the case of the latter, it means tearing the whole machine down..

A wind turbine usually comprises the following general components:

Rotor: The blades of the rotor are designed to spin in the wind, driving the turbine generator. Sometimes gearing is used to increase the frequency for electricity generation.

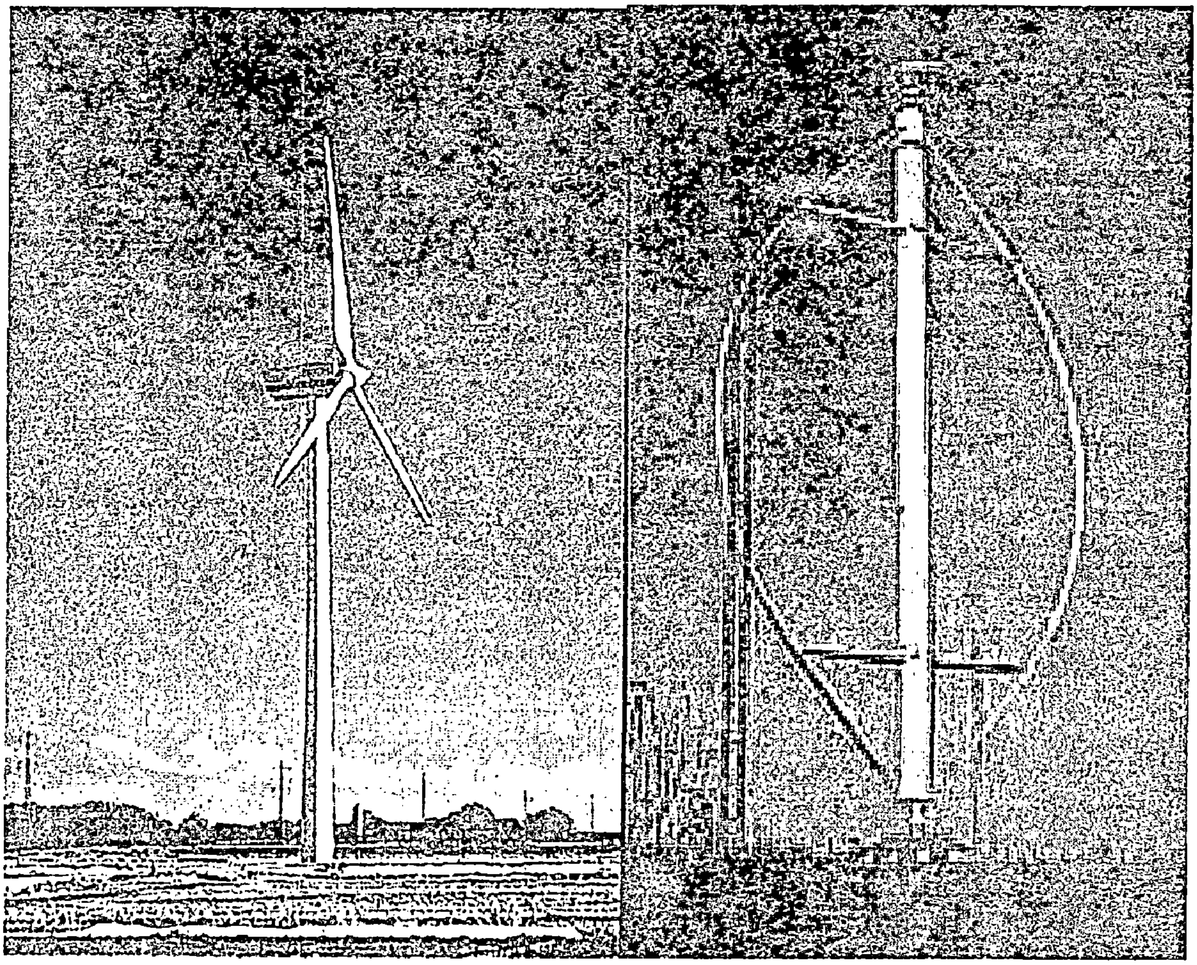


Figure 4-3: A Typical Three-Bladed HAWT and a Darrieus VAWT

Generator: This generates the electricity when there is sufficient wind to rotate the blades. There are now many designs of generator, including some with new powerful permanent magnets. Electricity is transferred to the next stage (either for storage, exporting to the grid or for direct use) using wiring. The generator, gear box and other machinery components are housed in a casing called nacelle.

Directional system: Horizontal axis machines require a mechanism to swing them into line with the wind. Small machines usually have a tail assembly. Large machines usually have a 'servo mechanism' that orients them to the direction of maximum power. This is called the yaw control. **Figure 4-5** shows the machinery and detail auxiliary components inside a WTG nacelle.

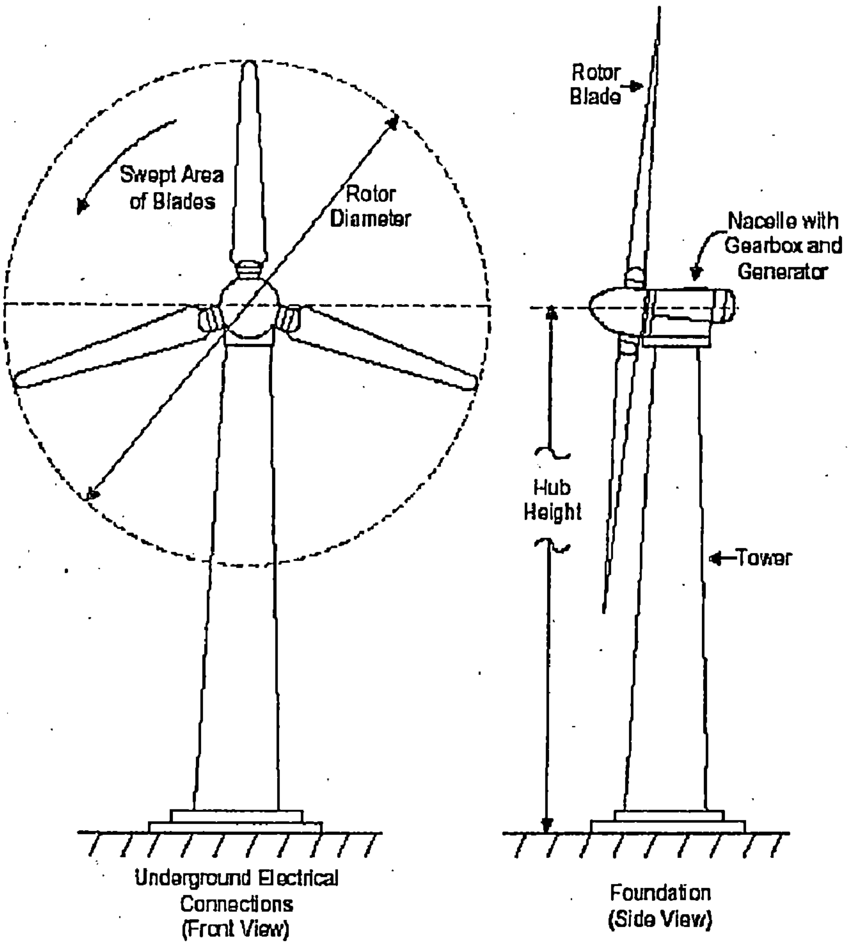


Figure 4-4: HAWT Type Wind Energy Conversion System Schematic

Protection system: Modern wind turbines are usually equipped with mechanisms to prevent damage in excessively high winds. Large machines may have complex arrangements to shut down generation at high wind speeds. Smaller systems change the blades' orientation so that they present a smaller surface to the wind and thereby reduce the speed of rotation, or they use mechanical brakes.

Tower: The tower raises the turbines assembly well above the turbulent air currents close to the ground and captures higher wind speed, as described earlier in this fact file. Tower design is particularly critical, as it must be as tall as economically possible, robust, enable access to the turbine for maintenance, and yet not add unnecessarily to the cost of the system. A particularly important aspect of tower design is elimination of resonance between the frequency range of rotating blades and the resonant frequency of the tower.

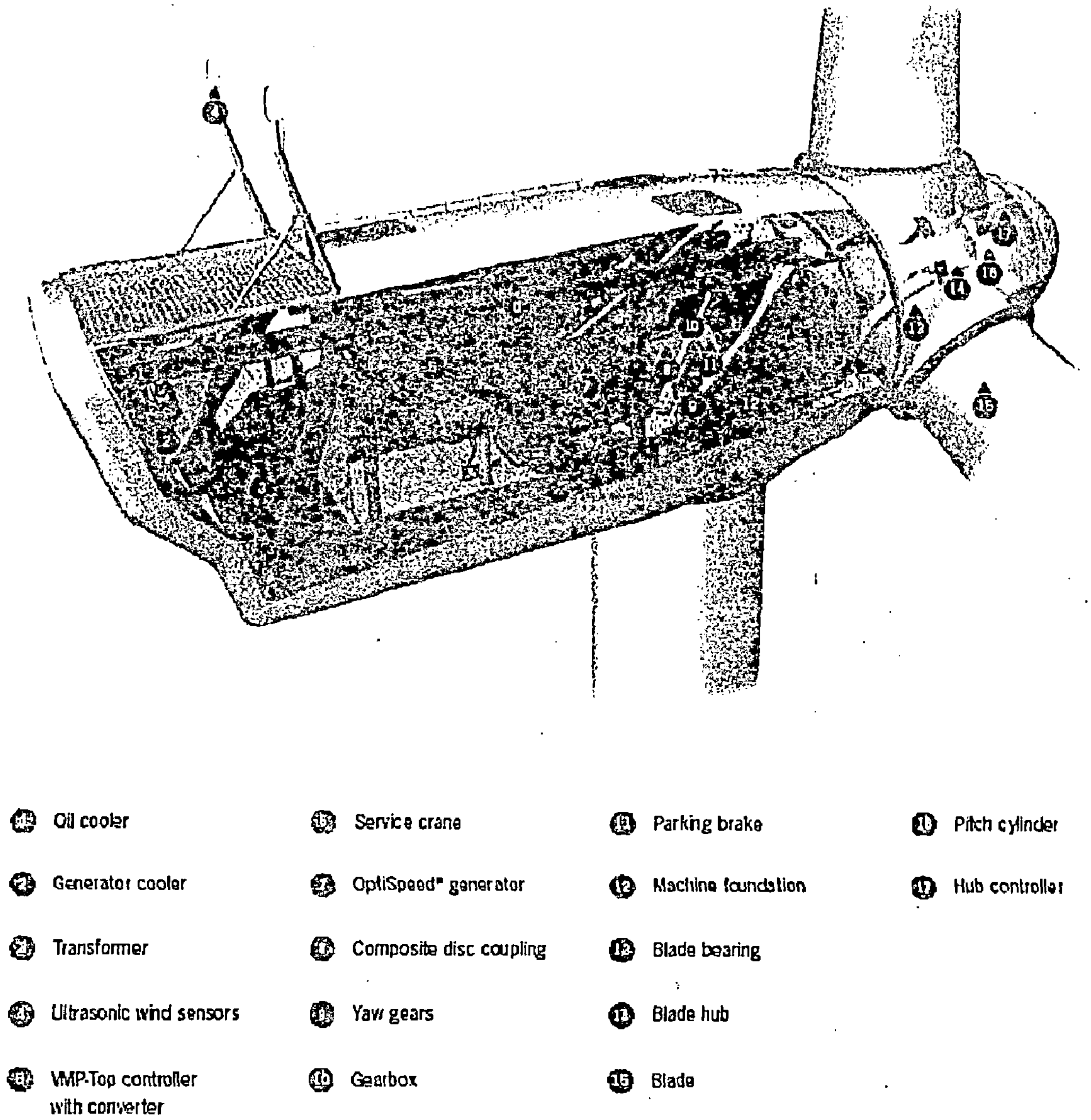


Figure 4-5: Machinery and Detail Auxiliary Components of a Vestas V90-3.0 MW Wind Turbine Generator (WTG) Nacelle

Standard modern wind turbine generator design is currently equipped with a single or two-generator version which is highly efficient in the vast majority of wind conditions, microprocessor-controlled **OptiTip®** technology pitch regulation, ensuring continuous and optimal adjustment of the angles of the blades in relation to the prevailing wind and **Optislip®** features for generator which allows the rotor and generator to vary their RPM by up to 10% to cope up with violent gusts of wind. The turbine is also equipped with lightning protection to protect the entire turbine from the tips of blade to foundation. **Table 4-1** shows the leading wind turbine generator manufacturer in the world based on installed MW and MW sold in 2001.

Manufacturer	Country of Origin	2001 MW Sold	2001 Market Share	2001 Total Installed MW	2001 Total Installed Share
Vestas	Denmark	1,648	24.1%	4,983	20.0%
Enercon	Germany	1,036	15.2%	3,206	12.9%
NEG Micon	Denmark	874	12.8%	4,510	18.1%
Enron / GE	U.S.A.	865	12.7%	2,288	9.2%
Gamesa	Spain	648	9.5%	2,125	8.5%
Bonus	Denmark	593	8.7%	2,306	9.3%
Nordex	Germany	461	6.7%	1,473	5.9%
MADE	Spain	191	2.8%	783	3.1%
Mitsubishi	Japan	178	2.6%	558	2.2%
Repower	Germany	133	1.9%	379	1.5%
Others		448	6.6%	3,482	14.0%
Total		7,075		26,092	

Table 4-1: Leading Wind Turbine Generator Manufacturer

(Source: **BTM Consult Aps**)

The nacelle (enclosure directly attached to the rotor) contains a gearbox and one or more generator as shown in **Figure 4-5.** For large turbines, the rotor rotates about 20 to 40 rpm. The gearbox then gets a high-speed shaft rotating at about 1500 rpm. The high-speed shaft is then connected to an electrical generator.

The rotor blades for large turbines are generally fiberglass/epoxy composites with some admixture of carbon fibre. The latter is expensive but does offer strength advantages, and may be used increasingly in future designs. Taking into accounts the fact that longer blades means higher loads on the mechanical components of the turbine, the transmission system in the nacelle has been greatly reinforced and at the same time, adjustments has been made on yaw systems and gearbox. Wind turbine parts are designed for 20-30-years life, which means approximately 120,000 to 180,000 hours of operation (assuming a 66% duty cycle).

The height of the tower can vary from about 1.5 times to 3 times the rotor radius. It is important to get the bottom of the blades well clear of the ground (or water surface, if the wind turbines are installed offshore) to avoid wind shear, that is, a differential airflow between the ground and the upper parts of the rotor. Making the tower higher obviously adds cost and exacerbates potential problems of strength of the tower. Commonly, the tower direction is actively controlled (rotated) so that the rotor faces into the wind. The design with rotor downwind from the tower has the disadvantage that the blades are shielded from the wind by the tower when they are pointed downward and this creates additional strain on the rotor. The rotor design and operation is strongly based on experience with propeller-driven aircraft.

There are generally two ways to generate electrical power. One approach controls the rotational speed of the wind turbine in order to synchronize the electrical output with the power grid. The second allows the wind turbine speed to vary and produce AC electrical power at changing frequency. This power is then rectified to DC, "inverted" back to AC (synchronized to the grid) using thyristors or large transistors to a few hundred volts, and then raised again to 10kV to 30kV by transformer for transmission. The first method is simpler but has the disadvantage that it does not allow the wind turbine to be operated at its maximum efficiency at every wind speed. The second approach allows the turbine to operate most efficiently at the cost of expensive electronics.

Power Ratings (kW)	Rotor Diameter (m.)
300	27 - 33
500	33 - 40
600	40 - 44
750	44 - 48
1000	48 - 54
1500	54 - 64
2000	64 - 72
2500	72 - 80
3000	80 - 90

Table 4-2: Rotor Design Diameters for Wind Turbines of Varying Power Ratings

Making wind turbines larger is desirable economically, and wind turbine sizes are slowly increasing. The limitations are, among other things, strength and durability of materials for the rotors and towers. **Table 4-2** shows the rotor diameter as a function of their power ratings.

4.4.2 Wind Speed Distribution and Power Curve

The strength of the wind resource is described quantitatively by the wind speed distribution. The wind turbine power curve is the quantitative relationship between the electric power output and the incident wind speed. Together, the wind speed distribution and the wind turbine power curve determine the annual energy production.

The wind speed distribution function F(v)*Δv gives the number of hours per year that the wind speed lies within the small wind speed interval or bin of width Δv located between the wind speed values v and v + Δv. The value used for the constant bin width Δv is Δv = 1 m/s (2.24 mph). The integer index k identifies the wind speed bins. For example, the bin k = 2 corresponds to the wind speed bin encompassing the range 1 to 2 m/s. The height of the bar for k = 2 indicates that the wind speed lies within this interval for about 980 hours/year. As noted on the wind distribution graph, the sum of all the bars is 8,760 hours, the number of hours in a year.

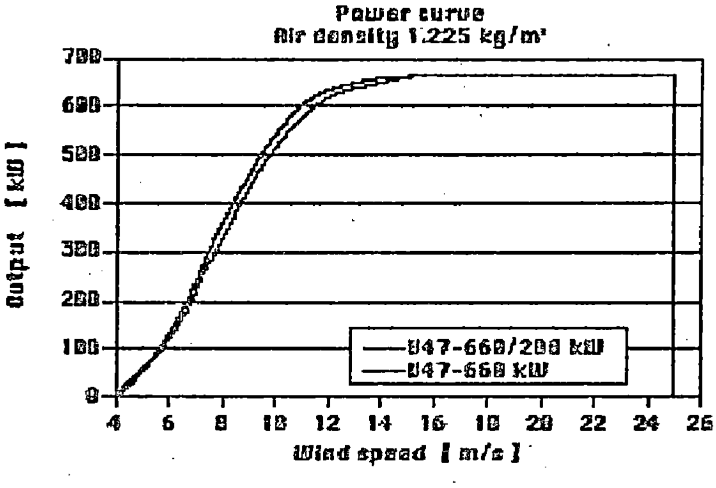


Figure 4-6 Power Curve for 660kW Vestas Wind Turbine

As indicated in **Section 4.3**, the power available from a moving air mass is proportional to the cube of the air velocity. The exact details of power output depend on the design and operation of the blades, generators, etc. The power curve **P(v)** is the continuous function that specifies the wind turbine's electric power output as a function of wind speed. In **Figure 4-6** shows the power curves for 660kW Vestas wind turbine with either one or two-generator version. At a wind speed of 16 m/s, the blades are adjusted to limit the power to about 660 kW. If the wind reaches 25 m/s, the turbine is shut-down.

Wind turbines are usually specified at their maximum output. Wind turbines generally operate at about 20-35 % of their rated capacity, whereas fossil fuel electricity generators are designed to operate at full capacity and often do so. This is significant in understanding potential electrical power as a function of installed wind capacity and in considering the economic of wind power.

4.4.3 Utility-Scale Wind Technology: Current Applications

Currently, the power ratings of wind turbines designed primarily for windfarm use range from approximately 300 kW to 750 kW, with corresponding rotor diameters ranging from 35 meters (m) (115 ft) to 50 m (164 ft). Over the past decade and a half of intensive development of these systems, their unit size has increased, and their reliability and economics have improved dramatically. The economics of large-scale, grid-connected wind systems now approach those of some conventional power generation systems. Regardless of the size, the defining characteristics of a windfarm are

1. the wind turbines are connected to a utility grid,
2. the wind generating capacity usually is a small fraction of the conventional capacity supplying the utility system load (low values of wind penetration) and
3. the wind turbines require some level of electrical support from the utility grid.

Depending on the details of the generator and other electrical technology employed in the wind turbine, this support can range from a simple frequency reference (for synchronization of the wind-generated electricity to that of the conventional sources) to the consumption of reactive power (required for operation of the wind turbine generators). Regardless of the wind farm size, standard utility techniques and components (e.g., transformers and protective switchgear) are used to connect the wind turbines to the grid. The wind turbine is the only non-standard utility component. A windfarm power rating generally represents no more than 15 percent of a grid's conventional generation capacity.

The very early water-pumping, small-scale wind turbines used extensively in the first half of this century in ranches and farms has been supplanted by their modernized, more efficient equivalents used primarily to generate electricity. Although there are no technical reasons why larger units cannot be used, the unit size of these systems typically ranges from 1 kW to perhaps 50 kW. They are intended for use individually or in small clusters. They may or may not be connected to the existing utility grid.

When connected to the grid, these systems are called ***distributed wind generation*** systems. From both utility and customer perspectives, distributed generation can be useful in providing end-of-line voltage support to an extensive grid. Distributed wind systems also can be used as an alternative to extension of the grid to distant loads. As will be noted, wind system applications form a continuum. Thus in many instances, the distinction between a windfarm and a distributed system may not be clear. The only difference may be one of the size or the number of the wind turbines.

When not connected to the grid, but connected directly to a load, the electric power is unregulated. The power quality and delivery characteristics are determined only by the load and the output of the wind turbine. In general, the output of the wind turbine depends on the wind speed. Thus the load must be capable of using such unregulated power without damage to either the load or the wind turbine generator. An example of such a load is electric resistance heating. Development work is under way to improve the regulation of the power from wind turbines not connected to the grid. Of particular interest is work aimed at successfully connecting an induction motor directly to a non-grid-connected wind turbine. Application examples include wind turbines used for water pumping, ice making and refrigeration.

Hybrid power systems employ wind turbines and possibly other renewable power sources together with diesel generators to form the equivalent of a miniature grid. While the unit size of wind turbines in these applications typically ranges from 1 kW to 50 kW, much larger machines and hybrid power systems have been fielded. They may be used with diesel generators, energy storage such as is provided by batteries and, where appropriate, other renewable power sources such as photovoltaics or hydropower. Used in this mode, such systems are often called ***hybrid power systems***. They typically are used where there is no utility grid. Because of the close coupling and control of all generation sources and some or entire connected load, the wind component of hybrid power systems can achieve 100 percent penetration. That is, given suitable wind conditions, the wind system can supply nearly all of the power demanded by the load.

From the preceding discussion, it is evident that there is a continuum of wind turbine sizes and scale of installations. There also is a continuum of applications. The differences between windfarms, distributed systems and hybrid power systems are the size of the installation, the degree of wind penetration, whether the grid is used for frequency or reactive power support and the degree of integration with other power sources.

Windfarms are composed of numbers of wind turbines connected to an existing, typically much larger grid system managed by a utility. Wind turbines in grid-connected, distributed applications are but a very small-scale windfarm. Hybrid power systems, while they may be connected to an existing grid system, form their own utility by virtue of the integration and close operational coupling of conventional generation sources.

4.4.4 Wind Energy Power Supply Integration

Integrating wind energy into utility systems presents the potential for some familiar power quality related problems and some not so familiar issues for most utility engineers. However, this integration "has not been a problem" according to an IEEE annual conference paper by Robert Putnam from Electrotek Concepts, "and any issues that have developed, such as intermittency and voltage regulation, can be addressed by accepted power system procedures and practices." Putnam divides integration issues that have arisen with wind into "interface (or engineering) issues, operational issues, [and] planning issues." [55]

Interface issues include harmonics, reactive power supply, voltage regulation, and frequency control. Power quality is obviously a major utility concern. Problems with power quality have been documented at various wind farms built in the early 1980's. Modern turbines are equipped with more sophisticated power electronics than their predecessors. These newer systems have largely eliminated past problems associated with harmonics, reactive power supply, and frequency control. The extent to which voltage regulation is an issue of concern today appears to be largely a function of grid strength at the point of integration.

Operational/planning issues essentially deal with the intermittent power output inherent in wind generation. These issues include operating reserve requirements, unit commitment, economic dispatch, modeling, and valuation. When integrating wind power into a utility system, reserve margins must also account for the maximum probable decrease in wind plant output over a given period. It's suggested that wind penetration must exceed 5% of system capacity to have an adverse affect on reserve requirements.

In terms of unit commitment and dispatch, the most conservative approach to integration of an intermittent resource is to discount the contribution of the resource. Much attention within the research community currently is being paid to forecasting wind plant output. Not unlike the issue of unit commitment and dispatch, planning issues also center on the modeling and valuation of intermittent wind resources. Models, which can reflect the real-time variation in load and wind plant output, are necessary to address concerns over the operational impacts of changing wind plant output. Further, modeling capability of this nature will allow better quantification of wind outputs capacity, environmental, and other distributed benefits to the utility system.

4.5 Global Wind Energy Potential and Installed Capacity

Wind electric power is now a mature technology. Wind power has characterized as the world's fastest growing energy source. Installed capacity has continued to grow at an annual average 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 the first half of 1999 installed grid-connected wind electric generation capacity worldwide had reached 10,000 MWe. By early 2000, this expanded to 13,000 MWe. By the end of 2002 capacity is expected to grow to more than 20,000 MWe, with 3,000 MWe in Asia alone (primarily India and China).

In the year 2000 alone, some 3,800 megawatts (MW) of new utility-scale wind energy generating capacity were brought online worldwide. At the end of that year the total installed capacity is about 17,300 MW, which enough to generate some 37 billion kWh of electricity each year. The new wind power capacity, which was installed in 2001 and 2002, was approximately 6,828 MW and 6,700 MW respectively. These are the largest increase ever in global wind energy installations, well above the capacity added in 2000 (3,800 MW) and 1999 (3,900 MW). The world's wind energy generating capacity at the close of 2001 stood at about 24,000 MW. By the beginning of 2003, global wind power installations had reached 31,234 MW. This provides enough power to satisfy the needs of around 14 million households, more than 35 million people.

Although Europe accounts at 75% of the 2003 capacity, over 48 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 in the developing world. **Table 4-3** and **4-4** present the top-wind energy market by regions and by country around the world from 2001 up to 2003.

REGION	YEAR		
	2001	2002	2003
Europe	12,972	17,500	23,357
North America	2,695	4,452	4,881
Asia	1,574	1,920	2,184
Pacific	221	410	524
Middle East & Africa	141	147	149
Latin America	103	105	139
TOTAL	17,706	24,534	31,234

Table 4-3: Global Wind Power Installed Capacity by Region, MW

Rank No.	COUNTRY	YEAR		
		2001	2002	2003
1	Germany	6113	8753	12001
2	USA	2555	4245	4645
3	Spain	2402	3335	4830
4	Denmark	2297	2556	2889
5	India	1220	1507	1702
6	Italy	389	697	785
7	Netherlands	448	483	686
8	UK	409	485	552
9	China	340	389	468
10	Japan	150	300	384
11	Sweden	231	280	328
12	Greece	189	272	302
13	Canada	140	207	236
14	Portugal	100	127	194
15	France	79	85	147
16	Austria	78	95	139
17	Ireland	118	125	137
18	Australia	34	73	103
19	Norway	13	17	97
20	Costa Rica	51	51	71

Table 4-4: Top 20 Countries in Installed Wind Power Capacity, MW

The Philippines has significant wind energy resources that can be commercially exploited using current technology. The potential is at least several thousand MWe and could be as much as 10,000 MWe, although the grid's capacity to accept wind electric power will limit the practical level to about 15–20 percent of total spinning reserve. In combination with large hydropower plants, wind electric power generation could contribute a significant amount of energy in backbone grid-connected applications without degrading grid performance or stability. Wind/diesel hybrid power units in regional and community mini-grids are also potentially important cost-competitive options for some regions.

4.6 Wind Power Economics

Many factors come into play when considering the economics of a wind generation project. The discussion in this section is meant to provide a few generally accepted averages typically used in discussion of wind generation projects. The cost of capital is always a significant factor in utility investments.

For windfarms, the installed capital cost has decreased from more than $2,500/kW in the early eighties to the current range of $900/kW to $1,200/kW. The actual cost for a given installation depends on the size of the installation, the difficulty of construction, and the sophistication of the equipment and supporting infrastructure. For further cost illustrations, the value $1,000/kW for the installed capital cost shall be used. This value is appropriate for smaller installations. With costs continuing to go down, this value also may be appropriate for smaller installations. The capital cost trends over the last 15 years are illustrated in **Figure 4-7**

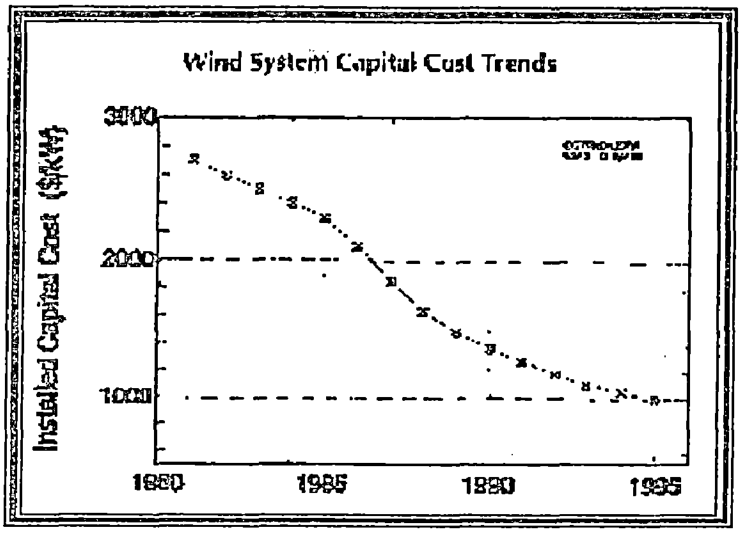


Figure 4-7: Wind System Capital Cost Trends

Plant costs can be determined after the compilation of a comprehensive profile of requirements and the definition of the usage details, including technical plant data and predictive costs for maintenance and repairs by the manufacturer or supplier. It is relevant to the cost calculation whether the converter will be used in isolated operation or combined with other energy generation units (in grids, with diesel units, etc.) and what demands will be made of the safety technical component groups.

Installed turbine prices generally tend to be in the neighborhood of $1000 per kW. One reason this tends to hold true across the range of the utility-scale turbines is that prices of turbines are much flatter above 600 kW than below. The two most significant factors affecting differences in turbine cost are tower height and rotor diameter. Installation cost typically comes in at around 30% of the total turbine cost. Economies of scale are certainly possible if more than one turbine is installed. Scale economies often become evident at the 20-25 MW level.

Installation cost will generally include foundations, road construction, transportation, communications equipment, transformer and other interconnection or transmission related cost. These costs can vary considerably depending upon such factors as soil type, distance from other roadways, and the possible need for grid reinforcement or other interconnection related expenses.

Overall, the additional costs of local transport, the costs of foundations, wiring and interconnection lie between 15% and 30% of pure plant costs. If investment costs subsidies can be maintained within the framework of promotional measures, these can be included in the calculation as a reduction in purchase costs.

Annual operating and maintenance cost for newer turbines tend to average 1.5% - 2.0% of turbine cost. Some analysts prefer to use an expense of $0.01 per kWh because wear and tear tends to increase with increased production. The design life of most onshore utility-scale turbines is 20 years or 120,000 hours. The actual lifetime of a wind turbine will depend both on the quality of the turbine and the local climatic conditions. Availability factors for wind turbines are quite high. Availability factors of 98% are common for the best manufacturers. Capacity factors for wind turbines typically range from 25% to 30%.

Static and dynamic calculation methods can be used to assess the economic viability of wind power plants. In the annuity method, returns and costs are assumed to remain constant (static) over the entire depreciation time. In contrast to this, the capital value method takes into account the loss of value of the loan due to inflation and increasing returns due to increasing remuneration for supply.

4.7 Environmental and Social Issues

The obvious environmental plus with wind generation is the fact that no CO_2 or other greenhouse gases are emitted into the atmosphere. There is also minimal or no risk of soil or water contamination.

There is however environmental and other externalities associated with wind energy development. These include potential impacts to birds and other animal habitat, soil erosion, noise, electromagnetic interference, and aesthetics. [57]

The interaction between birds and wind turbines is an issue of current debate. It's often said that with careful sighting, this concern can be largely mitigated. The wind industry is currently working with other interested parties to address this important issue. The crux of the problem is the attractive nature (to birds) of the pasture and prairie lands where the best wind resources are located. The best advice is to carefully assess the potential for avian interaction in the early stages of project siting.

Wind turbines, like all mechanical systems do make noise. Turbines can create low frequency impulsive (thumping) and broadband (swishing) sounds. There are two sources of noise from wind turbines: mechanical noise, from the gearbox; and aerodynamic noise, from rotating rotor. Design changes in recent years have done a great deal to lessen these noises. Present-day gearboxes have been carefully designed and muffled to minimize noise, and modern, large wind turbines actually have less noise than smaller, older ones. This is because the rotors on large turbine go slower than those on small turbines and the amount of noise is proportional to the 5th power of the angular velocity. Much of the noise created by wind turbines is masked by the sound of the wind itself. At 250 meters the sound from a wind turbine is in the 45-50 decibel range. This is often compared to the sound of a typical household refrigerator.

Predictable levels of television interference have been associated with wind turbines, particularly in older machines with metal blades. Blades today are typically made with a composite material, which doesn't reflect television signals as much as past designs. However modern blades also tend to have lightning protection, on the surface of the blade, which tends to increase electromagnetic interference.

Wind turbines are tall (as much as 100-150 meters high) man-made structures, which some people believe spoil the aesthetic or landscape value near the windfarm site, and therefore resist their establishment. There are often strong winds near seacoasts or in mountains, and wind turbines in these settings can be controversial.

HYDROPOWER

5.1 Introduction

Hydropower is using water to power machinery or to generate electricity. Water constantly moves through a vast global cycle, evaporating from lakes and oceans, forming clouds, precipitating as rain or snow, and then flowing back down to the ocean. The energy of this water cycle, which is driven by the sun, can be tapped to produce electricity or for mechanical tasks like grinding grain. Hydropower uses a fuel—water—that is not reduced or used up in the process. Because the water cycle is an endless, constantly recharging system, hydropower is considered a ***renewable energy***.

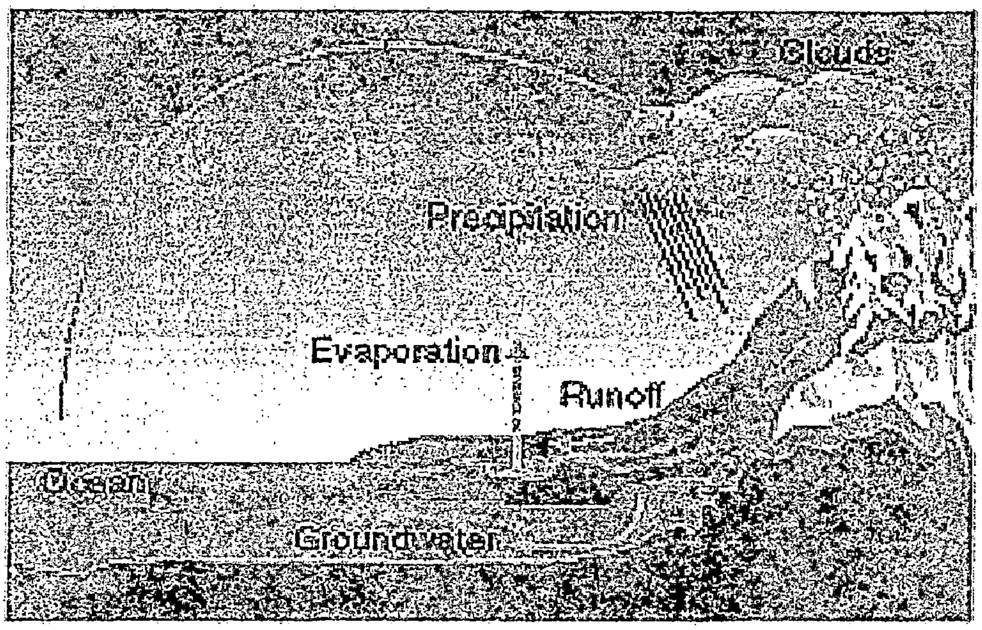


Figure 5-1: Earth's Hydrologic Cycle of Water

When flowing water is captured and turned into electricity, it is called ***hydroelectric power or hydropower***. There are several types of hydroelectric facilities; they are all powered by the kinetic energy of flowing water as it moves downstream. Turbines and generators convert the energy into electricity, which is then fed into the electrical grid system to be used in homes, businesses, and by industry.

5.2 Hydropower Development

Through the ages the force of falling water has been humankind's important source of power and energy. The origins of waterwheels can be traced back to ancient Egypt, Persia and China where these were used for irrigation as well as grinding grain or flour. At the end of the last century and the beginning of this century, the primary objective in developing hydropower was to utilize it through a mechanical drive to the driven machinery. These devices consisted of ropes, belts and some types of gear trains. The early hydraulic units were relatively small and their outputs rarely exceeded few hundred kilowatts. Small hydropower provided the early settlers in the United States with mechanical power to drive looms and lathes. The first hydroelectric generation facility was built in Appleton, Wisconsin in 1882, and it was rated at 125 kilowatts. Even today hydropower remains a significant source of electricity in all parts of the world.

Tremendous strides have been made in the field of hydro-dynamics in order to develop and improve equipment to meet increasingly complex requirements of larger and larger hydroelectric power plants. The earlier waterwheels and hydraulic turbines used for providing mechanical shaft power have been developed into vast hydro installations serving millions and millions of people all over the world. Large scale hydroelectric generation remains one of the cheapest and least controversial sources of electricity in the United States and in many countries around the world. However, the best sites for hydroelectricity in many countries have been used up, and the remaining ones are coming under stringent environmental scrutiny.

Hydropower provided much of the energy for the industrial revolution in England, and the industrial development in the northeastern United States till the 1930's and 1940's. From that time till the 1970's in the United States the hydropower's contribution in the electricity generation mix steadily declined from 30 percent to about 15 percent. The advent of abundant and inexpensive fossil fuels, first coal then oil, and finally natural gas in the United States coupled with advances in generation technology which led to the economies of scale, resulted in large scale development of thermal power plants in the United States and many industrialized countries.

Construction of small hydroelectric facilities virtually stopped in the United States in the 1950's and 1960's and many existing sites were abandoned because of economics. Other countries however, continued with their program of small scale hydropower development. Notable among them is China. Starting in 1958 China has continued a focused policy on small scale hydropower development at the local level in parallel with the large scale development planned and executed by the central government.

The increase in gas and oil prices in the United States and the increased concern about adverse environmental impacts of coal burning and nuclear energy, have improved the relative attractiveness of small scale hydro. Similar concerns are now visible in many industrialized and industrializing countries

5.2.1 Types of Hydropower Development

There are various types of hydropower development: storage, run-of-the-river, pumped storage and tidal power development. **Figure 2** shows a typical arrangement of a hydropower plant.

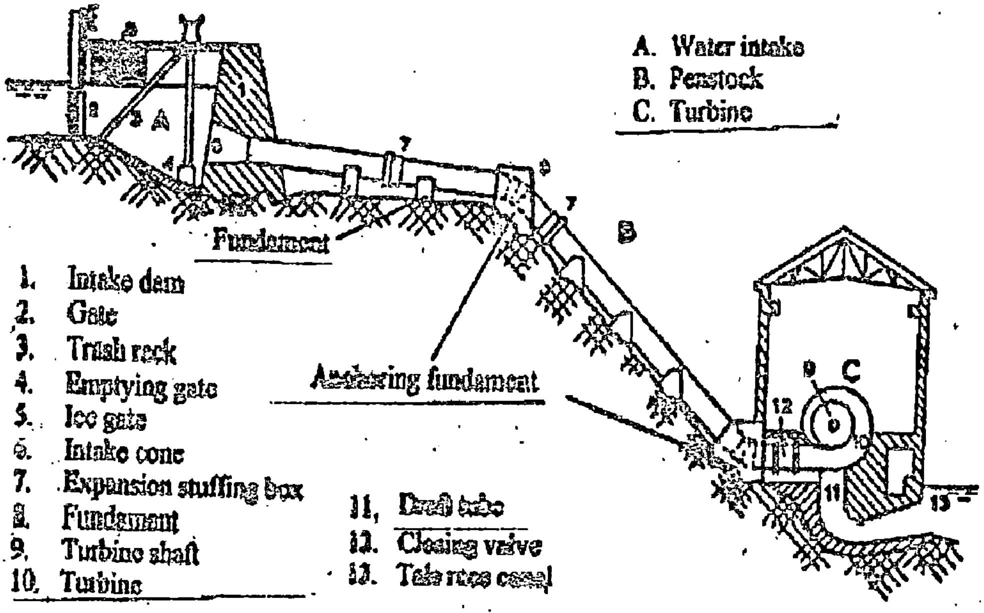


Figure 5-2: Typical Arrangement of a Hydropower Plant

- **Storage Plants**

The most common type of hydroelectric power plant is the conventional hydro storage power plant. Storage plants are necessarily associated with valleys or mountainous regions. An impoundment facility, typically a large hydropower system, uses a dam to store river water in a reservoir. Storage is done during wet or rainy season when flow is in excess of demand to maintain continuous hydropower generation. The demand is met from the run-of-river when the flow is in excess of demand and from the storage during the low supply period. These storage plants are designed so that the estimated yield for reliability is 90 percent. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. The water may be released either to meet changing electricity needs or to maintain a constant reservoir level.

The power output is largely firm. Such power facility can be used as base load as well as peak load plant. Storage plants are designed for small as well as large heads. Accordingly, they are classified into high, medium and low head power stations.

- **Run-of-River Hydropower Development**

The run-of-river plants generate electricity with the continuous stream flow as it comes throughout the year with minor seasonal variations; normally there being little or no pondage or provision is only for taking care of diurnal fluctuations. The available flow governs the capacity of the plant. A weir or barrage is usually constructed across a river or stream, which raises the water level creating some head for power generation. This type of development has minimal impact on environment as this does not substantially alter the original topography along the banks of the stream or river because submergence is low.

Another type of run-of-river hydropower development is the diversion canal plant. This plant generates power by taking advantage of the level difference on a curved meandering stretch of the river with a steep bed slope. A diversion canal with a flat slope in which the flow from the river is diverted takes off from the higher reaches of the main river. A weir is constructed at the end of the canal to create a small pool of water, called the forebay. The water from the forebay is fed by means of the penstocks to the power house situated in the lower reach of the stream or river.

- **Pumped-Storage Hydropower Development**

A pumped-storage hydropower development is, in effect, a large storage battery. When the demand for electricity is low, pumped-storage facility stores energy by pumping water from a lower reservoir to an upper reservoir. During periods of high electrical demand, the water is released back to the lower reservoir to generate electricity. A typical pumped-storage plant is a net consumer of energy; it returns approximately 3 kilowatt-hours (kWh) of electricity for each 4 kWh required for pumping. However, it offers the following important benefits:

- The energy generated during peak periods has a higher monetary value than the energy required for pumping during off-peak periods;
- It permits continuous operation of the highest efficiency plants in the utility's system;
- It provides rapid and flexible response to system load changes. Typically, very large load swings can be accommodated; and
- The utility's overall fuel consumption is reduced because the pumped-storage plant's on-peak generation avoids or displaces generation at the least efficient thermal plants in the system.

Normally, the pumping and generation modes at modern pumped-storage plants use the same turbo-machinery and generator-motor equipment. There are cases, however, where separate pumps and turbines are used. Most separate pump and turbine applications are in Europe.

- **Tidal Power Development**

Water at the time of high tide when stored in a basin at a high level can be made to fall into sea during low tide through turbines to produce electricity from tidal power. In a tidal power plant, a basin is formed on an estuary by constructing a dam or a barrage, sluice gates and a powerhouse. The installation capacity of the plant is fixed by economic consideration rather than by available flow. Tidal power generation is, however, has to be justified by the minimum reliable peaking power it generates as an alternative to a stand by thermal plant of similar capacity.

5.2.2 Sizes of Hydropower Plants

In the Philippines, hydro resources for power generation are divided into four categories based on the relation of the power plant size or capacity to the magnitude of socio-economic concerns. They are classified as:

- **Large Hydropower** : more than 50 MW (> 50MW)
- **Small Hydropower** : 10 MW to 50 MW
- **Mini-Hydropower** : 101 kW to 10,000 kW
- **Micro-Hydropower** : up to 100 kW

5.2.3 Classification Based on Available Head

Hydropower plants can be classified on the basis of the operating head or the vertical difference in elevation between water intake and the powerhouse. The general head classifications are:

- **Low Head** : less than 30 meters
- **Medium Head** : 30 to 300 meters
- **High Head** : more than 300 meters

5.3 Hydro Turbines

Hydro turbine is the key element in a hydroelectric power station that converts the energy contained in the water flowing through it into useful mechanical energy of the rotating shaft. The selection, type and specification of other equipment in the power station are dependent upon the hydro turbine and similarly the type of structure and its dimensions and design are also dependent upon the hydro turbine being used at the station (Das, 1996).

5.3.1 Classification of Hydraulic Turbines

The hydraulic turbines are classified based on the following categories:

1. Classification Based on Hydraulic Action:

a. **Impulse Turbine** - The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. There is no suction on the down side of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high head, low flow applications. Impulse turbine includes the following: **Pelton**, **Turgo** and **Crossflow** (Michell-Banki) as shown in **Figure 5-3**.

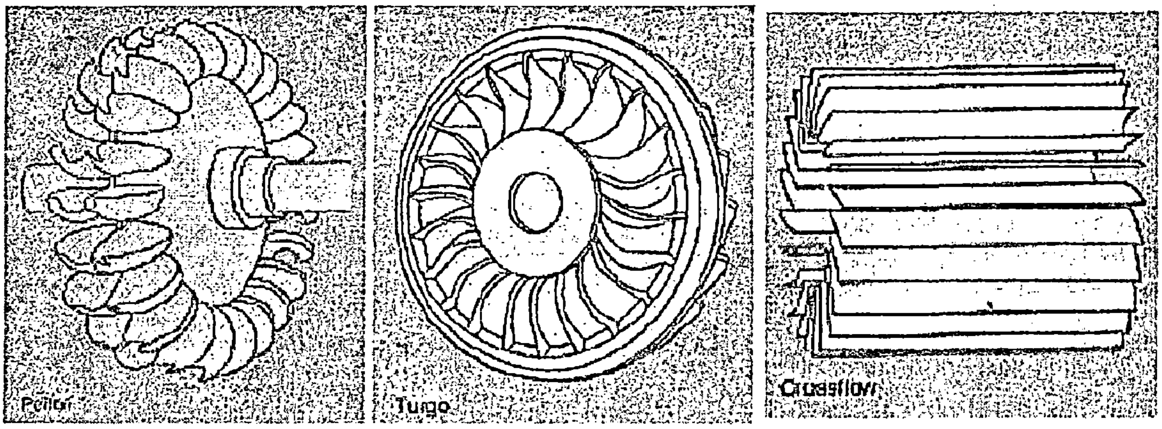


Figure 5-3: Impulse Turbines: Pelton, Turgo and Crossflow Turbines

b. **Reaction Turbine** - A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually. Reaction turbines are generally used for sites with lower head and higher flows than compared with the impulse turbines. Reaction turbines includes; **Francis, Kaplan, Propeller, Bulb, Straflo. Figure 5-4** and 5-5 shows the reaction turbines and cross-section of Kaplan turbine plant.

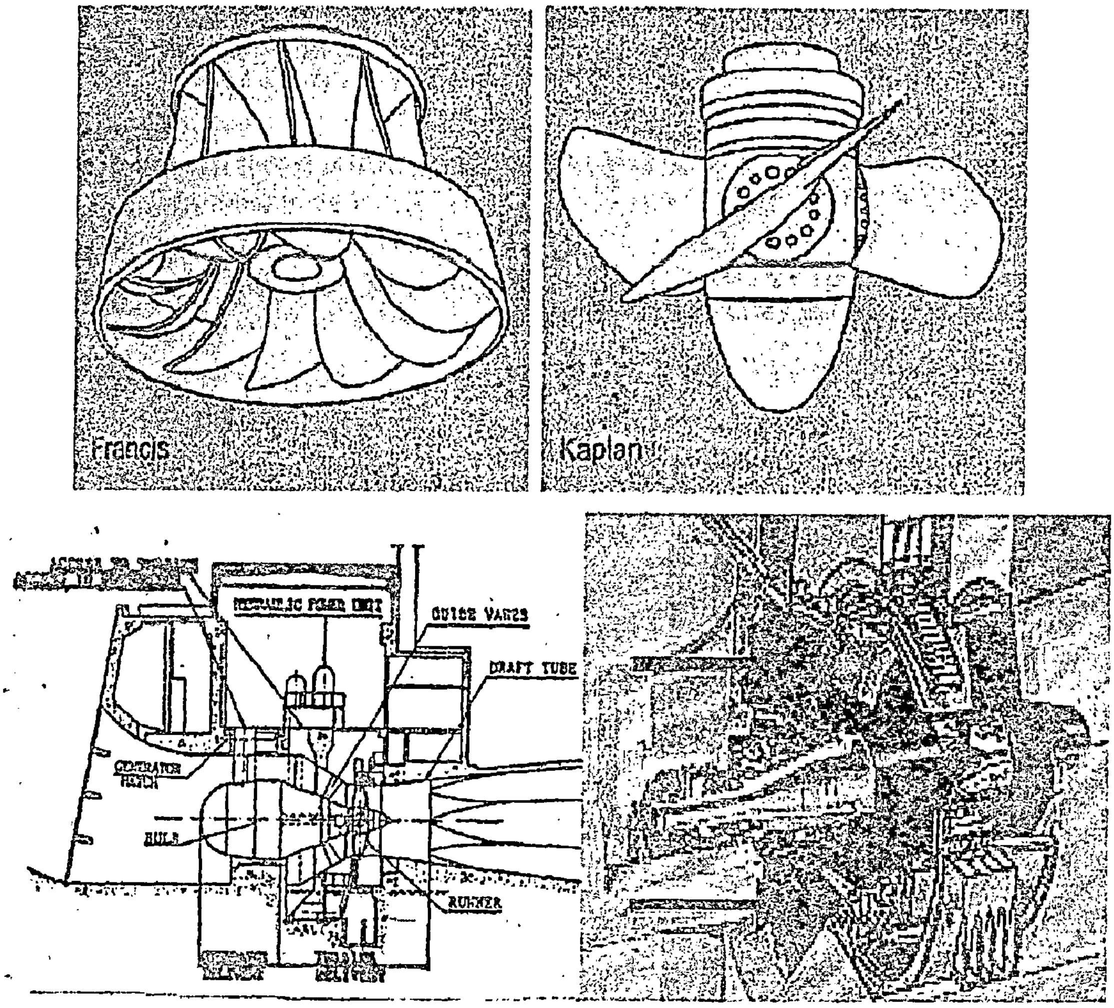


Figure 5-4: Reaction Turbines: Francis, Kaplan, Bulb and Straflo Turbines

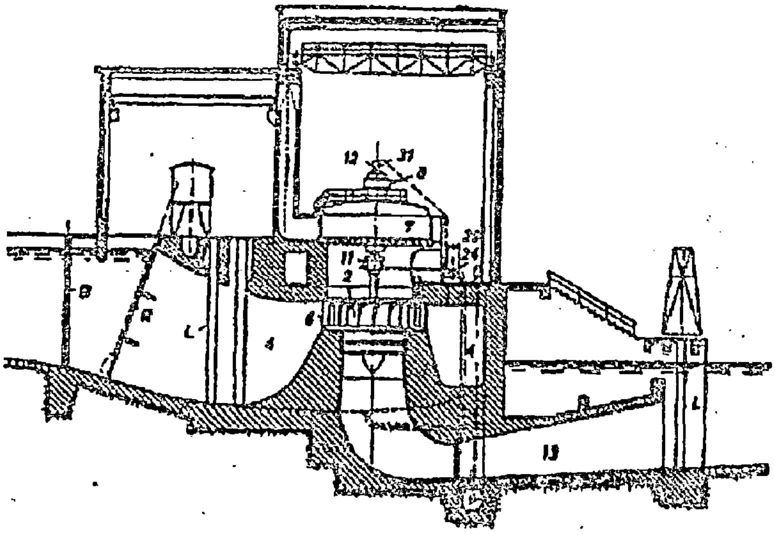


Figure 5-5: Vertical Section of a Kaplan Turbine Plant

2. Classification Based on Direction of Flow

Types of turbine with respect to the direction of flow are given in **Table 5-1.**

Flow Direction	Type of Turbine
Radial inward or mixed type	Francis
Tangential	Pelton, Turgo, Crossflow
Axial	Propeller, Kaplan, Bulb, Straflo, Tubular
Diagonal	Deriaz

Table 5-1: Type of Turbine based on Flow Direction

3. Classification Based on Specific Speed

Types of turbine based on specific speed are given in **Table 5-2.**

unit?

Type of Turbine	Specific Speed
Pelton	15 - 65
Francis	60 - 400
Kaplan	300 -800
Deriaz	200 - 400

Table 5-2: Type of Turbine based on Specific Speed

4. Classification Based on Head

The types of turbines on the basis of the maximum net head in meters are given in **Table 5-3**. Relationship between head in meters and discharge flow (m^3/s) for small and large capacity hydropower are also shown in **Figure 5-6 and 5-7**.

Type of Turbine	Maximum Net Head (m.)
Pelton	Above 300
Francis	300 – 400; even up to 500 – 600
Deriaz	50 – 150
Kaplan	10 – 60
Bulb	3 – 20

Table 5-3: Type of Turbine based on Various Head

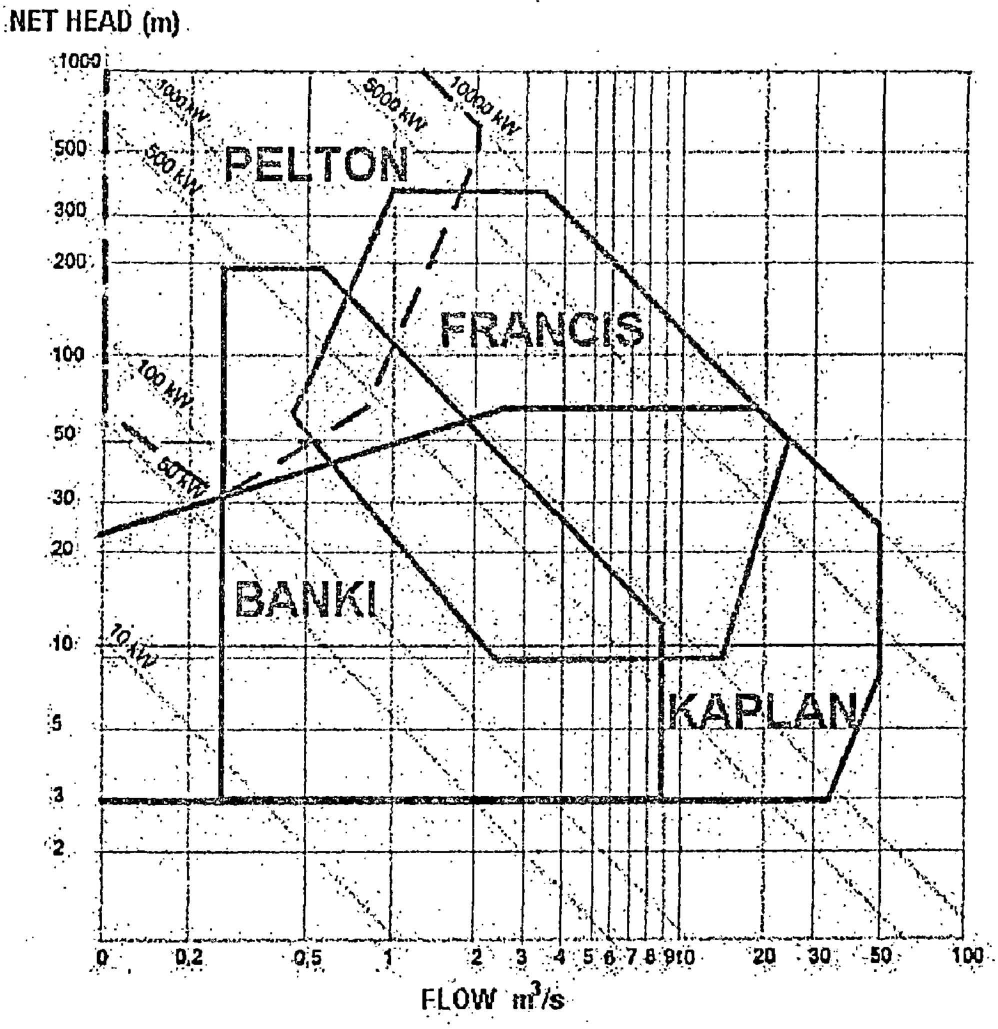


Figure 5-6: Relationship between Head and Discharge Flow

5.3.2 Selection of Turbines

The four types of turbines Pelton, Francis and Kaplan and Bulb turbines mainly have each their own region of speed numbers. In that way they are ideally supplementing each other. Therefore, when the actual speed number is estimated, the determination of the turbine type is normally done as well. On the other hand there are many questions to deal with before relevant values of speed numbers are estimated. Main problems are connected with evaluation of the costs of the plant and the trends in the development of the design of turbines. Furthermore the operating conditions play a principal role.

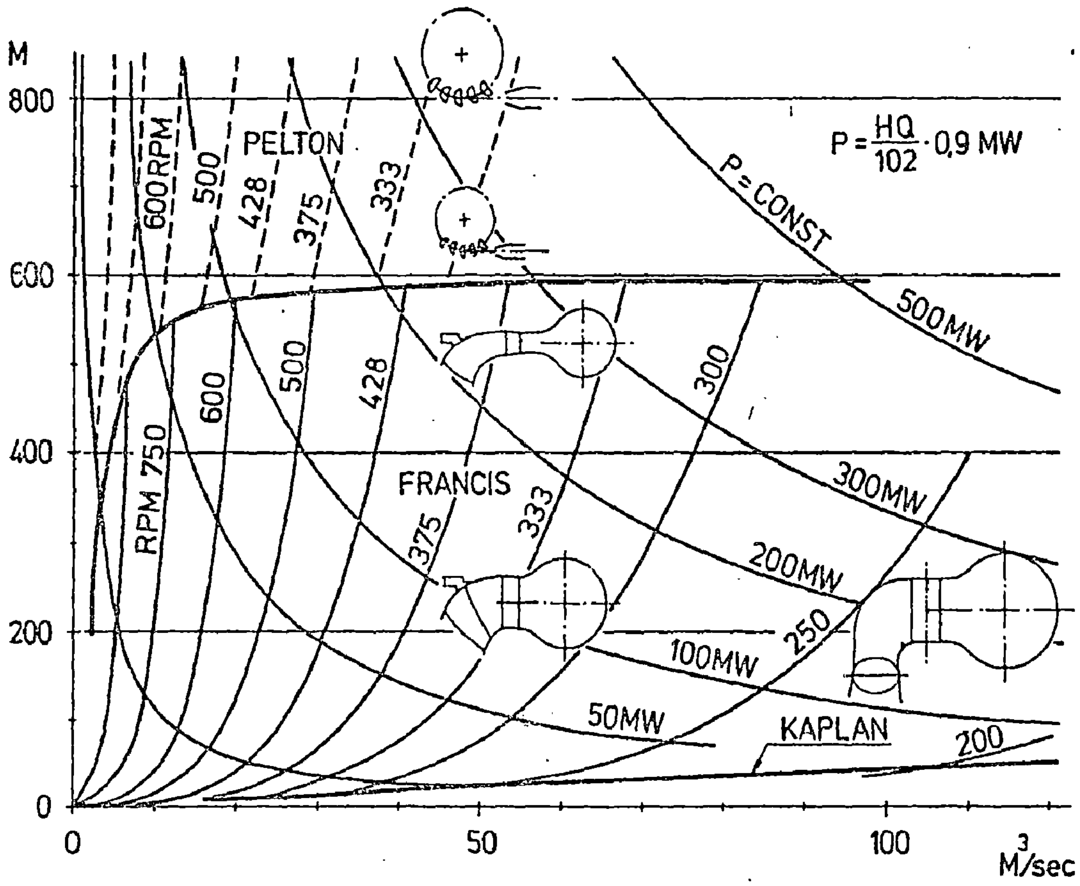


Figure 5-7: **Relationship between Head and Discharge Flow for Large Capacity Hydropower Projects**

The costs of Pelton and Francis turbines are compared in the diagram **Figure 5-8**, where the abscissa divides the diagram in one upper field where the Pelton are the cheapest turbines and one lower field where the Francis are the cheapest ones. The prices of the turbines of the same type become cheaper the higher the rotational speed. That means a decreasing price with increasing speed number. **Figure 5-9** again shows the limit price curve between Pelton and Francis fields in a (Q - H)-diagram, which also has curves of constant power output and constant rotational speed for Pelton and Francis turbines respectively.

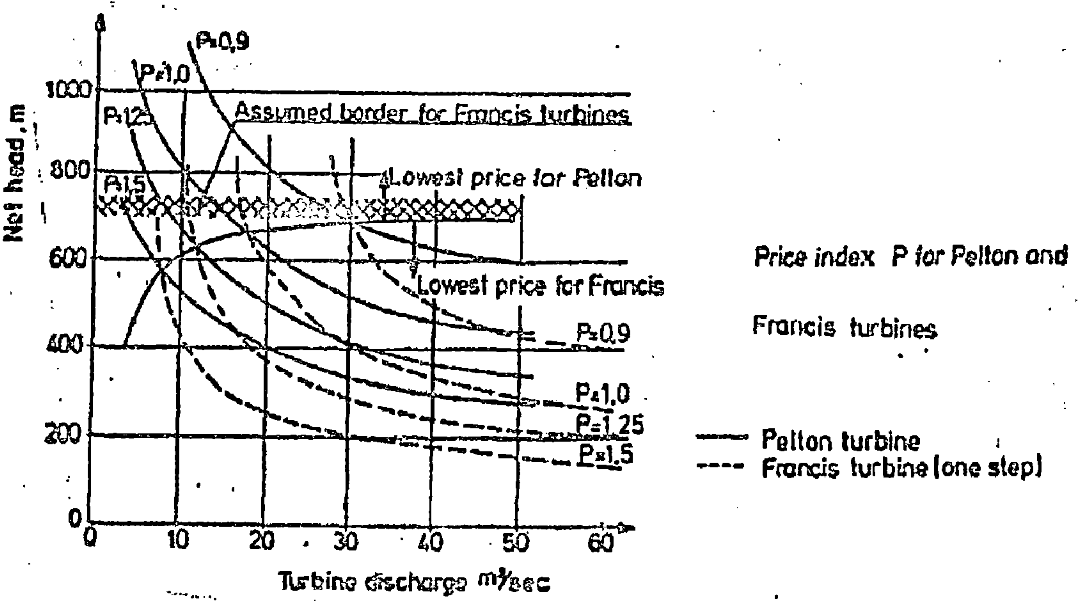


Figure 5-8: Comparison of Price Index between Pelton and Francis Turbines

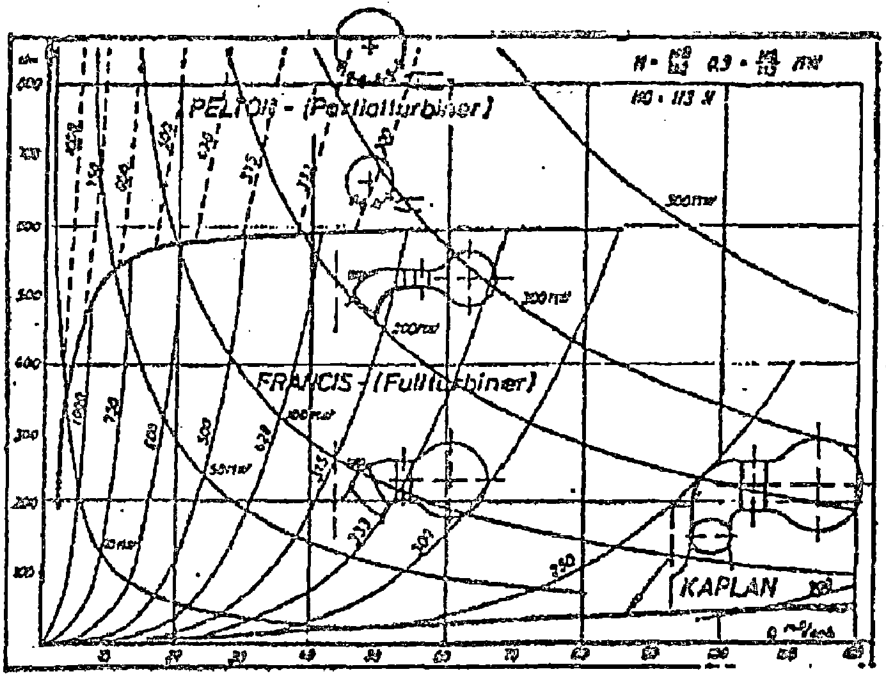


Figure 5-9: Diagram Indicating Decreasing Prices versus Increasing Speed Number of Turbines

The **Figures** 5-8 and 5-9 show that Francis turbines can be the cheapest choice for heads up to 700 meters and even higher for large units. But for higher heads than this limit the Pelton turbines are ruling the domain.

However, to compare the ***economy*** of the turbines the ***efficiency characteristics*** must be compared as well. **Figure 5-10** shows average qualitative efficiency curves of four types of turbines as functions of capacity ratio. Generally the Pelton and Kaplan turbines perform the well rounded efficiency curves, while the Francis turbines and also the propeller without any adjusting control of the runner blades, perform more pointed efficiency curves the higher the speed number.

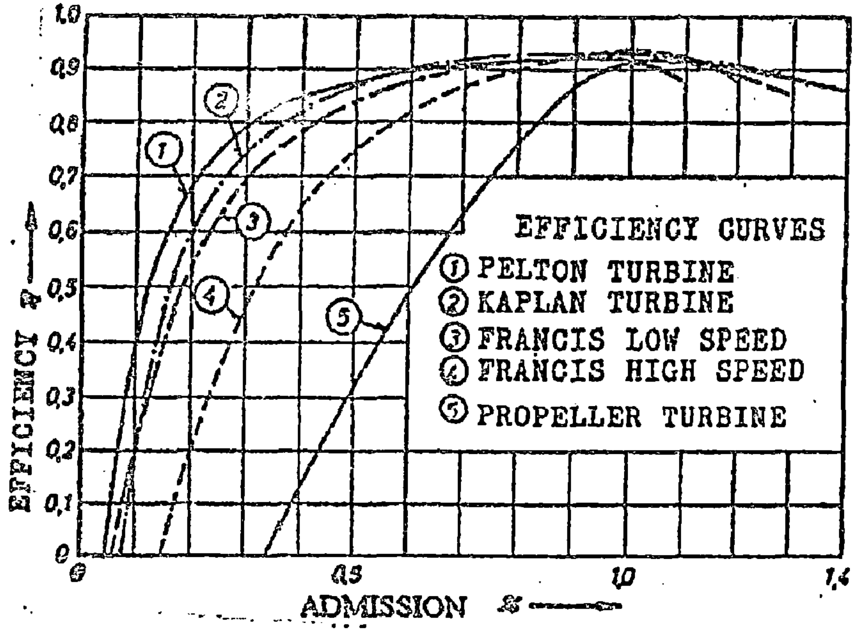


Figure 5-10: Efficiency Characteristics of Different Types of Turbines as a Function of Capacity Ratio

For the best efficiency point it can be noticed a slight increase in the optimal efficiency value of Francis turbines with increased speed number. This is due to a reduction of frictional losses. But the character of this tendency depends also on the design and the finish of the guide vanes and the runner.

The choice between Francis and Kaplan turbines may be made in a similar way as for Francis and Pelton turbines. But the parameters are somewhat different.

In general the Kaplan turbines are chosen for heads below 30 m. But Kaplan turbines have been built for higher heads as well even up to 60 m. The reason is to a large extent given by the more wellrounded efficiency curve compared with a low head Francis turbine (see **Figure 5-10**). A Kaplan turbine offers also an advantage with its smaller dimensions for a certain capacity than the corresponding Francis turbine. Especially for large machines where capacities of 200 – 500 m3/sec are wanted the Kaplan turbine is chosen. In this case one big high-speed unit allowing for a cheaper powerhouse than the alternative with more than one Francis turbine or one big Francis turbine which can handle such capacity.

The upper economic and practical limit for the Kaplan turbine head is in the range of 60 m, though extreme cases of 70 - 75 m have been planned for this turbine type as well. The head limit is caused by mechanical strength problems in hub and blades.

For low heads Bulb turbines will be an alternative to the Kaplan turbines. The Bulb turbine offers more favorable inlet flow conditions to the runner than a Kaplan turbine. These favorable flow conditions have the effect that the runner diameter of a Bulb turbine may be made 15 % smaller than for a Kaplan turbine under otherwise equal conditions. The flow conditions will also reduce the cavitation risk for the Bulb turbine, which means a less submergence is needed than for the Kaplan turbine.

The Bulb turbine is still more favorable if only one unit shall be built because the scroll casing of a Kaplan turbine makes the power station much wider. The Bulb turbine will however, reach an upper limit design head because of the concentrated hydraulic load on the concrete foundation through the ribs. Thus the pressure will be limited to 15 - 20 m head for this turbine type.

5.3.3 Power and Efficiency of Hydraulic Turbine

A water flow from an upper level to a lower level represents a hydraulic power potential. This power flow can be utilized in a water power plant by conversion to mechanical power on the shafts of turbines. However, some fractions of the power potential are lost partly in the plant's conduits and partly in the turbines.

The specific energy of a hydro power plant is the quantity of potential and kinetic energy which 1 kilogram of the water delivers when passing through the plant from an upper to a lower reservoir. The expression of the specific energy is Nm/kg or J/kg and is designated as $[m^2/s^2]$.

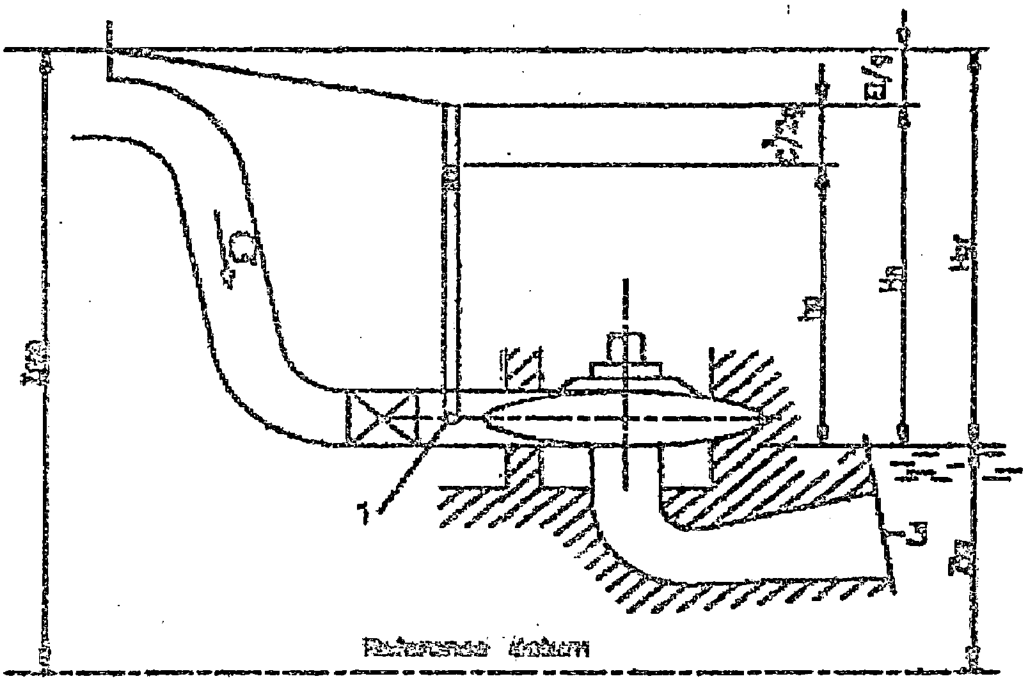


Figure 5-11: Definition of Gross Head, H_{gr} and Net Head, H_n in Hydropower Plant

In a hydro power plant in **Figure 5-11**, the difference between the level of the upper reservoir z_{res} and the level of the tail water z_{tw} is defined as the ***gross head***

$$H_{gr} = z_{res} - z_{tw} \tag{5.1}$$

The corresponding *gross specific hydraulic energy*

$$E_{gr} = gH_{gr} \tag{5.2}$$

where g is the acceleration due to gravity, 9.81 m/s^2.

When a water discharge **Q** [m^3/s] passes through the plant, the delivered power is

$$P_{gr} = \rho Q g H_{gr} \tag{5.3}$$

Where P_{gr} is the ***gross power*** of the plant, kW

ρ is the density of the water, 1000 kg/m^3

Q is the water discharge, m^3/s

g is the acceleration due to gravity, 9.81 m/s^2

H_{gr} is the gross head, m

To look further on the hydropower system in **Figure 5-11,** the specific hydraulic energy between the Sections (1) and (3) is available for the turbine. This specific energy is defined as ***net specific energy*** and is expressed by

$$E_n = gH_n \tag{5.4}$$

and the ***net head*** of the turbine $H_n = \dfrac{E_n}{g}$ (5.5)

As shown on **Figure 5-11,** there are two ways of expressing the evaluation of the net head.

The one way is

$$H_n = h_p + c^2/2g \tag{5.6}$$

And the other way is

$$H_n = H_{gr} - \frac{E_L}{g} = H_{gr} - H_L \tag{5.7}$$

where hp is the piezometric head above tailwater level measured in section (1), $c^2/2g$ is the velocity head in section (1) and E_L/g is specific hydraulic energy loss between reservoir and section (1) converted to head loss H_L.

Thus, the total available net power of a plant is

$$P_n = \rho Q g H_n \tag{5.8}$$

The ***net head*** H_n is defined at the inlet of the turbine referred to the level of the tail water of reaction turbines or the outlet of the nozzle of a jet turbine.

The equation of hydraulic turbine efficiency is expressed as

$$\eta_h = \frac{P_R}{P_n} \tag{5.9}$$

The power transfer to the runner is further exposed to additional losses before the resulting power **P** is transferred to the generator shaft. These losses are composed of mechanical friction in the bearings and stuffing boxes, viscous friction from the fluid between the outside of the runner and the covers of the reaction turbines and ventilation or air friction losses of the runner in impulse turbines. Through the space between the covers and the outside of the runner a leakage flow also passes according to the clearances of the labyrinth seals, from the inlet rim to the suction side of the runner. Some energy is also required for operation of the turbine governor, tapping water for sealing boxes, ejectors and cooling of bearings and the governor oil.

On account of all these losses the turbine efficiency is always lower than the hydraulic efficiency. Therefore, at the discharge **Q** and the power **P** transferred from the turbine shaft to generator shaft, the turbine efficiency is

$$\eta = \frac{P}{P_n} = \frac{P}{\rho Q g H_n} \tag{5.10}$$

Usually the maximum efficiency point which is represented by the best operating conditions, is reaching values of say $\eta = 0.93$ to 0.95 of the larger and best reaction turbines. Corresponding values estimated for the hydraulic efficiency $\eta_h = 0.95$ to 0.97. For the best Pelton turbines η_{max} reaches values about 0.92

5.4 Global Hydropower Potential and Installed Capacity

5.4.1 Global Hydropower Potential

Although hydropower currently provides about one fifth of the world's electricity supply, development of the world's remaining technical potential could, by no means, cover the growth in future demand. However, carefully planned hydropower development can, and does, make a great contribution to improving electrical system reliability and stability throughout the world. Also, future development will play an important role in the improvement of living standards in the developing world, where the greatest hydropower potential still exists. This development, together with the existing installed hydropower capacity (some 700 GW), will make a substantial contribution to the avoidance of greenhouse gas emissions and the related climate change issues.

Current hydropower capacity provides about 19% (2,650 TWh/yr) of the world's electricity supply. Based on information received from WEC Member Committees, supplemented by data published by *The International Journal on Hydropower & Dams*, indicates that the world's total technically feasible hydro potential is about 14 400 TWh/yr, of which just over 8 000 TWh/yr is currently considered to be economically feasible for development. Installed hydro-electric generating capacity is some 692 GW, with a further110 GW under construction (see **Table 5-4**).

Region	Gross theoretical capability	Technically exploitable capability	Total Hydro Installed Capacity	Actual Generation in 1999	Capacity under Construction
	TWh/yr	TWh/yr	MW	GWh	MW
Africa	3,876	1,888	20,170	73,159	2,471
North America	6,818	1,668	160,113	711,225	1,937
South America	6,891	2,792	106,277	496,016	15,873
Asia	16,443	4,875	174,076	567,501	71,171
Europe	5,392	2,706	214,368	735,655	8,917
Middle East	688	218	4,185	8,434	9,751
Oceania	596	232	13,231	41,918	63
Total World	**40,704**	**14,379**	**692,420**	**2,633,908**	**110,183**

Table 5-4: World Hydropower Status at end of 1999 (all schemes)

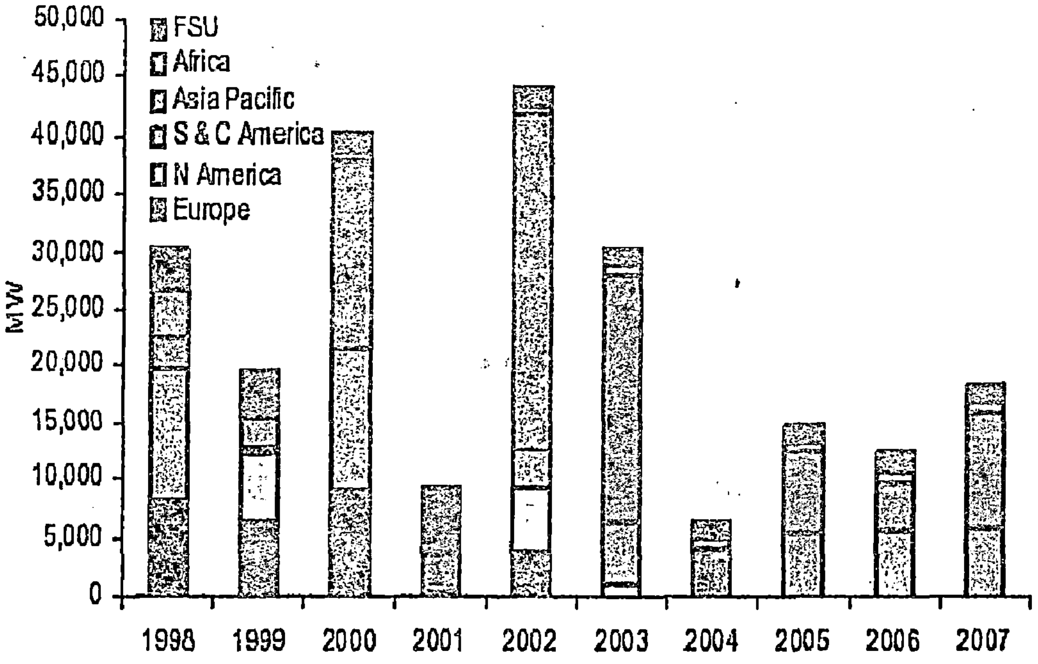


Figure 5-12: Hydropower – Annual Installed Capacity by Region 1998-2007

MW	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*03-07*
Europe	8,155	6,512	8,976	352	3,759						0
N America		5,632			5,707	1,170					1,170
S & C America	11,636	704	12,672		3,139	5,310		5,416	5,551	5,690	21,966
Asia Pacific	2,784		16,192	3,344	29,200	21,600	4,162	7,041	4,330	10,256	47,390
Africa	4,190	2,464	704	176	805	825	846	867	889	911	4,338
FSU	3,608	4,283	1,584	5,632	1,449	1,471	1,493	1,516	1,538	1,561	7,580
Total	30,373	19,595	40,128	9,504	44,060	30,376	6,501	14,840	12,308	18,418	82,444

Table 5-5: Hydropower – Annual Installed Capacity by Region 1998-2007
Source: BP Statistical Review 2002, IEA, Douglas-Westwood

Hydro currently represents 17% of global electricity generation and is expected to maintain growth in the region of 1-2% per annum, very much in line with global primary energy demand of 1.7% per annum. Asia Pacific is expected to maintain its position as the area of significant growth with China the largest single market. The Asia Pacific market is driven primarily by the need for copious amounts of new generating capacity to satisfy its growing industrial and domestic needs. Indeed, the period is dominated by the massive Three Gorges Dam in China, which will bring an enormous amount of capacity online when it is finally complete, albeit at catastrophic humanitarian and environmental costs.

The environmental concerns surrounding large-scale hydro systems are acting as a brake on many developments, particularly in OECD countries. However, whilst such concerns are important in developing countries they are challenged by ever pressing demands for increased power supply and although small-scale hydro schemes are popular, only large scale schemes can deliver the volumes required by many of the world's developing nations.

5.4.2 Philippine Hydropower Potentials

The hydro resource potential of the Philippines is estimated at around 14,367 MW. In the main island of Luzon, 8,874 MW of the 10,000 MW of hydro potentials remain to be developed in the future. Of the 10,000 MW Luzon potentials, more than 30% of which are located in the provinces comprising the Cordillera Autonomous Region

(CAR). The Southern Tagalog region is next with more than 1,500 MW or around 15% of the total potential. For the Visayas, around 638 MW of untapped hydroelectric power resources were identified while in Mindanao, 2,641 MW can still be harnessed. On the countryside basis, around 11,913 MW of hydro capacity or about 83% of the total potential capacity, offer an opportunity for future development.

In terms of individual capacity, there are 28 large hydro potential sites with capacities ranging from 52 MW to 600 MW. Total large hydro potential stands at 4,400 MW, small hydro at 1,150 MW and mini-hydro at 3,600 MW.

The Philippine hydropower database prepared by the Philippine Department of Energy in February 2003 identified 60 proposed small and large hydropower projects for future development ranging from 11.3 MW to 345 MW with a total combined capacity of 3,375 MW. The existing operational large and small hydroelectric power capacities are 2,223 MW and 141 MW respectively. Additional to the existing large hydro will be the San Roque hydroelectric power plant in Region 1 with an installed capacity 345 MW which is still under construction and will be commissioned in 2005. Kalayaan Hydroelectric power plant, the only existing pumped-storage type hydropower plant in the Philippines is in the process of upgrading its capacity from 300 MW to 350 MW and the additional capacity will be on-line in 2004.

The total identified mini-hydropower resource potential is about 1132.476 megawatts (MW). To date, there are 51 existing mini-hydroelectric plants with a combined installed capacity of 89.07 MW, which represents a mere 7.9 % of the identified mini-hydro resource potential. The DOE has undertaken an extensive assessment, feasibility study and promotion of implementable mini-hydro sites.

For the period 2000-2009, the DOE has identified 12 mini-hydro sites for development with a combined capacity of 70,190 kW. This will represent an additional contribution of 307.43 Gigawatt-hour (GWh) to the energy mix and will displace an equivalent of 0.53 million barrels of fuel oil equivalent (MMBFOE). By the end of 2009, the total mini-hydropower capacity is expected to reach 159.26 MW, producing an average energy generation of 557.43 GWh.

The 70.19 MW capacity additions during the period 2000-2009 will form part of the 368.77 MW mini-hydro capacities identified for implementation up to 2025. At the end of this period, the total mini-hydro capacity is about 457.84 MW representing 40.43% of the total identified mini-hydro resource potential with an estimated annual average energy generation of 2,005.34 GWh.

The country has 51 existing mini-hydropower facilities spread across the Philippine archipelago, with an installed capacity of 82.07 MW. A 7 MW plant in Bukidnon is already nearing completion thus increasing the total installed capacity to 89.07 MW. This magnitude represents a mere 3.86 % of the total installed hydropower capacity of 2,304.64 MW. The average annual power generated by these mini-hydro plants is around 200 Gigawatt-hours contributing 0.34 million barrels of fuel oil equivalent (MMBFOE) to the country's energy mix.

The mini-hydropower contribution to the country's energy mix is expected to grow from 0.515 MMBFOE in 1999 to 0.875 MMBFOE by the year 2009 with the development of additional 12 mini-hydropower sites nationwide. Aggregate installed mini-hydropower capacity is expected to reach 151.29 MW at end of the 10 yr. planning period.

5.5 Economics

The economics of power generation through non-renewal sources of power- fossil fuels - changes with the exploitation of every successive ounce of such fuels. The renewable sources of hydro and tidal offer the only option in the long run. With the status of technologies developed for exploitation of this renewable sources of energy and substantial unexploited potential, along with a number of other major technical and economic advantages by virtue of non-polluting nature, high conversion efficiency, flexibility in operation, relatively low cost of generation, operation and maintenance, longer life of equipment, etc., hydropower development is economically attractive.

Comparing to other renewable energy technologies, hydropower is a very well-established technology. The water-control systems and the turbo-generators to extract the power are standard items. There are various installations of hydropower plants in operation around the world, which produce a large range of electricity from hundreds of watts to megawatts. Despite all the available data, it is very difficult if not impossible to generalize meaningfully about "the cost of hydroelectric power'.

The reason lies in the combination of heavy front-end loading and extremely site-specific construction costs. The dominant factor in determining the total cost per unit output is the initial capital cost, and a major part of this can be the civil engineering costs which vary greatly from site to site. On average, the civil works account for perhaps two-thirds of the total capital cost. But it could be over 80%- or at the other extreme, if the plant can make use of existing dams and reservoirs, as little as 25%. Assuming that the machinery cost to be fixed amount for a given plant capacity, thus the total capital cost can vary between less than half and more than twice the average. This could certainly make the difference between viability and non-viability of the hydropower project.

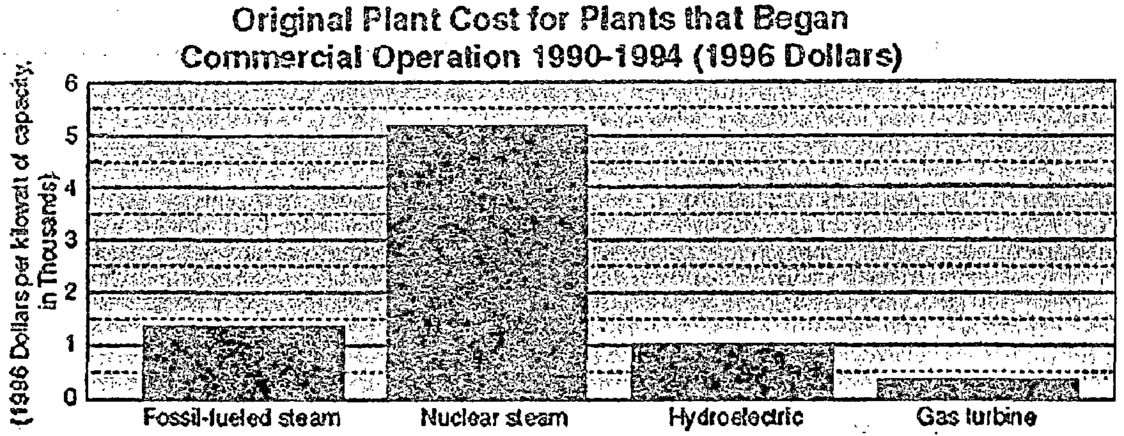
Where a specific new proposal for hydropower development is concerned, past experience means that the capital cost can be estimated rather accurately, using various methods of appraising and expressing the economics of the project. These economic indicators are simple payback period (years), simple return of investment (ROI), net present value (NPV), internal rate of return (IRR) and benefit-cost ratio (B/C). Wide range of estimates can result from different plant sizes and sites. In Europe for example, the original 1989 estimate for the new Danube scheme was about $1,200 per installed kilowatt (New Civil Engineer, 1989). It is claimed that the capital cost of the huge Itaipu plant in Brazil, South America was as low as $800 per kW (Helps,1990), but on the other hand, World bank figures indicate an average of $1900 per kW (1988) for the 'Third World' hydropower development (Munasinghe, 1989). In U.S., 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 also depends on the specifics of each site.

In calculating the effect of capital cost on the cost per unit of output (British pence or U.S. cents per kilowatt-hour), the critical non-economic factor is the load factor of the plant. Clearly, it makes a great deal of difference to the return on investment whether the plant runs constantly at full power, or intermittently, using on average only a fraction of its installed capacity. Hydroelectric plant world-wide runs with an average load factor of 40%, compared with perhaps 60% - 80% for conventional (fossil fuel or nuclear) base-load plant in general. There are three main reasons why the load factor of any plant will be less than 100%: shortage of input, lack of demand, and outage during maintenance or due to equipment failure. The speed of response of hydroelectric plant favors its use for rapid load-following rather than base load in systems where it co-exists with other types, and its load factor will obviously be low in these circumstances. As compensation, it has a long lifetime. Furthermore, a hydropower plant has a high cost of transmitting its electricity to consumers due to its isolated sites or locations thus requiring long power transmission lines.

To calculate the anticipated cost per unit of output it is necessary to estimate:

- the capital cost and anticipated time-scale for construction;
- the annual operating and maintenance costs;
- the load factors over the life of the plants;
- the appropriate discount rate

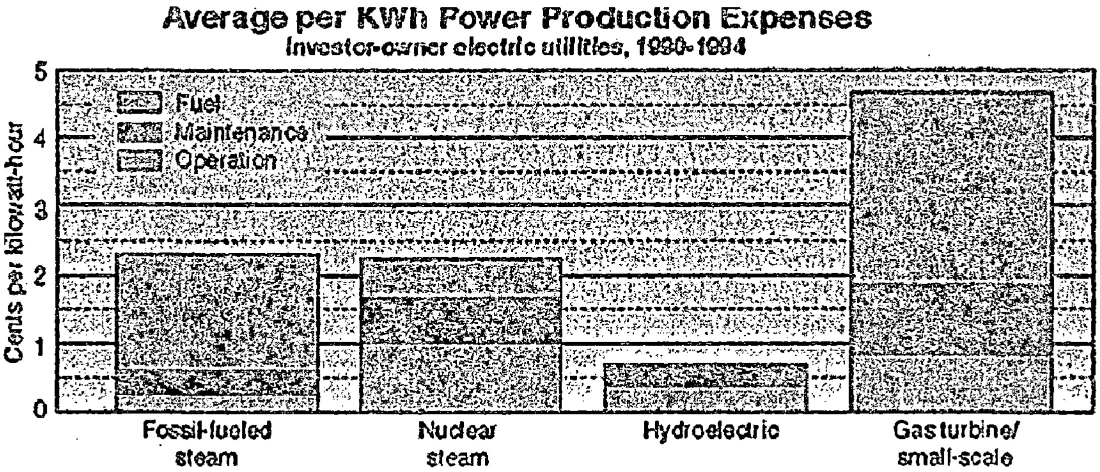
An approximate cost can be obtained in the case of hydropower by assuming that the running costs are small compared to the cost of the capital investment, and that the load factor remains the same throughout the life of the plant. The cost in pence per kilowatt-hour on these assumptions is approximately equal to the capital cost in £ per kW divided by 350. In Scotland, for instance, with its large proportion of hydro power, the average unit cost (1994) is only 1.5 pence per kilowatt-hour. In U.S., it costs about one cent per kWh (kilowatt-hour) to produce electricity at a typical hydro plant. In comparison, it costs coal plants about four cents per kWh and nuclear plants about two cents per kWh to generate electricity as shown in **Figure 5-13**. Producing electricity from hydropower is cheap because, once a dam has been built and the equipment installed, the energy source—flowing water - is free. Hydropower plants also produce power cheaply due to their sturdy structures and simple equipment. Hydro plants are dependable and long-lived, and their maintenance costs are low compared to coal or nuclear plants.



EIA, Electric Plant Cost and Power Production Expenses 1990, Table 5
EIA, Electric Plant Cost and Power Production Expenses 1991, Table 5
EIA, Financial Statistics of Major U.S. Investor-Owned Electric Utilities 1992, Table 4
EIA, Financial Statistics of Major U.S. Investor-Owned Electric Utilities 1993, Table 4
EIA, Financial Statistics of Major U.S. Investor-Owned Electric Utilities 1994, Table 4

43 Plants Placed in Service During Period and Financial Data Is Available.
6 Hydropower, 8 Fossil-Fueled Steam Electric
29 Gas Turbine, 0 Nuclear Steam Electric
Costs Indexed to 1996 Dollars at 3% annually

Figure 5-13: Hydroelectric Power Plant Cost that Began Commercial Operation, 1990 -1994



Note: Operation expenses include rent. Hydroelectric includes pumped storage. Small-scale includes internal combustion, wind, and solar.
Source: EIA/DOE, Financial Statistics of Major U.S. Investor-Owned Electric Utilities, 1994, Table 14.

Figure 5-14: Hydroelectric Power Plant Average per kWh Power Production Expenses, 1990 -1994

5.6 Environmental and Social Issues

A fear syndrome has been created in the recent years against hydropower development projects by exaggerating the likely or assumed adverse environmental impacts and by ignoring and suppressing their needs and tremendous benefits. Anxiety is perhaps caused as a result of absence of information on the steps being taken, overestimating the effects of damages and underestimating the benefits of these projects.

Environmentalists have their prejudices and apprehensions about hydropower projects and doubt about the effectiveness of mitigative measures in-spite of a growing awareness among the hydropower developers about the need to take all the necessary mitigation measures to minimize their adverse impacts (Singh, 2002).

5.6.1 Environmental and Social Impacts of Large Hydroelectric Projects

While hydro power has benefits in terms of carbon dioxide emissions and air pollution, it also has significant negative environmental impacts. Hydro-electric power installations have a detrimental effect on river flows and water supplies. Large-scale hydro schemes result in the flooding of large areas of land, often leading to the displacement of people living in the area, and to negative impacts on local fauna and flora. Proposed hydro power projects often face pressure from environment and human rights groups concerned about the social and environmental impacts of the projects, eg. the 18.2GW Three Gorges dam project in China, the 2.4GW Bakun project in Malaysia, the 400MW Maheshwar and 1,000 MW Tehri projects in India and 345 MW San Roque Multi-purpose Hydro Project in Philippines.

Any developmental project is bound to have some adverse effect on the environment. A typical hydroelectric projects being large in size, affects a large number of environmental components having manifold dimensions of impacts- positive as well as negative. Each category of positive and negative impacts can further be classified as direct or indirect, short term or long term, tangible and intangible, local or regional and reversible or irreversible. The direct impacts result from the physical presence of the facilities and the way they are designed, build and operated. The indirect impacts stem from the economic activities surrounding construction and the induced economic effects resulting from improved access. Each and every hydroelectric project does not have all the positive and negative impacts. Moreover, some impacts may be only marginal. Following are the stages of impacts of hydroelectric projects.

- **Pre-construction Stage** – These activities are taken up prior to start up of the actual construction of the project and include land acquisition and rehabilitation and resettlement. These activities may not have any direct impact on environment as such but may lead to socio-economic impacts from the local inhabitants who are likely to be displaced and relocated or lose their properties due to land acquisition or submergence.

- **Construction Stage** – Construction of hydroelectric projects cause land alterations in accordance with the project design and a variety of physico-chemical (due to clearing of vegetative cover thereby causing soil erosion resulting in turbidity in surface runoffs), ecological (due to removal of forests and field habitat resulting in destruction of terrestrial organisms), aesthetic and socio-economic (related to generation of employment, displacement, loss of natural resources coming under submergence and other areas to be acquired for project work) impacts of varying duration and magnitude.

- **Operation Stage** – Operation of hydroelectric projects involves various activities and includes reservoir filling, flood control and other functions such as pumping, conveyance and release of water, generation of electricity, all of which can cause impacts on flow regime in the river, ecology, aesthetics, socio-economics and health.

➢ Negative Impacts

Artificial reservoirs required for hydroelectric projects have some adverse impact on environment of varying intensity depending upon physiography, climate, river flows and the pattern and size and locations of the projects. They do result in submergence of large tracts of land forest and disturb established habitats of human and wildlife. As such it become unavoidable the adverse or negative impact of hydroelectric projects viz. deforestation, loss of bio-diversity including disappearance of rare species of animals and plants, soil erosion, faster rate of reservoir sedimentation, socio-economic implications, relocation and rehabilitation of people, increased in seismic risk, change in aquatic system, climatic change, change in flow regimes downstream of the dam and outbreak of disease.

➢ Positive Impacts

While expressing concerns about the adverse environmental impacts of hydroelectric projects, there are also beneficial ecological changes brought about by these projects. These projects may help in rolling back the process of deforestation, converting semi-arid areas into lush green fields of food crops, moderating the climate, change the life-style of the people of the area. Following are the additional benefits or positive impacts accrued from large storage based hydroelectric projects which include reduction in drought frequency, flood moderation, assured supply of drinking water and water for irrigation and industry, benefits of electricity generation with consequent economic progress, improved food production, tourism, additional employment opportunities, pisciculture, afforestation, good water recharge, etc. benefit the humanity at large and are so immense that they outweigh the costs of the immediate human and environmental disruptions and the feared negative impacts, which are in fact apprehensive and can be kept to a minimum by integrating environmental concerns in the project planning.

5.6.2 Environmental and Social Impact of Small Hydropower Development

Compared to storage based hydroelectric projects, small hydropower schemes are considered to be less destructive to aquatic life, and cause less damage to the general environment and other aesthetic factors. The small hydropower schemes have relatively small associated reservoirs for which available storage space or impoundment time is of little concern. Some of these reservoirs may be small regulating reservoirs with cycle times measured in hours or days instead of months or years. Others of these reservoirs may have little or no active pool such as in run-of-river plants.

The small hydropower is distinct from the conventional high and medium size hydroelectric projects in that it is simple in layout and mostly does not interfere with the existing regime of the flowing water. They involve minimal submergence, rehabilitation and resettlement, deforestation, etc. and practically no adverse effect on the environment and ecology of the area.

Recent trends towards awareness of environmental issues needs to be strengthened. But it is undesirable to take a narrow view of the environment by focusing on only one or a few aspects and neglecting the others. A holistic approach is needed in examining, analyzing and evaluating both positive and negative environmental impacts of hydroelectric projects (Singh, 2002).

ENERGY STORAGE SYSTEM

6.1 Overview of Energy Storage System

Energy storage systems are enabling technologies, as their goal is to enhance and extend the operating capabilities of other assets on the grid. Although electricity cannot be (cheaply) stored directly, it can be easily stored in other forms and converted back to electricity when needed. By decoupling the production and consumption of electricity, resources such as solar and wind energy that may normally not be cost-effective can be made competitive and viable solutions to a far wider set of energy needs.

Electric power has a tremendous weakness; it must always be used precisely when it is produced. Based on this tenuous balance of supply and demand, its inherent monetary value also changes by the hour. Storage not only helps marginally competitive resources get around these limitations, but can also improve the economic efficiency and utilization of the entire system. By optimizing the existing generation and transmission assets in the system, less capital is needed to provide a higher level of service - while giving energy sources such as renewables more opportunities for development.

Grid-connected distributed power type generation can be augmented by energy storage in three ways. First, energy storage can be used for stabilization purposes, permitting the distributed power generation to run at a constant, stable output level, even if the loads fluctuates greatly and rapidly. Second, proper amount of storage can provide energy to ride through periods when the distributed power generation unit is unavailable, i.e. when the distributed power generation unit is being maintained or repaired. Third, energy storage can permit a non-dispatchable distributed power generation unit to operate as a dispatchable unit, by permitting its output at any moment to differ from the power being released to the demand or into the grid.

6.2 Energy Storage Technologies

Energy technologies can be categorized as: (1) those needed to convert an energy source into electricity or heat, and (2) those used for energy storage. Possibilities under the first category for small scale applications include diesel-electric generators (DEGs), wind turbines, micro turbines, hydro power, thermoelectric generators, photovoltaic devices, fuel cells, furnaces and boilers, and hybrid systems combining two or more of the above technologies. For the second, one can consider conventional fossil fuels, hydrogen, thermal, hydro and compressed air storage, flywheels and batteries.

Storage is a critical part of any technology where the energy resource is intermittent, such as wind and other solar energy. Energy storage densities can vary from 38kW-hr/kg for hydrogen down to 0.02 kW-hr/kg for lead acid batteries. Premium fossil fuels such as fuel oil and natural gas have storage densities around 13 kW-hr/kg [20,000 Btu/lb-m]. These fuels can be used in heat engine such as DEGs to produce about 1 unit of electricity per 3 units of fuel.

A number of energy storage technologies have been developed or are under development for electric power applications. These are:

- Pumped hydropower
- Compressed air energy storage (CAES)
- Batteries
- Flywheels
- Superconducting magnetic energy storage (SMES)
- Supercapacitors

6.2.1 Pumped Hydro

Pumped hydro has been in use since 1929, making it the oldest of the central station energy storage technologies. In fact, until 1970 it was the only commercially available storage option for large generation applications. Conventional pumped hydro facilities consist of two large reservoirs, one is located at base level and the other is situated at a different elevation. Water is pumped to the upper reservoir where it can be stored as potential energy. Upon demand, water is released back into the lower reservoir, passing through hydraulic turbines which generate electrical power as high as 1,000 MW. Figure 6-1 shows a typical pumped-storage hydropower plant.

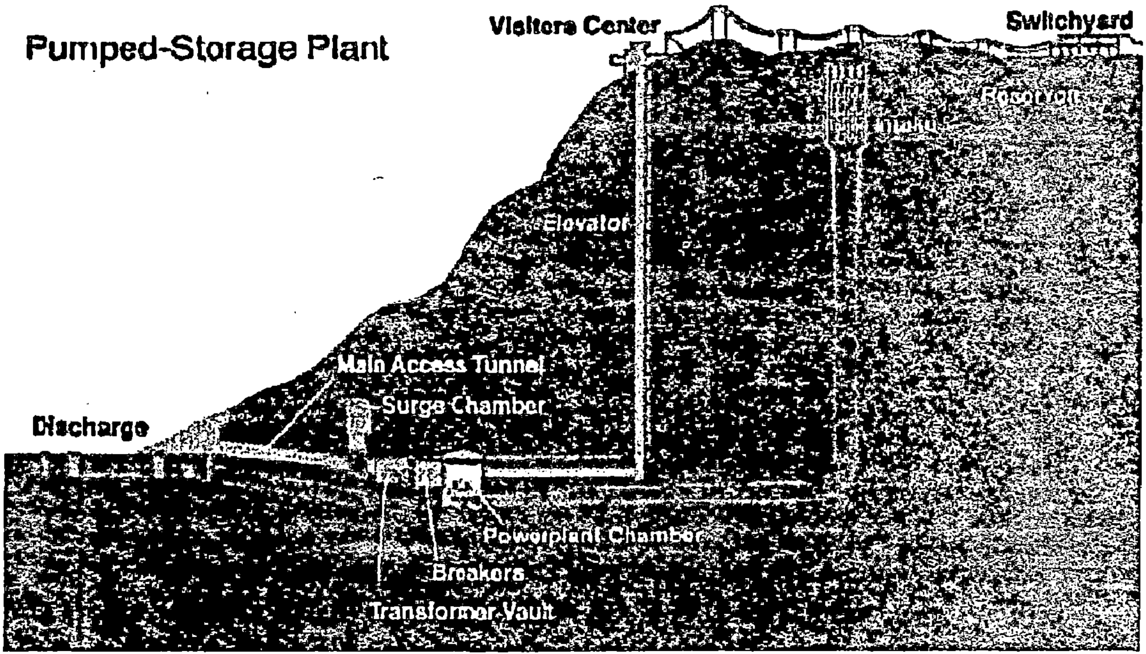


Figure 6-1: A Typical Pumped-Storage Hydroelectric Power Facility

The barriers to increased use of this storage technology include high construction costs and long lead times as well as the geographic, geologic and environmental constraints associated with reservoir design. Currently, efforts aimed at increasing the use of pumped hydro storage are focused on the development of underground facilities.

6.2.2 Compressed Air Energy Storage (CAES)

CAES is not a simple energy storage system like other batteries. It is a peaking gas turbine power plant that consumes less than 40% of the gas used in conventional gas turbine to produce the same amount of electric output power. This is because, unlike conventional gas turbines that consume about 2/3 of their input fuel to compress air at the time of generation, CAES pre-compresses air using the low cost electricity from the power grid at off-peak times and utilizes that energy later along with some gas fuel to generate electricity as needed. The compressed air is often stored in appropriate underground mines or caverns created inside salt rocks. It takes about 1.5 to 2 years to create such a cavern by dissolving salt.

The first commercial CAES was a 290 MW unit built in Hundorf, Germany in 1978. The second commercial CAES was a 110 MW unit built in McIntosh, Alabama in 1991. The construction took 30 months and cost $65M (about $591/kW). This unit comes on line within 14 minutes. The third commercial CAES, the largest ever, is a 2700 MW plant that is planned for construction in Norton, Ohio. This 9-unit plant will compress air to 1500 psi in an existing limestone mine some 2200 feet under ground.

6.2.3 Batteries

In recent years, much of the focus in the development of electric energy storage technology has been centered on battery storage devices. There are currently a wide variety of batteries available commercially and many more in the design phase. In a chemical battery, charging causes reactions in electrochemical compounds to store energy from a generator in a chemical form. Upon demand, reverse chemical reactions cause electricity to flow out of the battery and back to the grid.

The first commercially available battery was the flooded lead-acid battery which was used for fixed, centralized applications. The valve-regulated lead-acid (VRLA) battery is the latest commercially available option. The VRLA battery is low-maintenance, spill- and leak-proof, and relatively compact. Zinc/bromine is a newer battery storage technology that has not yet reached the commercial market. Other lithium-based batteries are under development. Batteries are manufactured in a wide variety of capacities ranging from less than 100 watts to modular configurations of several megawatts. As a result, batteries can be used for various utility applications in the areas of generation, T&D, and customer service.

6.2.4 Flywheels

Flywheels are currently being used for a number of non-utility related applications. Recently, however, researchers have begun to explore utility energy storage applications. A flywheel storage device consists of a flywheel that spins at a very high velocity and an integrated electrical apparatus that can operate either as a motor to turn the flywheel and store energy or as a generator to produce electrical power on demand using the energy stored in the flywheel. The use of magnetic bearings and a vacuum chamber helps reduce energy losses. A proper match between geometry and material characteristics influences optimal wheel design. As a result, engineers have focused on the development of materials with high working strength-to-density ratios. Development of flywheels for utilities has been focused on power quality applications.

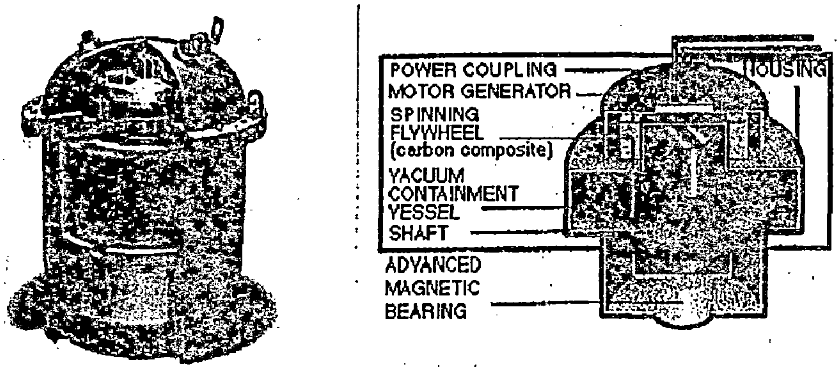


Figure 6-2: Flywheel Energy Storage Devices

6.2.5 Superconducting Magnetic Energy Storage (SMES)

A SMES system stores energy in the magnetic field created by the flow of direct current in a coil of superconducting material. To maintain the coil in its superconducting state, it is immersed in liquid helium contained in a vacuum-insulated cryostat. The energy output of a SMES system is much less dependent on the discharge rate than batteries. SMES systems also have a high cycle life and, as a result, are suitable for applications that require constant, full cycling and a continuous mode of operation.

Although research is being conducted on larger SMES systems in the range of 10 to 100 MW, recent focus has been on the smaller micro-SMES devices in the range of 1 to 10 MW. Micro-SMES devices are available commercially for power quality applications.

5.2.6 Advanced Electrochemical Capacitors

Supercapacitors (also known as ultracapacitors or supercapacitors) are in the earliest stages of development as an energy storage technology for electric utility applications. An electrochemical capacitor has components related to both a battery and a capacitor. Consequently, cell voltage is limited to a few volts.

Specifically, the charge is stored by ions as in a battery. But, as in a conventional capacitor, no chemical reaction takes place in energy delivery. An electrochemical capacitor consists of two oppositely charged electrodes, a separator, electrolyte and current collectors. Presently, very small supercapacitors in the range of seven to ten watts are widely available commercially for consumer power quality applications and are commonly found in household electrical devices. Development of larger-scale capacitors has been focused on electric vehicles.

No energy storage technology is suitable for all applications. Each technology stores energy in a different form, giving it inherent properties that tailor it for one role rather than another. To rank the technologies for each application on technical grounds, they are evaluated on five issues.

1. **Real power capacity**

   - Real power is the MW output of generation facilities, and is used for commodity power sales and peak shaving strategies.

2. **Reactive power capacity**

   - Reactive power maintains the electric field of AC equipment and is required for the proper operation of the grid; it is measured in megavars (MVAR).

3. **Discharge endurance**

   - The length of time a storage facility can discharge energy. Generally, longer endurances tend to be real power, with shorter times, reactive power.

4. **Reaction time**

   - Some applications, like grid support, require discharges to commence less than a second after beginning; others, like power sales, can be scheduled allowing for a reaction time of a few minutes.

5. System footprint

- Some applications require that the storage facility be housed inside, taking up valuable floor space and requiring additional space-conditioning costs.

Storage Method	*Fuel Cells*	*Flywheels (low-speed)*	*Flywheels (high-speed)*	*UTES*
Capital Cost / MWh	**$15,000**	**$300,000**	**$25,000,000**	**$550**
Weight / MWH	**30 kg**	**7,500 kg**	**3,000 kg**	**300,000 kg**
Efficiency	**0.45 - 0.8**	**0.9**	**0.93**	**0.8**
Maintenance Cost / MWh	**$10**	**$3**	**$4**	**$15**
Maturity	**Commercial**	**Commercial**	**New Commercial**	**Commercial**
Capacity	**0.3-2000 kWh**	**50 kWh**	**750 kWh**	**400 kWh**
Lifeltime	**10 years**	**20 years**	**20 years**	**40 years**
Storage Method	*Pumped - Hydro*	*Compressed Air (CAES)*	*SMES*	*Supercapacitor*
Capital Cost / MWh	**$7,000**	**$2,000**	**$10,000**	**$28,000,000**
Weight / MWH	**30,000 kg**	**2.5 kg**	**3,000 kg**	**10,000 kg**
Efficiency	**0.8**	**0.85**	**0.97**	**0.95**
Maintenance Cost / MWh	**$4**	**$3**	**$1**	**$5**
Maturity	**Mature Commercial**	**Commercial**	**Commercial**	**Commercial**
Capacity	**22,000 MWh**	**2,400 kWh**	**0.8 kWh**	**0.5 kWh**
Lifeltime	**40 years**	**30 years**	**40 years**	**40 years**

Table 6-1: Some Key Properties of Different Large-Scale Energy Storage

Large -scale stationary applications of electric energy storage can be divided in three major functional categories:

1. Power Quality. Stored energy, in these applications, is only applied for seconds or less, as needed, to assure continuity of quality power.

2. Bridging Power. Stored energy, in these applications, is used for seconds to minutes to assure continuity of service when switching from one source of energy generation to another.

3. Energy Management. Storage media, in these applications, is used to decouple the timing of generation and consumption of electric energy. A typical application is load leveling, which involves the charging of storage when energy cost is low and utilization as needed. This would also enable consumers to be grid-independent for many hours. Although some storage technologies can function in all application ranges, most options would not be economical to be applied in all three functional categories.

6.3 Renewable Energy Storage Models

One of the greatest challenges facing the electric power industry worldwide is how to harness the immense renewable energy resources and deliver them in a useable form as a higher-value product. By storing the power produced from renewable sources off-peak and releasing it during on-peak periods, energy storage can transform this low-value, unscheduled power into schedulable, high-value 'green' products. Developing these resources will not only lessen environmental impacts but also increase each country's domestic energy security (lowering payments for imported energy).

Two challenges in particular are well known to renewable energy proponents. First, many of the potential power generation sites are located far from transmission facilities. Although the costs of connecting these sites to the transmission system will delay these resources from being tied into the local grid for a long time, it leaves the possibility for off-grid applications.

The second challenge is the timing of resource itself. Generally, renewable energy sources are intermittent or vary in intensity throughout the day, with much of the potential for generated power not coincident with the peak demand. Renewables - especially wind - suffer from lower prices in the wholesale market due to the inability to guarantee delivery levels.

Besides these challenges with the renewable resources, technical hurdles must also be overcome - even with mature storage media such as lead-acid batteries. According to Steve Drouilhet, President of Sustainable Automation, LLC (Denver, Colorado, US), system integration must be thought through properly to create a viable system. Two issues make or break most projects: first, 'properly sizing and dispatching the energy storage to achieve an economically optimal system (lowest lifecycle cost of energy)'; and secondly, 'designing the power converter interface between the AC power bus and the energy storage to be efficient, reliable and robust'.

6.3.1 Energy Storage Models

Energy storage facilities can interact in the electric value chain within three 'business models' which correspond to the market areas where they will interact: wholesale, retail and renewable.

Within the wholesale market, large-capacity storage facilities are able to arbitrage power generation from night- to daytime peak prices. These facilities also provide ancillary services to the grid, to promote stability and provide for power transfers across the grid. Technologies include pumped hydro, compressed air energy storage (CAES), superconducting magnetic energy storage (SMES) and flow batteries.

In the retail market, small-scale energy storage facilities provide energy management, power quality and power reliability services to end-use consumers. By providing 'clean' and reliable power and a ride-through capability in the event of a power outage, a manufacturer can get back to his business with peace of mind - and a lower utility bill. Technologies include batteries, flywheels and thermal storage.

Renewable energy storage strategies include both wholesale and retail strategies that leverage the strengths of renewable resources. Three general strategies correspond to the level of integration to a transmission system: off-grid, distributed generation support and baseload wind concepts.

6.3.2 Off-Grid Strategy

Off-grid applications for renewable resource and storage systems are well understood. Remote or simply self-generation applications of solar have been used throughout the world for decades - and so, more recently, have wind applications - to ensure sufficient supply of electrical power when needed. In these off-grid systems, the decision to go forward isn't necessarily the cost of the electricity produced, but rather the value of running electrical equipment.

It is likely that the cost of stringing out power lines to these remote locations will prohibit electrification for years, if not permanently. Many such locations are in environmentally sensitive locations, and this tips the scale in favor of renewables, rather than small generators, which in themselves would require a fuel delivery infrastructure. Utilizing renewable energy and a storage facility obviates the need for the fossil technology with its accompanying supply infrastructure.

6.3.3 Distributed Power Generation Support

Renewable energy storage can also support distributed generation facilities, significantly lowering their operation costs in small grid environments. Without storage power generators on a small grid will run sporadically to match peak demands. Many times, the peak usage will sometimes last only a few minutes, necessitating multiple starts and stops for the generator set, which dramatically raises the operating costs and shortens the unit's life.

Reducing the number of generator starts by providing the first few minutes of power to the grid from the wind turbine-charged storage system can significantly increase fuel savings in the generators. To maximize the savings from the hybrid system, the duration of the energy storage system discharge was found to be a crucial component. Discharges from the system could last from simply a ride-through for diesel generator starts to load shifting, storing power to allow service without the generator being in operation.

Based on a study the US National Renewable Energy Laboratory conducted in 1997 on a system in Deering, Alaska, the largest fuel saving came from relatively short-term storage. Evidence from this test indicated that a storage capability of 10 minutes reduced the fuel use by 18%, the diesel running time by 19%, and the number of diesel starts by 44%.

6.3.4 Baseload Wind Storage

One of the most exciting market opportunities lies in enabling renewable energy to become more competitive in the wholesale electric power market. Coupling storage (of 100 MW or more) with a large-scale wind project is a key part of this strategy to minimize the total cost of power delivered. By storing the power from renewable sources during off-peak periods, and releasing it at on-peak times, coincident with periods of peak consumer demand, energy storage can transform this low-value, unscheduled power into schedulable, high-value products.

Current large-scale merchant wind developments must contend with utility push back towards these facilities. Some utilities support wind projects while others do not; their response generally depends upon the level of constraint on the local transmission system. In Europe, utilities are integrating weather forecasts on the supply side as well as demand, in an attempt to anticipate the level and timing of the wind resources for grid management.

A way around this is to rethink the production of power from wind resources. Instead of smoothing energy production from wind turbines, the maximum energy production would be produced and then stored on-site for release later. Not only does this strategy allow for the guaranteed delivery of 'green' power during peak power costs, it also increases the potential wind energy produced from the wind resources.

Baseload wind developments will still need transmission connections, but by increasing the value (monetarily for the developers and strategically for the grid operators) of the wind resources through storage, the number of potential sites effectively increases. Discharges would normally occur once per business day (250 times per year), allowing the sale of a block of power into the peak daily market. In addition to these weekday sales, the storage facility could also operate at weekends, but the peak pricing would lower the revenue from operations - possibly below the cost of production. Once the storage facility was fully charged, it would be able to act as an emergency back-up power source for the grid, providing additional revenue to the project.

6.3.5 Large-Scale Renewable Energy Storage Studies

The great potential of wind energy in the future depends on the generated energy reliability and the higher cost effectiveness. Energy storage systems will be decisive in order to integrate wind energy into the grid or in isolated power supply systems. There are several studies that have been carried out regarding different energy storage technologies. One study provides an overview of the advantages and drawbacks of these new storage systems compared to the existing systems and study their potential use in the distribution grid (Sels, et al., 2003). An analysis of the study on the performance and economic attributes of different energy storage systems (batteries, flywheel, compressed air, hydrogen, hydraulic and hydro) for different capacities (short, medium and long term) and different power scales applications shows that for medium term energy storage systems for load leveling application, mini-hydro storage system of range 10 kW to 50 MW can provide higher efficiency (0.87) and lower energy related cost (5-15 **€/kWh**) while for long term energy storage systems for high wind capacity credit application 500 – 1,500 MW pumped-storage hydroelectric system can provide higher efficiency (0.87) and lower energy related cost (10-50 **€/kWh**) compared to other energy storage system technologies such as batteries, CAES, regenerative fuel cell and hydrogen EZ + FC. However, both energy storage systems suffer higher power related cost which range from 2,000 – 4,500 **€/kWh** for mini-hydro and 1,100 – 1,200 **€/kWh** for pumped storage hydroelectric system. [79]

Using life-cycle assessment, metrics for the calculation of input energy requirements and greenhouse gas emissions from utility energy storage systems have been developed and applied to three storage technologies: pumped hydro storage (PHS), compressed air energy storage (CAES), and advanced battery energy storage systems (BESS). The study revealed that change in EPR and emissions rate is relatively small when PHS is used, but is significant when CAES or BESS is utilized. CAES produces substantial emissions from the combustion of natural gas during operation, while BESS systems are highly energy intensive in the construction phase. Coupling storage and renewable energy systems can increase the per unit GHG emission rate by a factor of 2-5 times over the base rate. Even so, this emission rate is still substantially lower than fossil fuel derived electricity sources. [81]

A technical paper report about the two modernization projects carried out recently on the Kalayaan Pumped Storage Power Station in Laguna, Philippines and the Geesthacht Pumped Storage Plant in Humburg, Germany in which the main objective within the frame of the modernization of an existing hydro energy storage station is to improve decisive plant features for enhanced regulation of the electricity grids shows the scopes and results as the appropriate examples of today's qualitative approach in coping with frequent breakdowns of electricity supply and the importance of the hydro pumped storage schemes in equalizing the power fluctuation in electricity grids. An abrupt change in energy consumption and/or supply implies disturbances in grid-balance. The adequate counter-balancing by the dispatch center activates then the grid's regulation capabilities available within a short response time. The modernization of the mentioned power plants renders optimal and effective dispatch in an enlarged range of regulation capabilities even in crucial situation. [82]

In the U.S.A., pumped storage plants account for just fewer than 3% of generating capacity. The latest plants have a cycle efficiency of about 80%, compared to 60% achieved by plants built in the 1960's. Improvements in efficiency could be achieved by using adjustable speed generator motors in new or refurbished pumped hydro plants. Besides a 3% improvement in efficiency, the adjustable speed motors could also be used to regulate system frequency in the pumping mode, allow the plant to pump at part load and operate with reduced vibration. An example of this new technology being used and highlighted is the Goldisthal project in Germany, which was partially commissioned in 2003.

ENERGY SYSTEM MODEL DEVELOPMENT

7.1 Overview of Conventional Energy Generation System

To be able to effectively develop the structure for an energy system model we need to identify that renewable energy systems are significantly different than conventional energy systems. An evaluation of the literature on existing renewable energy system models provide insight into both what is required for systems and also where work needs to be done.

This chapter provides an overview of energy system configurations, discusses the sources of data that can be used in energy system modeling, reviews the literature on renewable energy system modeling identifying the areas that have not been investigated adequately, and concludes by describing the overall model configuration developed in this study.

The general architecture of conventional energy systems is significantly different from grid-connected renewable energy systems as well as from the isolated renewable energy system configuration. The traditional approach used by utilities to choose a generation power technology is based on a linear programming model that finds the minimum cost of generation portfolio for a given load. Submitted to base, medium and peak load constraints, this approach assumes that, at every time step, the cheapest generation technology is used. The results for this situation imply a specialization for each technology: without any surprises, conventional hydro or thermal plants including nuclear are chosen for base load, gas turbine or diesel for peak load.

A schematic of a conventional energy system is shown in **Figure 7-1** and from this, one can see that the system is, in general quite simple. The resource has the ability to follow the demand and therefore requires no other components to function. Both large-scale and small-scale system have been developed in this manner. The major difference between large-scale and small-scale systems is the time constant that the system operates on. A large-scale system, due to "averaging" of the load from the many different devices from the system, does not need to respond rapidly to load changes. A small-scale system needs to respond quickly to changes in load. Conventional power system such as coal power plants, combined-cycle gas turbines and diesel generators generally rely on fossil fuels. Nuclear power plant is also considered as conventional power source [83].

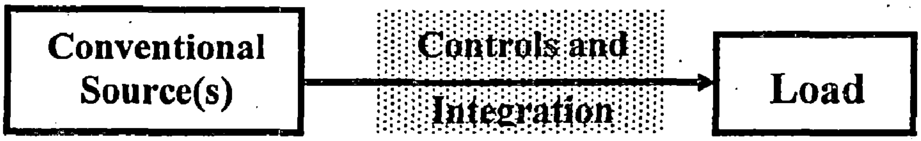


Figure 7-1: Conventional Energy System

Stand-alone independent renewable energy systems, which do not rely on any conventional energy sources, need some manner of matching the demand cycle with the resource cycle(s). This implies a need for some form of storage. Including storage into the energy system diagrams, the schematic of an integrated renewable energy system is obtained, as shown in **Figure 7-2**.

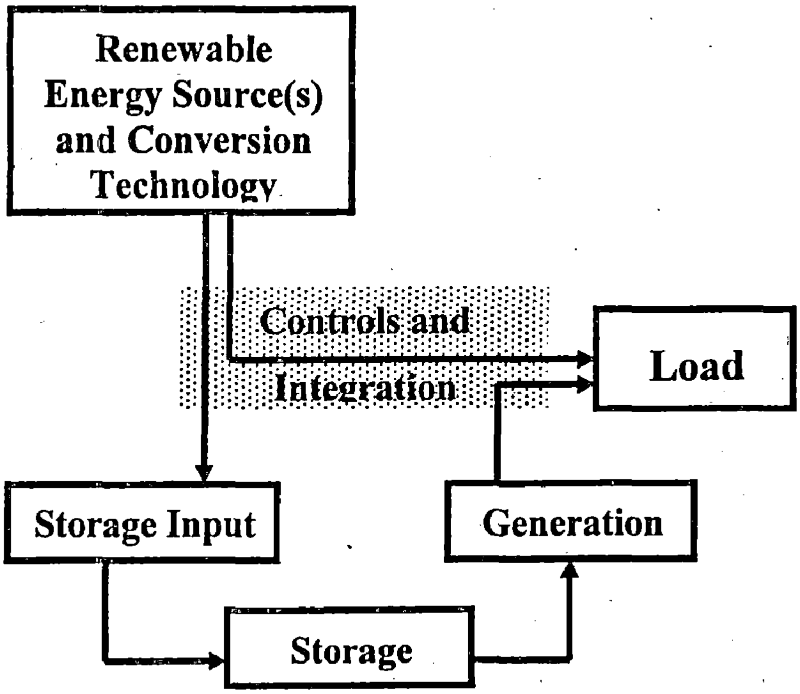


Figure 7-2: Stand-Alone Independent Renewable Energy System

This system can be developed with either a conventional energy backup system, or the system can be installed without a backup, as shown. Most housing and/or village renewable energy installations, since they are replacing conventional energy installations, maintain the conventional energy as a backup until the renewable energy system is proven to work effectively. This is not the case for many telecommunications systems, which are often new installations and are therefore installed without any conventional backup system.

Renewable energy sources have been added to conventional energy systems, as shown in **Figure 7-3**. This configuration, if the renewable resource is less environmentally intrusive than the conventional resource it is replacing, has the ability to reduce the impact of our energy services. However, in this configuration, renewable resources will never exceed 12-25% of the energy generation capacity, as this would cause grid instabilities. [84, 85] Often, forecasting of the renewable resource on times scales from 1 minute up to a few days is required for adequate operation of such systems and for load scheduling. Although there has been much work on this, this is not a trivial task and research is ongoing in this area [86, 87].

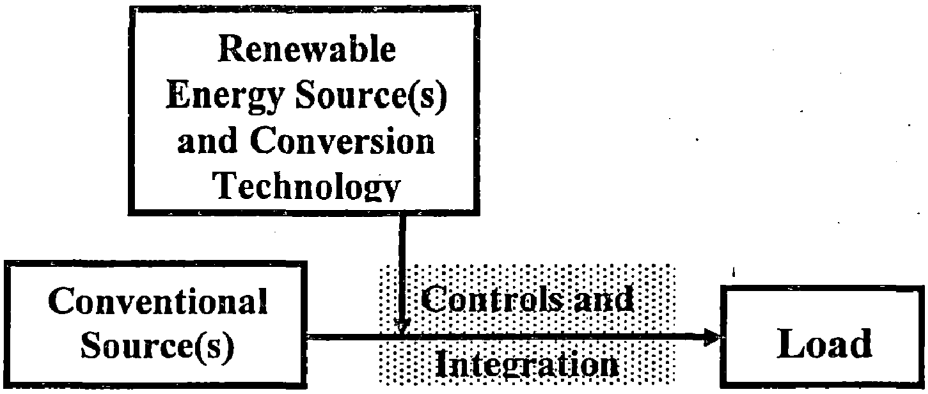


Figure 7-3: Grid-Connected Renewable Energy System

Grid-connected renewable energy is conceptually no different than adding a second conventional generator onto the grid as long as the penetration of the renewable resource does not exceed 15-25% of the load. Below this level, the grid can absorb the fluctuations in the renewable energy source by relying on the load following characteristics of the conventional resource. Above this load factor, the consideration of storage is needed to follow the load as conventional resources on a large scale have very slow response times. Such systems are similar to stand-alone independent renewable energy systems discussed previously. Diesel-hybrid systems, incorporating renewable energy, do not suffer from this limitation since small-scale diesel engines can respond to the load rapidly [88].

For the purposes of this study, since the objective is to optimize a proposed alternative power system to obtain the least cost of energy production using renewable energy resources of the selected isolated island's small grid system in the Philippines, we will, from this point onwards, be primarily interested in the grid-connected renewable energy system with energy storage capability using pumped hydro and the stand-alone independent renewable energy system will not be discussed further.

7.2 Review of Existing Hydro/Wind Concept Models

There is but few works that has been published on large-scale grid-connected hydro/wind system concept models application. This section gives an overview of these works and discusses the current progress, its strengths and weaknesses of the different approaches, especially in terms of the ability to examine the effects of various parameters on the overall system designs. Most of these studies are still feasibility studies but some are now undergoing actual development in the European and North American regions.

When wind turbines represents a significant share of the total power generation system, as it is already the case in some European regions, the management practices will no longer determine the priority of utilization for a given load level on the sole basis of pure economic competitiveness of a technology. Many reasons change the management context in the electricity industry, especially for short and medium term energy planning. Changes in energy market structure influence the load security reserve management by transferring a part of the risk coverage on neighboring systems. According to larger energy exchanges between power systems, generation portfolio is modified in order to maximize the use of existing facilities, namely reservoirs and peak load thermal plants.

The intermittence of wind power supply forces utilities to use wind when available. Any other planning options decrease the competitiveness of wind. So the integration of wind power in a large hydro-based system can be an option to improve the annual management of reservoirs for some conditions. For instance, the best context for the hydro/wind concept implies a complementary energy exchange between neighboring networks in order to reduce the risk of lack of power in peak periods. The capacity factor of wind power option is therefore optimized, while the reservoirs play the role of a regional "battery".

One question therefore arises: how large can be the share of wind power in an existing hydro-based system before significant investments in new dams and/or in generation sources as well as in new transmission capacities? Such a study was conducted for the Québec/Labrador power system, the largest power system in Canada with total generation capacity of around 40,000 MW, including a large share of hydropower reservoirs. [89]

In many parts of the world large areas exist where the wind resources are good or very good and the grid is relatively weak due to small population. In these areas the capacity of the grid can very often be a limiting factor for exploitation of the wind resources. There are two main problems concerned with wind power and weak grids. The first is the steady state voltage level and the other is the voltage fluctuations. Some or all of these can be avoided if a so-called power control concept such as a pumped hydro storage is applied together with the wind farm [90].

The idea behind the power control concept is to eliminate the violations of the steady state voltage level by buffering the power from the wind turbines in periods where the voltage limits might be violated and combined this ability for smoothing of the power output. Investigations have shown that the power control concept can compete with grid reinforcement and usually the dumping of wind energy will be the most expensive option. Related to the two case studies made for this control concept in Madeira, Portugal and County Donegal, Ireland reveals that sometimes the least cost and most attractive option is change in operating strategy of the power system and the options for pumped hydro storage are good combined with good wind resources. The least cost option for the feeder studied is either grid reinforcement or a power control system based on a pumped storage if rather large amount of wind energy are to be absorbed by the power system. The cost estimates for the two options are in the same range.

Analysis of the studies on a combined wind pumped storage hydro power system aiming to generate low cost electricity and increase the penetration of the renewable energy sources (RES) in the power system of the remote island of Crete in Greece suggested that the concept is absolutely profitable investment [91]. Parametric analysis was performed on the techno-economic basis in order to find the optimum size of each component of the wind/hydro power system such as the number and nominal power of wind turbines, the nominal power of hydro station and the optimum size of the water reservoirs, and the number of hours without enough energy (power shortage) and the loss of operation of this station.

Studies on non-dynamic simulation of each subsystem's of a hybrid power system using medium–term pump–storage as energy storage for excess wind capacity in the islands of Ikeria and Kythos in the Aegean Sea which aim to find the optimum size of each subsystem at the lowest electricity cost also conclude that the wind/pump-storage hydro hybrid system is an absolutely profitable investment [92, 93].

The one year operation experience of the intelligent power system (IPS) of Kythnos and especially the results of the preliminary study of the IPS of Ikaria, combined with pumped storage, creates fantastic possibilities for economical use of the Aeolian Energy in the Aegean region for both low cost electricity supply and water desalination with the Aeolian Energy surplus. This is very important because of big shortage of water on the Aegean islands.

This exploitation can be achieved with the development, installation and use of IPS with the collaboration between the appropriate wind turbines, pumped storage and existing power stations. In this way, the economic penetration of RES in autonomous island grids is feasible from about 10% for the time being, to approximately 90% or even 100% for small autonomous grids. As additional result we can achieve drastic reduction in the fuel energy conversion costs into electricity.

Works on the actual development of the combined wind-hydro power station (WHPS), an innovative concept in hybrid of renewable energy technologies, had already started in the island of El Hierro in Spain. This development will allow the island of El

Hierro (Canary Islands), Spain to be self-sufficient in renewable energy in the succeeding years. The island recently declared Biosphere Reserve by UNESCO has an area of 276 km² and a population of approximately 10.000 inhabitants, and is not connected to a continental electricity grid. Currently, the electricity demand is covered by a conventional thermal power station (diesel system: 8.285 MW).

A technical feasibility study of the wind-hydro power station was carried out by ITC, which financed by the Spanish utility ENDESA (which is the utility operating on El Hierro), during 2001. According to this study, the WHPS will consist of the following subsystems:

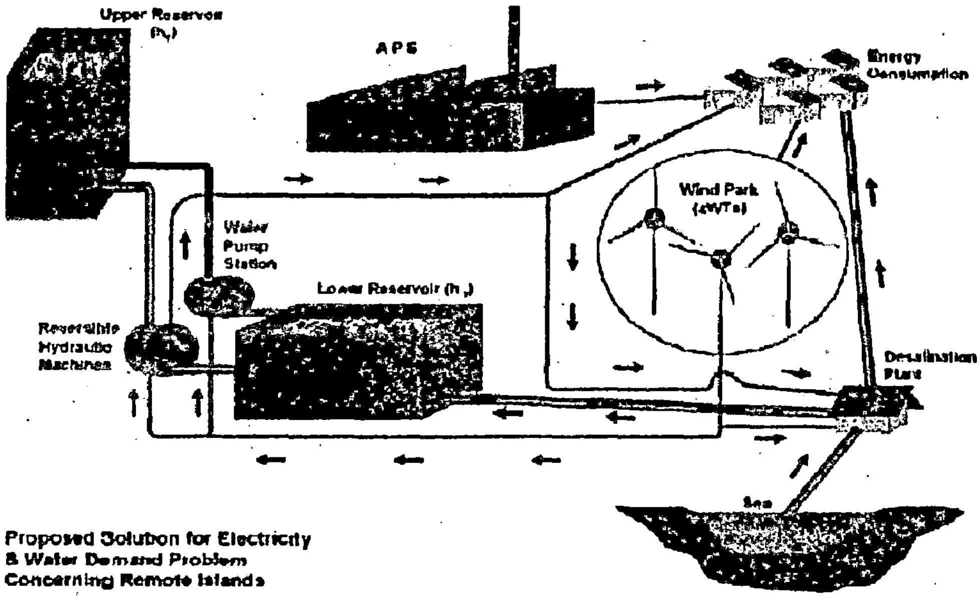


Figure 7-4: Basic Scheme of the Wind-Hydro Power System

Wind farm	9,35 MW
Pumping station	7 x 800 kW + 2 x 200 kW (6 MW)
Minihydro power station (Pelton turbines)	3 x 3,3 MW (9,9 MW)
Diesel power station (existing)	8,28 MW
Desalination plant	5 - 10 m^3/d
Upper reservoir	200.000 m^3
Lower reservoir	200.000 m^3
Penstock	
Distribution system	

Table 7-1: Main Components of El Hierro Wind Hydro Power System

The feasibility study on the concept of WHPS reveals that with the implementation of the said project, it will be possible to cover 75% of the island's electricity demand and achieve a 30% direct wind penetration into the grid. The general economical feasibility of the wind-hydro power station concluded that if the electrical system on El Hierro should continue to be as it is now (diesel power plant), and considering no electricity demand increase, the diesel purchase costs for the next 20 years would sum up to approx. 42 M€ (assuming a cost increase of 3%/y), i.e. almost double of the WHPS investment cost [94].

7.3 Proposed Power System Architecture

The system operation of a wind farm combined with a reversible-hydro power station and a parallel water pump station is described. This study aims to reduce considerably the dependence of the island's power generation from fossil fuel and its derivatives. The schematic diagram and the energy flow of the proposed hybrid system are shown in **Figure 7-5**. The operation of this system is based on the following steps:

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 reservoir to a higher reservoir 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 (low 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 island's existing diesel power stations within the vicinity or from the grid system to provide the necessary power.

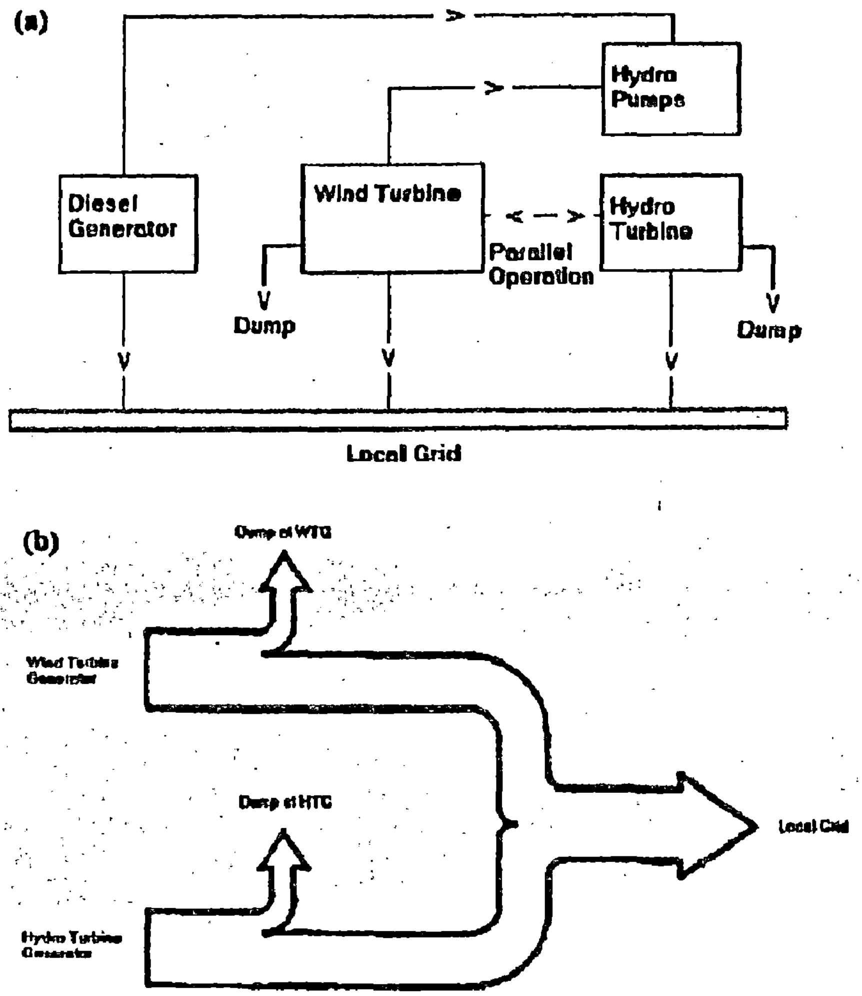


Figure 7-5: Schematic diagram of (a) the combined system and (b) energy flow

The system shall also use the potential run-of-river hydroelectric power station of the area as power system's base load supply to optimize its renewable energy resources contribution to the island's power generation system and at the same time will divert portion of the discharged water at tail water reservoir to the lower reservoir of the pumped-storage hydro to serve as the source of the make-up water for losses due to evaporation instead of a desalination plant used in the El Hierro wind hydro storage power system concept. **Figure 7-6** illustrates the schematic of the load and components of the proposed of the wind/hydro system concept for isolated islands in the Philippines.

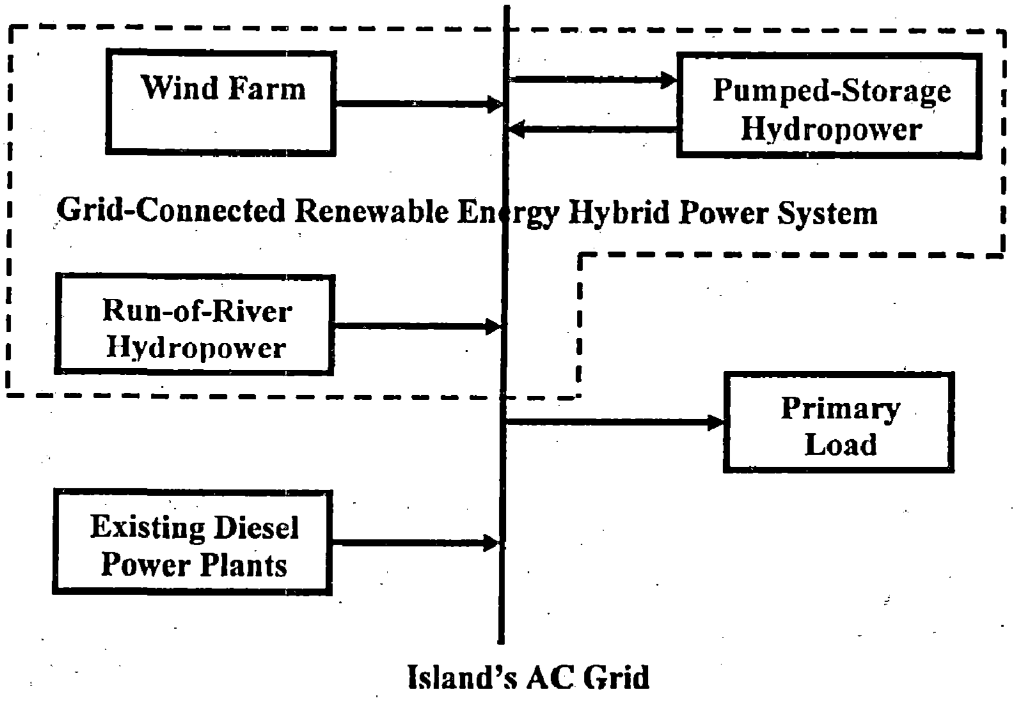


Figure 7-6: Schematic diagram of the proposed alternative system of a wind/hydro hybrid concept for isolated islands in the Philippines

More precisely, the proposed system is based on the following sub-systems:

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

ii. a pumped-storage hydroelectric power plant (PSH), which consists of reversible water turbines and rated power P_{PSH} and with an optional water pump station, which in the combination of reversible water turbines (operating as water pumps, rated power P_P). Moreover, it should have the capability of absorbing the system's wind power surplus, rated power P_{PSH}.

iii. two water reservoirs at elevations h_1 and h_2 ($h_1 > h_2$) working in closed circuit and the corresponding water conductor system.

iv. a run-of-river hydropower unit will be included in the system at rated power P_H

v. an interconnection to the grid system based on several existing internal combustion engines. Rated power P_D

The objective is to integrate the system to the existing transmission interconnection of the island power system to cover the electricity load P_L of the study area and to minimize the oil consumption in the power system.

In order to calculate the power of the system it is necessary to specify the rated power of the main wind/hydro power subsystems and the P_D within the grid:

$$(P_{WP} + P_H + P_{PSH})\text{ system} + P_D > P_{Lmax} + dP$$

$$(P_{WP} + P_H + P_{PSH})\text{ system} > P_{Lmax}$$

$$P_D > P_{Lmax}$$

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

The following installation design steps which are necessary requirements for economic optimization of the best system with least production cost shall be 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. Assessment of the topography of the study area for potential water reservoirs position of the pumped hydro storage and the size in conjunction with the ground configuration and the necessary system autonomy to include monthly water streamflow for the run-of-river hydropower.
3. Selection of different available installed capacity of hydroelectric power projects of the study site with completed feasibility studies.
4. Determination of the amount of energy as deferrable load of the system to pump water to higher reservoir for use in the pump storage hydro power plant to serve as 4 hours peaking plant in the system.
5. Rational use of the system towards achieving maximum reduction in fossil fuel consumption to attain the least possible cost of energy production.
6. Determination of the amount of reduced greenhouse gas or carbon emissions with the integration of the renewable energy in the power grid system of the island.

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.

7.3.1 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:

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

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 in kWh

P is the wind turbine rated power in kW

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

Ta 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:

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

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%.

7.3.2 Water Reservoirs

The selection of the capacity of the water reservoir depends on the required system's autonomy, energy required to be stored and the topographical configuration of the area. It is equal to the magnitude of the peak-load multiplied by the hours of generation. The duration is as follows:

(i) Plants working on	(a) 4 to 6 hours capacity daily cycle
	(b) 8 to 10 hours capacity in the first stage if expansion of the installed capacity id planned
(ii) Plants working on weekly cycle	- Depending on individual network working, say up to 30 hours capacity
(iii) Plants working on a seasonal cycle	- Two to three months capacity

The volume to be stored is determined by the following formula,

Gross energy stored, kWh = (Useful volume stored, m^3 x average head, m.) $\div$ 367

This should be equal to

(Magnitude of peak load, kW x duration of peak load, hours) $\div \eta_{overall}$

where $\eta_{overall}$ includes efficiencies of conduit system, turbine generators, transformers and transmission lines.

The pumping and generating cycle efficiencies of the pumped storage plant are:

Transformer - 98 %

Motor-Generator - 96 %

Turbine - 92 %

Pump - 88 %

Penstocks - 96 % to 98 % (depending upon the length)

The overall cycle efficiency obtained ranges from 65% to 75%. This means for every 3 to 4 MW drawn from the network during the off-peak period, 2 to 3 MW are returned back to the network during the peak period, while 1 MW goes as losses.

7.3.3 Run-of-River and Pumped-Storage Hydropower Plants

Run-of-river hydropower plant shall be utilized in the system as baseload plant. The nominal power for the pumped-storage 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 constituting the hydropower station is a function of turbine net head H and the corresponding rate of flow Q is given as:

$$P_{PSH} = \rho * g * H * Q * \eta_t * \eta_g$$

Where, ρ is the density of water, 1000 kg /m^3

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

H is the rated head, m.

Q is the rated flow rate of the turbine, m^3/sec

η_t the water turbine's efficiency, say 0.92

η_g the electric-generator's efficiency, say 0.96

7.4.4 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**,

$$Pp = [\ \rho * g * H * V\ ] \div [\eta_p * \eta_m\ ]$$

Where,

Pp is the pump station capacity, in kW

ρ is the density of water, 1000 kg/m^3

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

H is the rated head, m.

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

η_p is the water pump's efficiency, say 0.88

η_m the efficiency of the water-pump's electric motor, say 0.96.

INTEGRATION OF WIND-HYDRO POWER SYSTEM (WHPS) GENERATION IN SELECTED ISOLATED SMALL ISLAND GRID POWER SYSTEM IN THE PHILIPPINES

8.1 Introduction

The Strategic Power Utilities Group of the National Power Corporation (NPC-SPUG) operates in 69 islands and 7 isolated areas and serves 44 customers (41 electric cooperatives and 3 municipalities) in Luzon, Visayas and Mindanao. NPC-SPUG operates 314 generating units with a combined installed capacity of 205 MW consisting of 85 land-based diesel plants, 18 power barges and a hydropower unit. It also purchases power from two (2) Independent Power Producers (IPPs), namely Paragua and Island Power.

Of the NPC-SPUG's 76 islands and isolated areas under its missionary electrification program, Palawan and Mindoro islands were chosen as the study sites for application of the proposed integration of wind and hydropower in its mini-grid system. The basis for the initial selection of the study site are the current inventory of its energy resources, topography of the area, availability of the transmission system and the power system service hours.

Based on 2002 results of operation, only Palawan and Mindoro islands in Luzon have transmission facilities compared to other small grid-power system under NPC-SPUG operation. In Mindoro, the 69-kV transmission line was extended from Mamburao in Occidental Mindoro to Calapan and Bansud in Oriental Mindoro. An on-going 69-kV transmission line extension project is being undertaken from Mamburao to San Jose, Occidental Mindoro to further establish a grid in the island. In Palawan, only three of the 7 power plants in the main island are interconnected by a 69-kV transmission line, namely Puerto Princesa, Narra and Brookes Point with plans to extend the connections to the Roxas and Taytay power plants in the coming years. Based also on the study of load demand and load profile of the isolated island small power systems, Palawan and

Mindoro island grids are the most dynamic and average load demand increase for the last 5 years are around 9.5% and 11.5% annually compared to the other small grid power systems. Daily power service operation on both areas is 24 hours.

8.1.1 Background of Study Area: Mindoro Island

Mindoro Island is situated at approximately between 12 degrees and 14 degrees north latitude and between 120 degrees and 121 degrees 45 minutes east longitude. It is located at the southwestern part of the main island of Luzon with the island of Palawan in its southwestern portion and the island of Panay in the southeastern portion. It is bounded in the west by the South China Sea, Sulu Sea at the south and in the east by Sibuyan Sea.

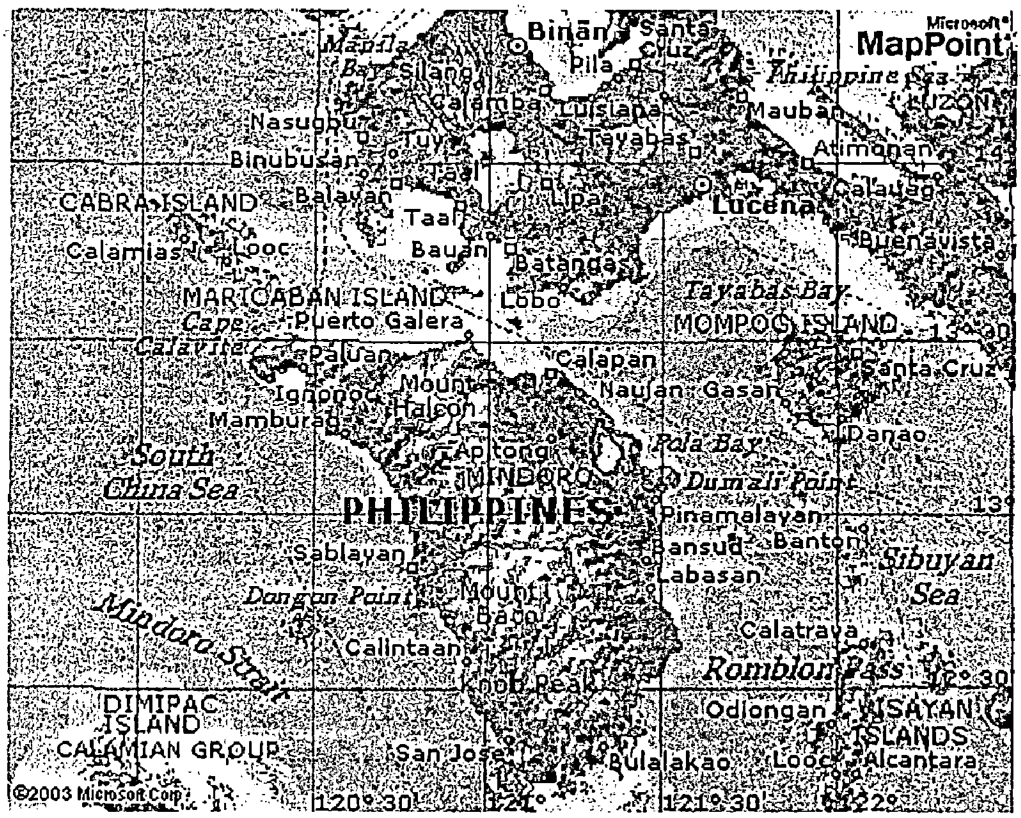


Figure 8-1: Map of the Mindoro Island, Philippines

The island of Mindoro is divided into two political provinces, namely Oriental Mindoro and Occidental Mindoro. Oriental Mindoro has a land area of 4,449.5 square kilometers (sq. km.) while Occidental Mindoro covers an area of about 5,865.7 sq. km. Oriental Mindoro is bounded on the north by Verde island passage, on the east by Maestra de Campo Island and Tablas Strait, on the south by Semirara Island and on the west by Mindoro Occidental. The provincial capital of Oriental Mindoro is Calapan. The province of Occidental Mindoro is bounded by Oriental Mindoro in the eastern side and the western portion by Apo East Pass. On the north, it is bounded by Calavite Passage and the Verde Island Passage. The southern end of the province lies in the area of Sibuyan Sea. The capital of Occidental Mindoro is Mamburao.

Most parts of the main island of Mindoro are mountainous. The entire area of the mainland of Mindoro is characterized by mountain ranges, intermittent valleys and elongated plateaus with rolling prairie lands along coastal regions. The mountains are fringed with foothills and coastal plains ranging from one to twenty kilometers wide. The tallest mountain in the northern part is Mt. Halcon at about 2,586 meters high and in the south by Mt. Baco. The plains are generally narrow and mostly confined along the South China Sea boards at the west and along the Pola Bay in the east of the island. On these strips of land are the seats of municipalities, barangays or villages and sitios or hamlets, and many of them are located along the highway that traverses the provinces from north to south.

Mindoro has an inland lake, Lake Naujan, located at the northeastern part of the island (14,567 ha, 13°04'-13°15'N, 121°17'-121°26'E) with an area of 8,125 hectares (ha.) of open water, 1,412 ha of marshland and 5,030 ha. of terrestrial catchment. The Naujan Lake is the fifth largest lake in the country. The lake watershed bounds the protected area. The plain areas within the watershed are intensively used for cultivation of paddy rice with irrigation water coming from the Lake. Surrounding it are 17 lakeshore communities. The local people use the lake as a communal fishing ground.

The climate of the island is characterized by a long dry season from November to May and rainy the rest of the year. For 13 years, the average annual rainy days is 125. The peak is in August when the monthly average reaches 23 rainy days and the lowest is in March when the average is as low as one rainy day. The annual rainfall average is 98.18 inches. The location and topography of the island on the western side of the great ocean body is another contributing factor in the rainfall pattern of the provinces. South China Sea, fed by warm water from a branch of south equatorial current, passes between Singapore and Borneo thus keeping the water bodies surrounding the island warm year-round and consequently providing excellent sources of moisture.

The coolest months are from December to February and its warmest temperature is registered in the months of March to June. The average maximum temperature up to 30 degrees Centigrade and its minimum is 22 degrees Centigrade. Humidity ranges from 63% to 87% with an annual average of 75.4%.

Based on the December 2002 National Statistics Survey, Mindoro Island has a combined island population of 1,062,068 of which 681,818 of the population belongs to the province of Oriental Mindoro and the remaining 380,250 resides in Occidental Mindoro. The population density of Oriental Mindoro is 156.2 persons per square kilometer while Occidental Mindoro has a density of 64.7 persons per square kilometer. Both provinces has identical average annual population growth rate of 2.46%. Oriental Mindoro has 1 city, 14 municipalities, 426 barangays and 2 districts. Average per capita in 2000 is PhP 24,096 with an average annual family income of PhP 69,580. The other province, Occidental Mindoro has 11 municipalities, 162 barangays and 1 district. Average per capita in 2000 is PhP 23,553 with an average annual family income of PhP 69,769.

The island of Mindoro is about 20 km from the nearest point in Luzon. It is completely isolated from the main grid. It is sourcing its electricity exclusively from land-based and power-barges installed around the island which consumes imported fossil fuels like diesel and bunker C. A 69 kV transmission line owned by NPC interconnects most of the power plants in the northern part (Calapan, Puerto Galera, Pinamalayan) of the island to the west (Mamburao). In the long-term, other power plants will be interconnected through the main 69 kV transmission line.

Mindoro Island's power requirement is provided by the government-owned National Power Corporation (NPC), two independent power producers (IPPs)-Mirant and Island Power Corporation through the island's electric cooperatives- Oriental Mindoro Electric Cooperative (ORMECO) and Occidental Mindoro Electric Cooperative (OMECO). As of July 2003, there are 7 power plants around the island with an aggregate capacity of 59 MW (including the 32 MW power barge and 1.6 MW mini-hydro). The 2002 total dependable capacity of Oriental Mindoro was 37.9 MW and Occidental Mindoro had 9.25 MW. The present peak power demands are 22 MW for Oriental

Mindoro and 8.3 for Occidental Mindoro. Based on ORMECO and OMECO forecasts, the peak demand in 2004 may reach 23.5 MW for Oriental Mindoro and 8.8 MW for Occidental Mindoro. Further, by year 2010, the maximum power demand will be 55.1 MW for Oriental Mindoro and 18.3 MW for Occidental Mindoro.

The island is blessed with a number of small as well as mini hydroelectric potential and a small geothermal potential on the eastern side of the island. Fossil-fired power plants are still considered the least cost option for power generation considering the island proximity to an oil depot in Luzon.

8.1.2 Background of Study Area: Palawan Island

The Palawan islands group generally lie between 7 degrees 47 minutes and 12 degrees 22 minutes north latitude and 117 degrees and 119 degrees 51 minutes east longitude. It is bounded on the north by the Mindoro Strait, on the south by Balabac Strait, on the west by the South China Sea and on the east by Cuyo Islands. Palawan province is about 600 kilometers from Manila and is located west-southwest of the main Philippine archipelago. It comprises a chain of 1,768 islands and islets stretching 650 kilometers from end to end. The largest province in the country, Palawan has a land area of approximately 1.64 million hectares (16,403.1 sq. km.) with the main island covering 80 percent of the total land area.

The island of Palawan is made up of a series of mountain ranges, narrow beaches, and coastal plains. It has short waterways which generally run either to the east or west. Dubbed as the "last ecological frontier", Palawan is endowed with rich natural resources and a relatively preserved environment. Its lowlands and low hills are suitable for agriculture while its vast forest area and mineral deposits have high commercial value. The 2,000-kilometer coastline and rich fishing grounds make Palawan one of the country's major sources of fishery products. About 40 percent of the country's coral reef areas are found in Palawan. Since the early 90's, offshore oil explorations have been successful and operation for natural gas extraction commenced since 2002.

Based on the climate map used by the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) utilizing the Coronas scheme, the southeastern section of the Palawan Island falls under Type III where seasoned are not very pronounced (relatively dry from November to April and wet during the rest of the year). The western and northernmost (including Busuanga and Culion islands) sections exhibit a Type I climate, having two pronounced seasons- dry from November to April and wet from May to October.

The average monthly temperature ranges from a maximum of 33 degrees Centigrade to a minimum is 23 degrees Centigrade. Mean monthly values vary slightly throughout the year with the month of March to June as relatively warm. Average annual temperature is 27 degrees Centigrade. Humidity ranges from 71% to 95% with an annual average of 84%.

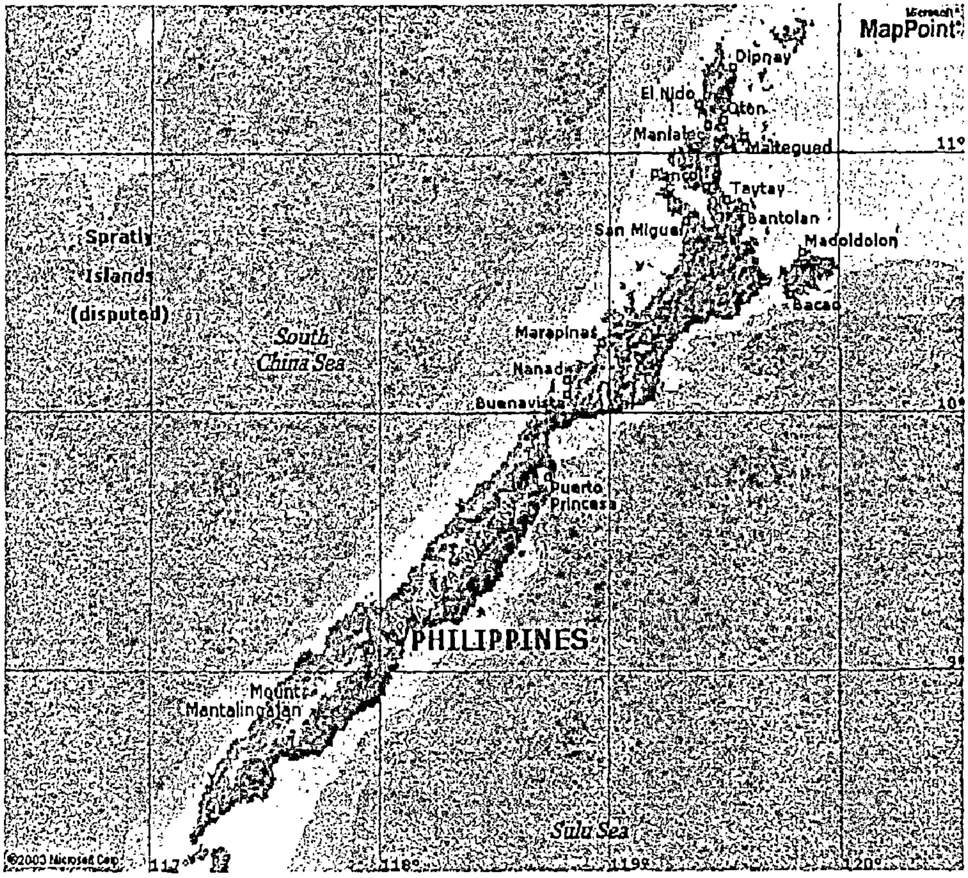


Figure 8-3: Map of Palawan Island, Philippines

Based on the December 2002 National Statistics Survey, Palawan province registered a population of 755,412 for reference period of May 2000. It is an in-migration area with an average annual population growth of 3.60 percent, almost 60 percent higher than the national average. The province of Palawan has 1 city, 23 municipalities, 431 barangays and 2 districts. The provincial capital of Palawan is Puerto Princesa. Average per capita in 2000 is PhP 26,279 with an average annual family income of PhP 78,541.

Palawan's power requirement is provided by the National Power Corporation through the Palawan Electric Cooperative (PALECO) and Busuanga Island Electric Cooperative (BISELCO). The power capacity of the island consists of the following: land – based diesel power plant – 15, 032 kW; island 3,608 kW and power generated by city - based independent power producer (IPP) Paragua Power Plant is 16,000 kW. There are 16 Diesel power plant station sites in Palawan where plant installed capacity varies from 54 kW situated at the island of Linapacan to 9,000 kW at the mainland.

Of Palawan's 431 barangays or villages (district unit, about 50-200 households per barangay), only 40% of the barangays are electrified, and there are at least 50,000 households without access to electricity in Palawan. The Local Government Unit (LGU) of Palawan has formulated the Palawan Provincial Energy Master Plan (1997-2021) which has set up the goal of increasing electricity supply from its current 25 MW to 250 MW in 2021, and the target of electrifying all the barangays by the year 2021. Under current Energy Master Plan, however, more than 95% of future expansion of electricity capacity will come from diesel generators. The growing dependence on fossil fuels to provide electric power services in Palawan will not only generate a substantial amount of GHG emissions, but is not necessarily an economically viable option as well. Most of the households in Palawan, particularly in Northern Palawan where a majority of people do not have access to electricity at present, are scattered on isolated islands. The transport costs of diesel fuel are high, and grid extension to remote communities is not economically viable.

Palawan has abundant renewable energy resources, including solar, wind, hydro, and biomass resources. Because of the existence of a large number of barriers encompassing policy, institutional, information, finance, marketing, and technical in character, the applications of renewable energy are insignificant in Palawan at present.

Currently, there exist great opportunities to promote renewable energy. Both the provincial and municipal governments in Palawan are highly committed to developing renewable energy in Palawan to provide electric power services to the households without access to electricity now. Particularly, recent explorations found that the largest natural gas reserves in the Philippines are located in Palawan. The provincial government is expecting to receive a substantial amount of revenues from the production and sales of natural gas in Palawan, which started in the year 2002. The expected revenues from the natural gas will increase the current budget of the

8.2 Resource Assessment of Probable Sites

8.2.1 Wind Resource

The wind resource in the Philippines is strongly dependent on three main factors: latitude, elevation, and proximity to the coastline. In general, the best wind resource is in the north and northeast, and the worst resource is in the south and southwest of the archipelago. The recently completed Wind Energy Resources Atlas of the Philippines by National Renewable Energy Laboratory (NREL) determined that Palawan has some of the highest potential wind energy in the Philippines with 3,000 to 5,000 MW of potential wind energy, compared to the total energy demand in Palawan of 250 MW by the year 2021.

The wind mapping results show many areas of good-to-excellent wind resource for utility-scale applications or excellent wind resource for village power applications, particularly in the northern and central regions of the Philippines. The best wind resources are found in six regions: (1) the Batanes and Babuyan islands north of Luzon; (2) the northwest tip of Luzon (Ilocos Norte); (3) the higher interior terrain of Luzon, Mindoro, Samar, Leyte, Panay, Negros, Cebu, Palawan, eastern Mindanao, and adjacent islands; (4) well-exposed east-facing coastal locations from northern Luzon southward to Samar; (5) the wind corridors between Luzon and Mindoro (including Lubang Island); and (6) between Mindoro and Panay (including the Semirara Islands and extending to the Cuyo Islands).

Class	Resource Potential		Wind Power Density (W/m^2) @ 30 m	Wind Speed [a] (m/s) @ 30 m
	Utility	Rural		
1	Marginal	Moderate	100 - 200	4.4 - 5.6
2	Moderate	Good	200 - 300	5.6 - 6.4
3	Good	Excellent	300 - 400	6.4 - 7.0
4	Excellent	Excellent	400 - 600	7.0 - 8.0
5	Excellent	Excellent	600 - 800	8.0 - 8.8
6	Excellent	Excellent	800 -1200	8.8 -10.1

(a) Mean wind speed is estimated assuming a Weibull distribution of wind speeds with a shape factor (k) of 2.0 and standard sea-level air density. The actual mean wind speed may differ from these estimated values by as much as 20%, depending on the actual wind speed distribution (or Weibull k value) and elevation above sea level.

Table 8-1 : Wind Power Classification

The wind power classifications for the Philippines are presented in **Table 8-1.** Two different classifications are used in the analysis: one for utility-scale applications and one for rural power applications. For utility-scale applications, areas with a Class 2 and higher resource potential are considered suitable for wind power development. For rural applications, areas with a Class 1 or higher are considered suitable for wind power development.

Mindoro, a large island in the Philippines archipelago, centered at 13 degrees north and 121 degrees east, is divided into two provinces, Occidental Mindoro and Oriental Mindoro. The topography consists of a coastal plain and a high mountain interior. Except in certain specific locations, the island has a limited developable wind resource. However, good-to-moderate wind resources for rural power applications can be found in several areas of the region: the northeast portion near Balingawan Point and Dumali Point, the northwest corner of the island at Calisurigan Point, along the southeast coastal sections from Soguicay Bay to Buruncan Point, and around Ilin Island on the south-southwest. Good-to-excellent wind resources are evident along the central mountain range from Tandrac Peak in the north to just north of Bulalakao in the south. Another area of good-to-excellent wind resource is evident in the high terrain north of Mamburao in the northwest and near Tusk Peak in the southwest. The Semirara Islands south of Mindoro have a uniformly good-to-excellent wind resource across all three islands.

For wind mapping purposes, the province of Palawan was divided into two regions—Northern Palawan and Southern Palawan. This region includes the northern part of Palawan Island and the islands at the northern end of Palawan, including Lincapan Island and Dumaran Island. The wind resource on the northern part of Palawan Island is generally classified as moderate to good for rural power applications and marginal for utility-scale applications. There are a very limited number of areas with a good-to-excellent resource in the higher terrain areas southwest of Roxas. The wind power on Lincapan and Dumaran islands is classified as moderate to good for rural power applications and marginal to moderate for utility-scale applications. The immediate coastline and high terrain in the far northern portion of Palawan is classified as having a good-to-excellent resource for rural power applications and a moderate-to-good resource for utility-scale applications. There are two small areas with the best resource (good to excellent). These are the high terrains east of El Nido and the high terrain northwest of San Vincente. Other areas with a good-to-excellent wind resource include the high terrain west of Caramay and southwest of Roxas. The wind resource in the immediate vicinity of Puerto Princesa is marginal for utility-scale applications, but moderate for rural power applications. However, the higher terrain west of Puerto Princesa is characterized as having a good to excellent resource.

At the Southern Palawan area, a moderate-to-good resource for rural power applications is evident in the coastal areas at the far southern end of Palawan, including Bugsuk Island, Balabac Island, and areas along the eastern coast near Bivouac Point. A limited area, characterized by a good-to-excellent wind resource, extends along the higher terrain in the center of Palawan. These areas are principally west of Aborlan, Panacan, and Tacbolubu, and north of Rio Tuba.

8.2.2 Wind Speed Data

Because the Philippines is an archipelago, there is a large amount of water surface surrounding the country. Due to its proximity to the coastline, its latitude and topography, SSMI data set was used to evaluate the wind power of the study sites. The Special Sensor

Microwave Imager (SSMI), which is part of the U. S. Defense Meteorological Satellite Program, provides 10-m ocean wind speed measurements. This data set provides much more uniform and detailed coverage of oceanic wind speeds than the Marine Climatic Atlas of the World. Comparisons of satellite-derived winds with ship observations along major shipping routes indicate consistent results. NREL currently has 9 years of SSMI data covering the period 1988 to 1996. These data also provide an excellent overview of the ambient wind conditions around the islands.

The wind speed frequency distribution at a site in the Philippines is influenced principally by the northeast and southwest monsoons and secondarily by latitude and elevation. The diurnal wind speed distribution, or wind speed versus time of day, is influenced by site elevation and proximity to the Pacific Ocean. The distribution at low-elevation, inland sites in simple terrain typically reveal a maximum wind speed during the afternoon and a minimum near sunrise. The primary forcing mechanism for this pattern is the daytime heating, which destabilizes the lower levels of the atmosphere, resulting in a downward transfer of momentum to the surface. The near-surface winds tend to peak in the early afternoon, which corresponds to the time of maximum heating. In the late afternoon and evening, the declining supply of sunshine leads to surface cooling and a decoupling of the thermally forced momentum exchange. Surface winds begin to decelerate, while winds aloft, previously restrained by friction, are free to accelerate. The minimum in surface wind speed near sunrise corresponds to the time of maximum atmospheric stability.

Mountaintop diurnal distributions differ from those of low-elevation sites. The strongest winds at mountain locations occur at night, while the lowest wind speeds are observed during the midday hours. Over the ocean, the diurnal variation of the atmospheric instability is typically reversed, resulting in a wind speed maximum at night and a minimum in the afternoon. However, diurnal wind speed changes are more complicated on the islands. The curves of average diurnal wind speed for island sites are often flatter than those observed over land.

The annual wind speeds for the 7-year period from 1988 to 1994, based on satellite data, are presented in **Figure 8-4**. The best wind speeds are along the northern

Luzon coast, the Batanes and Babuyan Islands, the northeast coastal areas, and the southeast coast of Mindanao. The lowest annual average wind speeds occur in the Celebes Sea, west of Mindoro, and the westsouthwest coast of Luzon. The annual data imply the presence of wind corridors in the straits between Luzon and Mindoro, Mindoro and Panay, and Panay and Negros.

The wind power density map (**Figure 8-5**) parallels the annual wind speeds with the highest density off the northwest coast of Luzon and the lowest density in the Celebes Sea. The SSMI data was also used to determine the Weibull k (shape) factor for the ocean areas. The k-value, shown in Figure 8-3, has a magnitude of 2.4–2.7 in the Batanes and Babuyan islands off the north coast of Luzon, a magnitude of 1.8–2.2 along the northeast coast, and a magnitude of 1.8-2.2 off the north and east coasts of much of the Philippines from northern Luzon southward to northern Mindanao.

The seasonal variation in wind speed and power density is dramatically illustrated for some areas in **Figures 8-8** and **Figure 8-9**. The wind corridors between the islands of Luzon and Mindoro, Mindoro and Panay, and Panay and Negros appear to have December monthly wind speeds in excess of 8.0 m/s. The wind power density in December exceeds 1200 W/m^2 off the northwest tip of Luzon. The wind power density in December is also quite good along the northeastern and eastern coast of the archipelago and along the wind corridors between the islands. In August, under the southwest monsoon conditions, the wind resource is substantially less across the archipelago. The northwest coast of Luzon continues to have a good wind resource with wind speeds of 6.5–7.0 m/s. There are also good areas of wind resource in August off the southeast Mindanao coast, with wind speeds of 7.0–8.0 m/s. The wind resource along the northeast Luzon coast is substantially less in August, because the terrain blocks the prevailing southwest monsoon flow. The analysis of the satellite wind-speed data indicates the highest wind power density in August is off the southeast coast of Mindanao and the northern portion of the Sibuyan Sea.

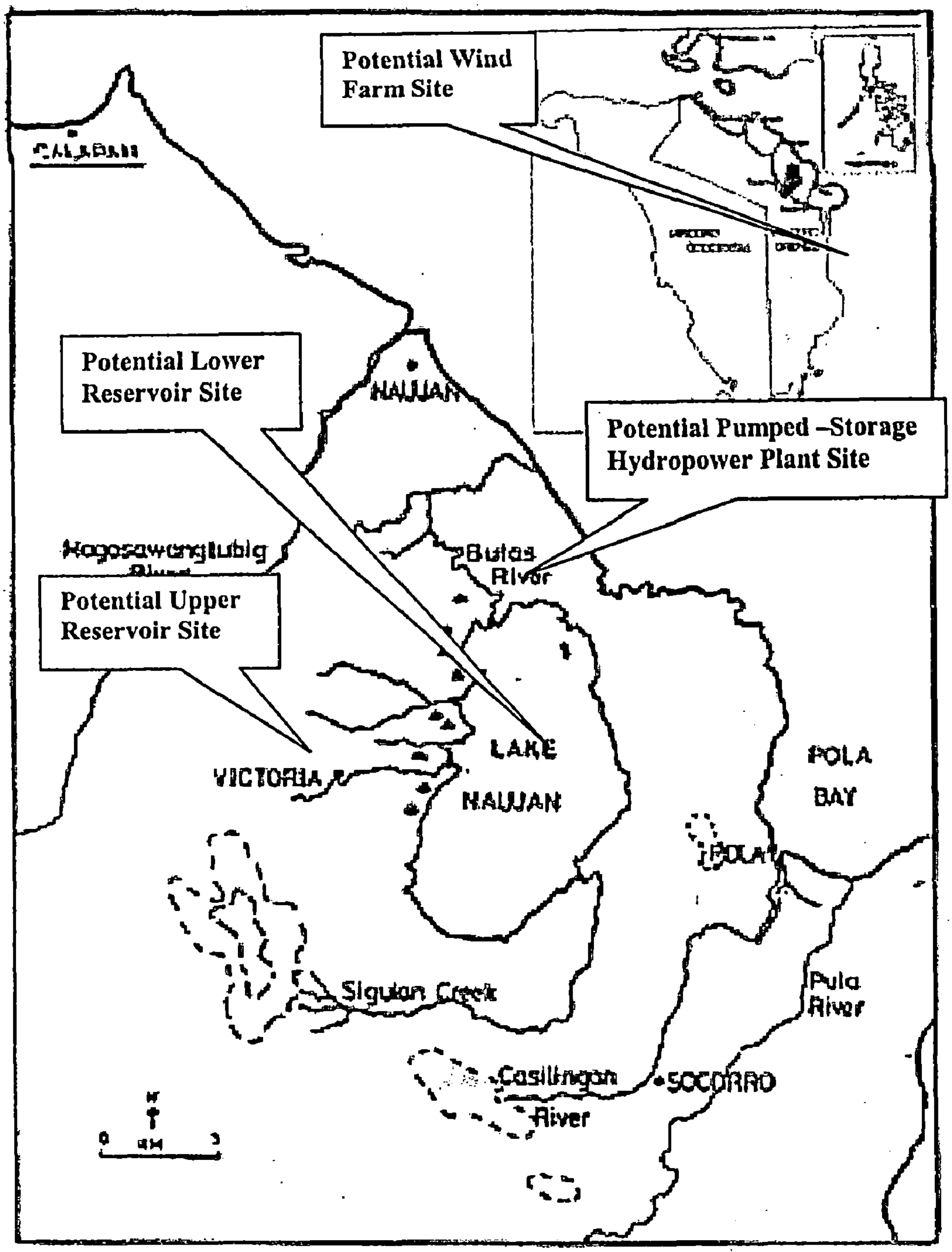


Figure 8-3 :Potential Site in Mindoro Island for Combined Wind/Hydropower Concept

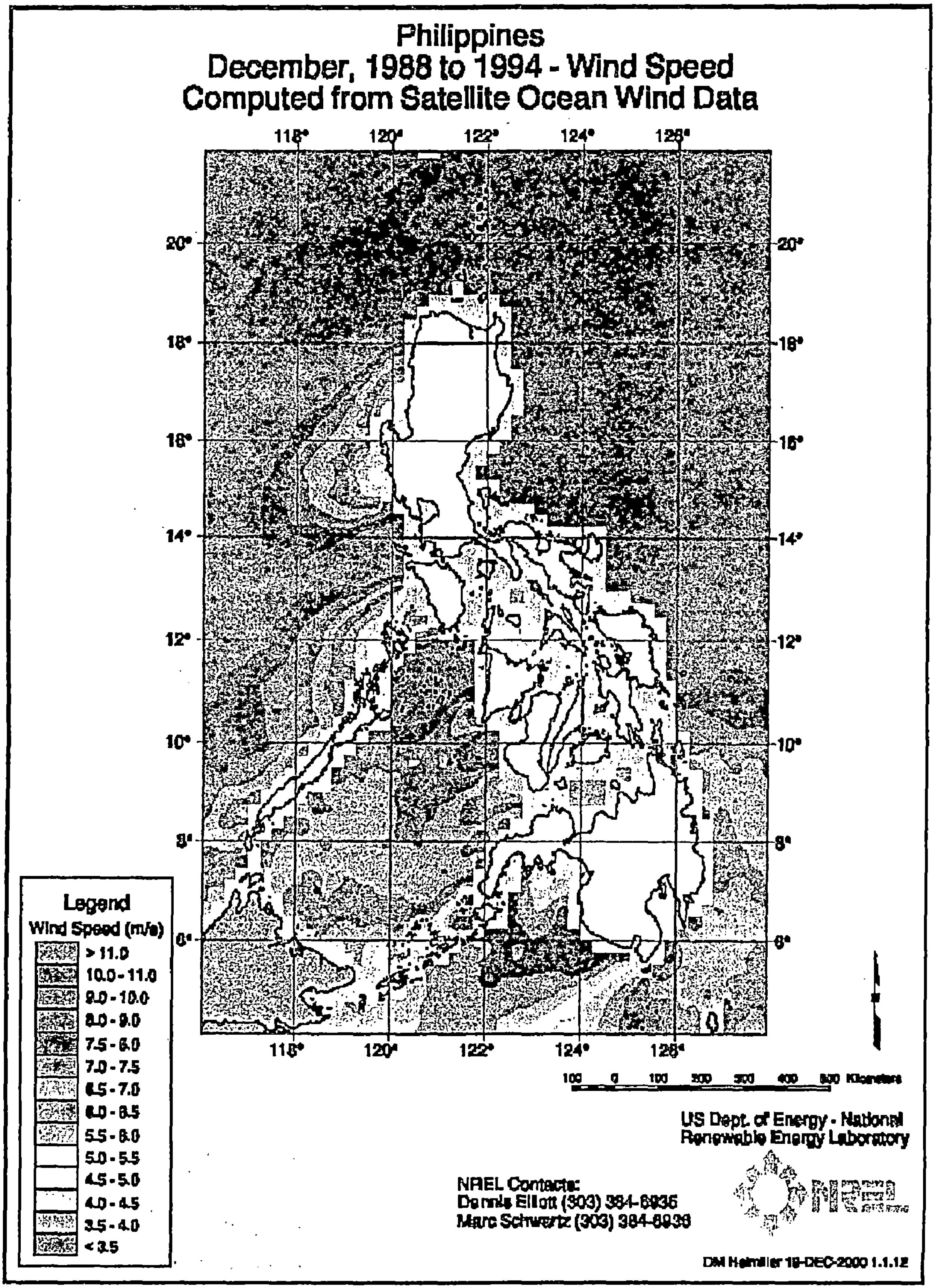


Figure 8-4: Philippine Satellite Ocean Wind Data Wind Speed, 1988 - 1994

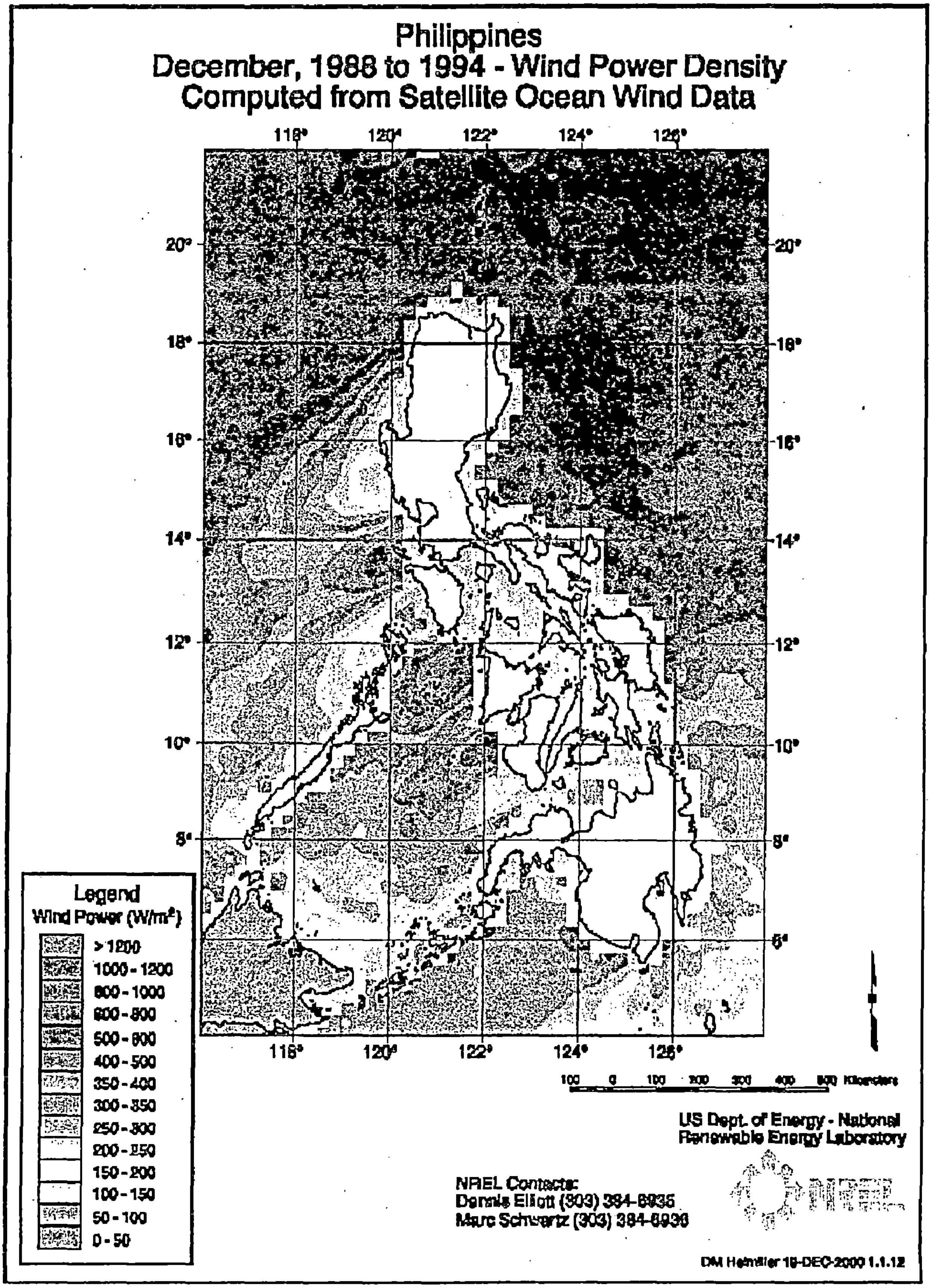


Figure 8-5: Philippine Satellite Ocean Wind Data Power Densities, 1988 - 1994

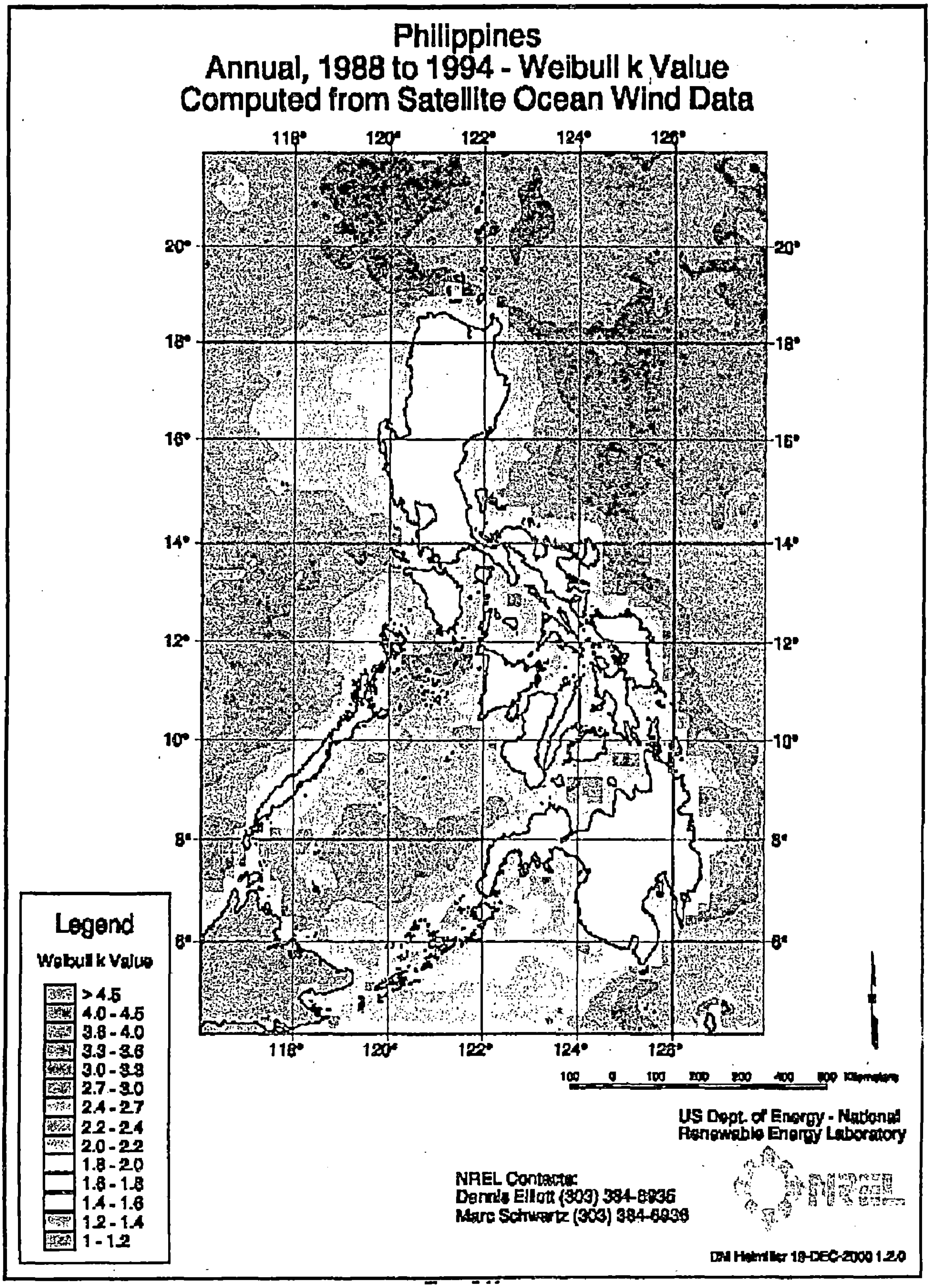


Figure 8-6: Philippine Satellite Ocean Wind Speed Data Weibull *k* Value, 1988-1994

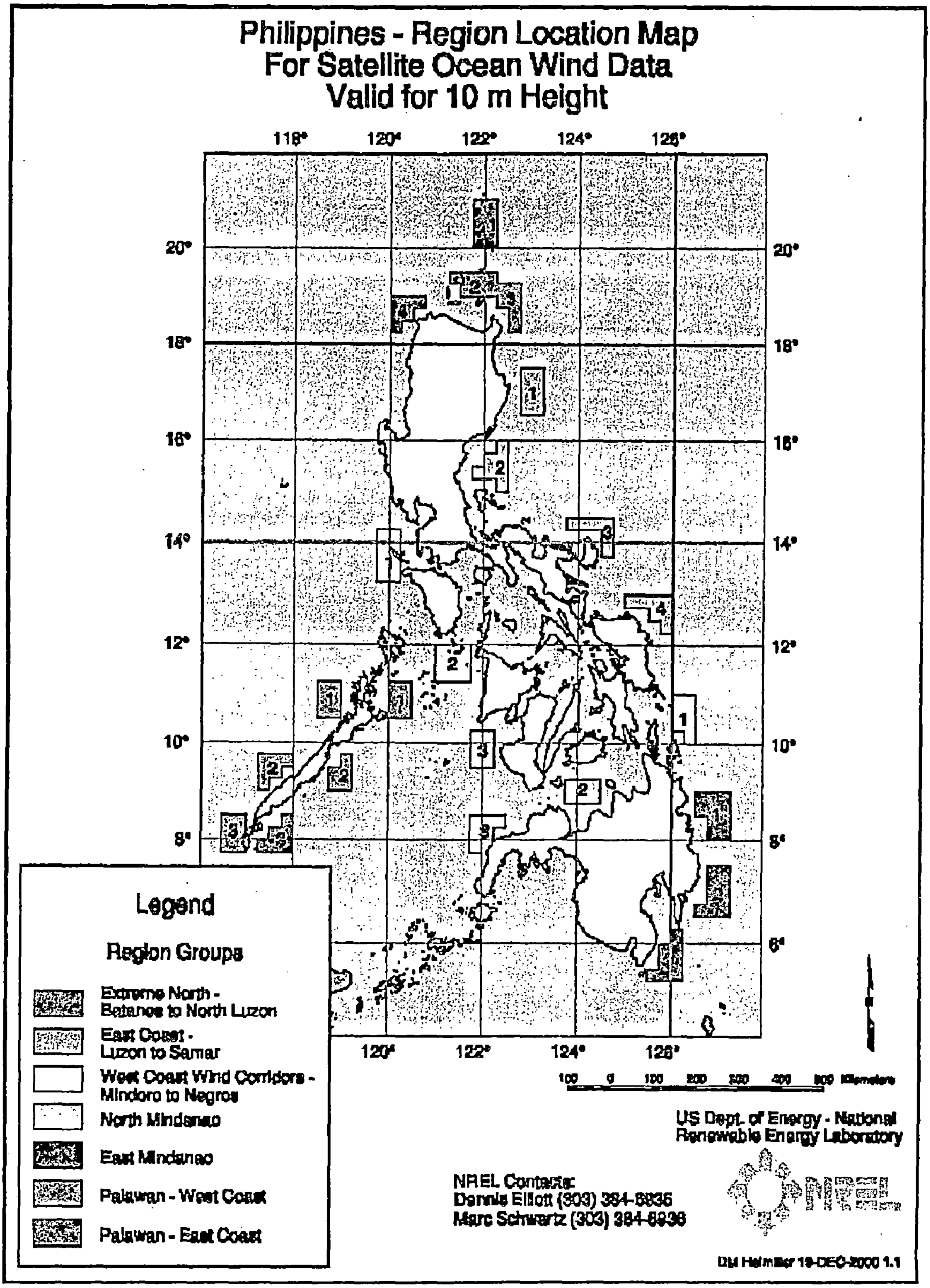


Figure 8-7: Philippine Region Location Map for Satellite Ocean Wind Speed Data

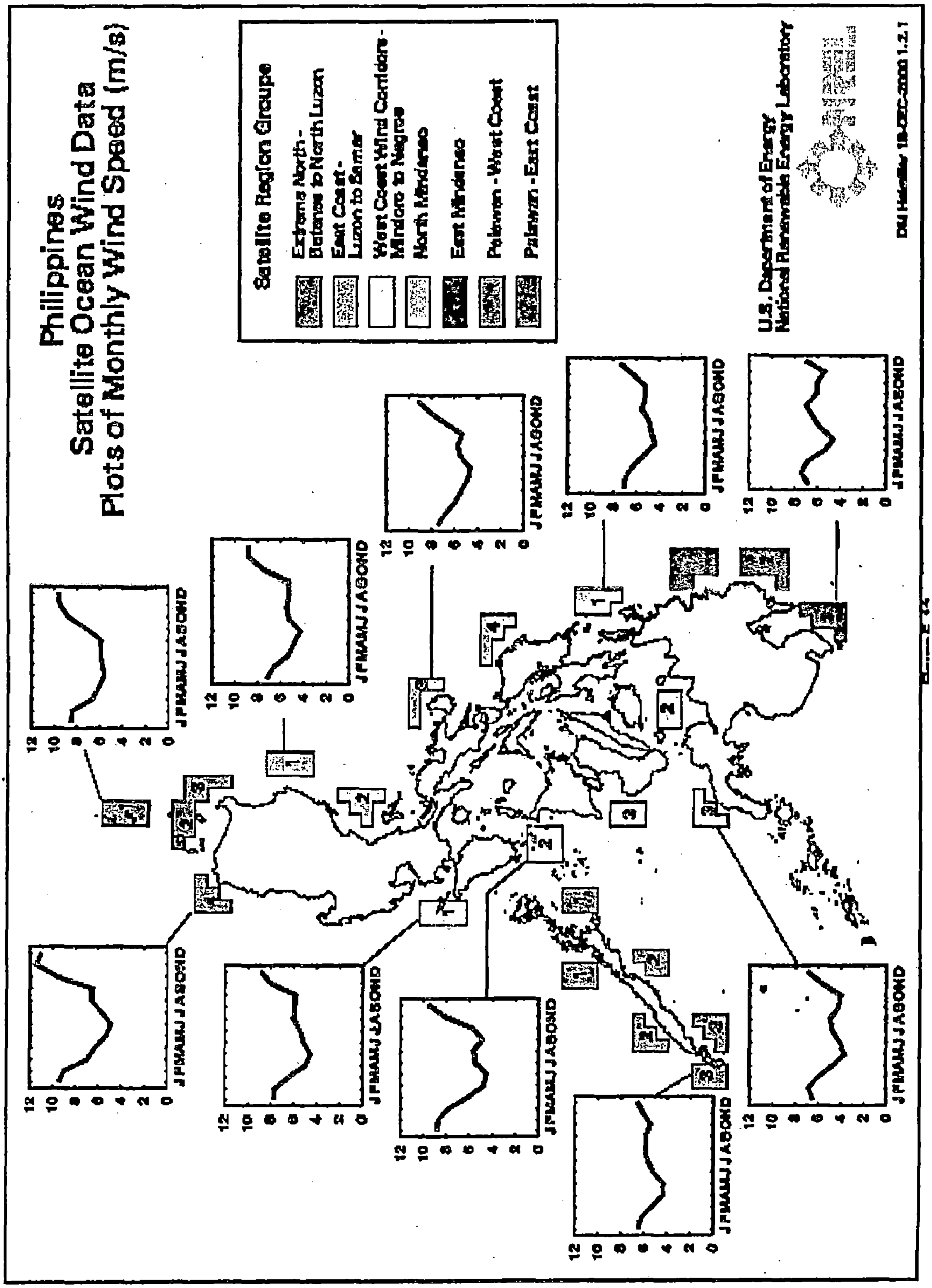


Figure 8-8: Philippines – Satellite Ocean Wind Data Plots of Monthly Wind Speed (m/s)

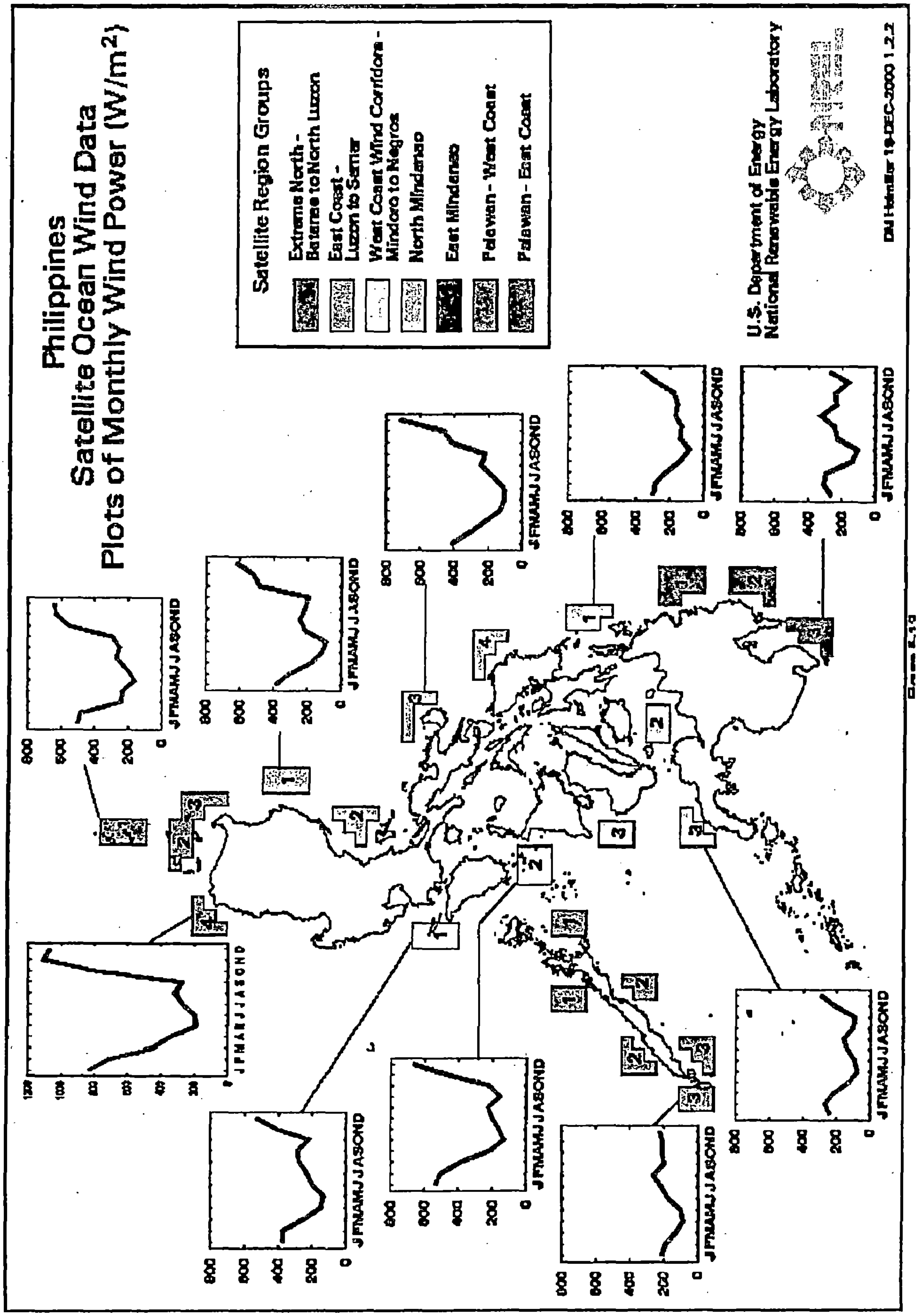
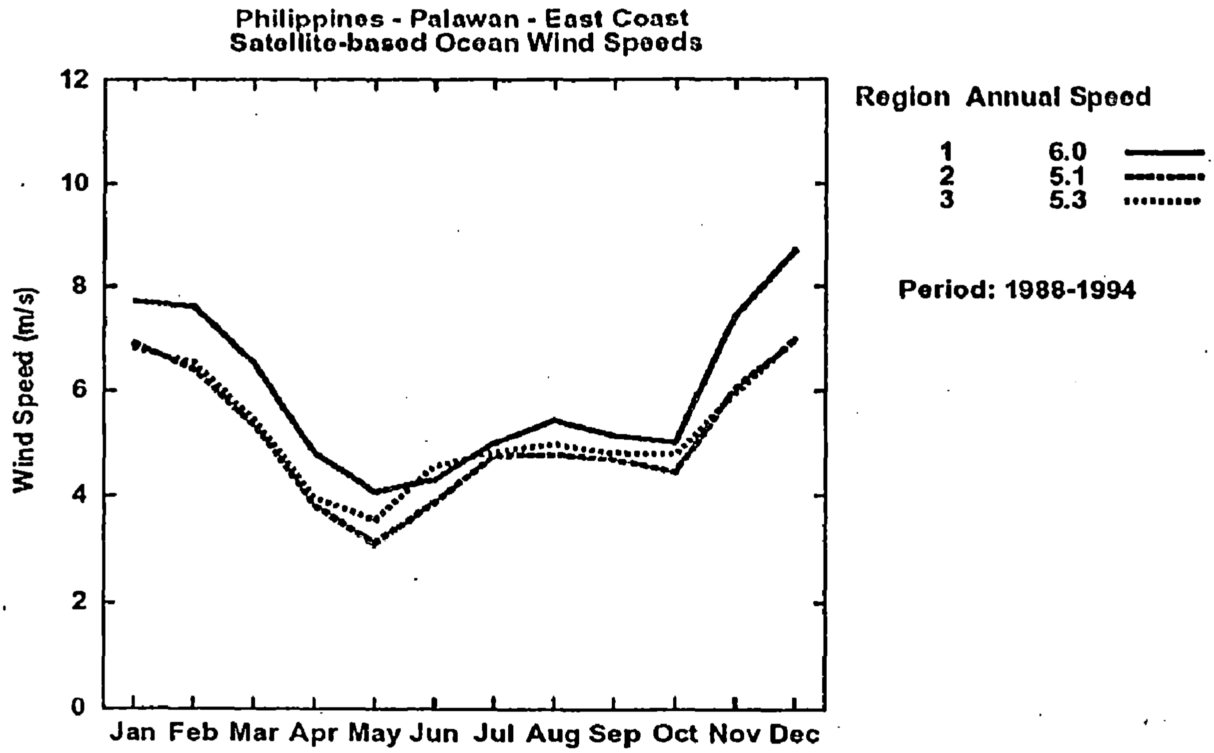


Figure 8-9: Philippines – Satellite Ocean Wind Data Plots of Monthly Wind Power (W/m^2)



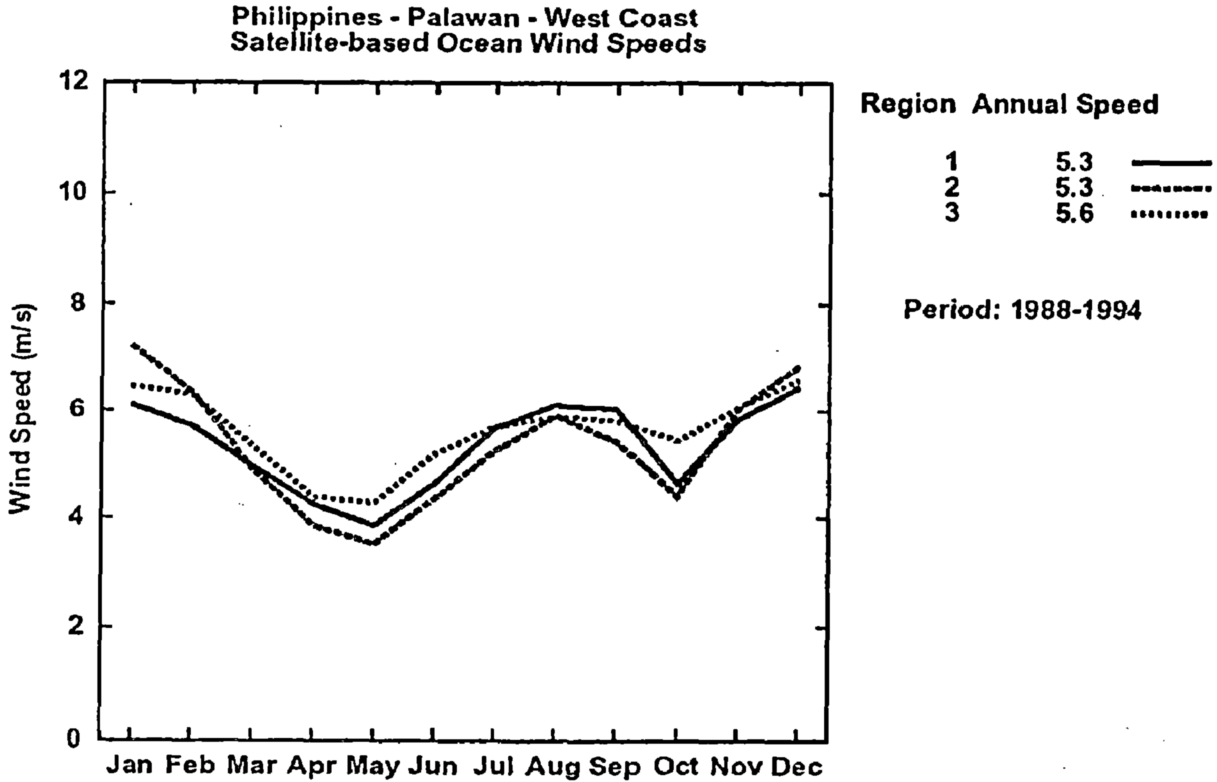


Figure 8-10: Average Monthly Palawan Island Satellite Ocean Wind Speeds, 1988 - 1994

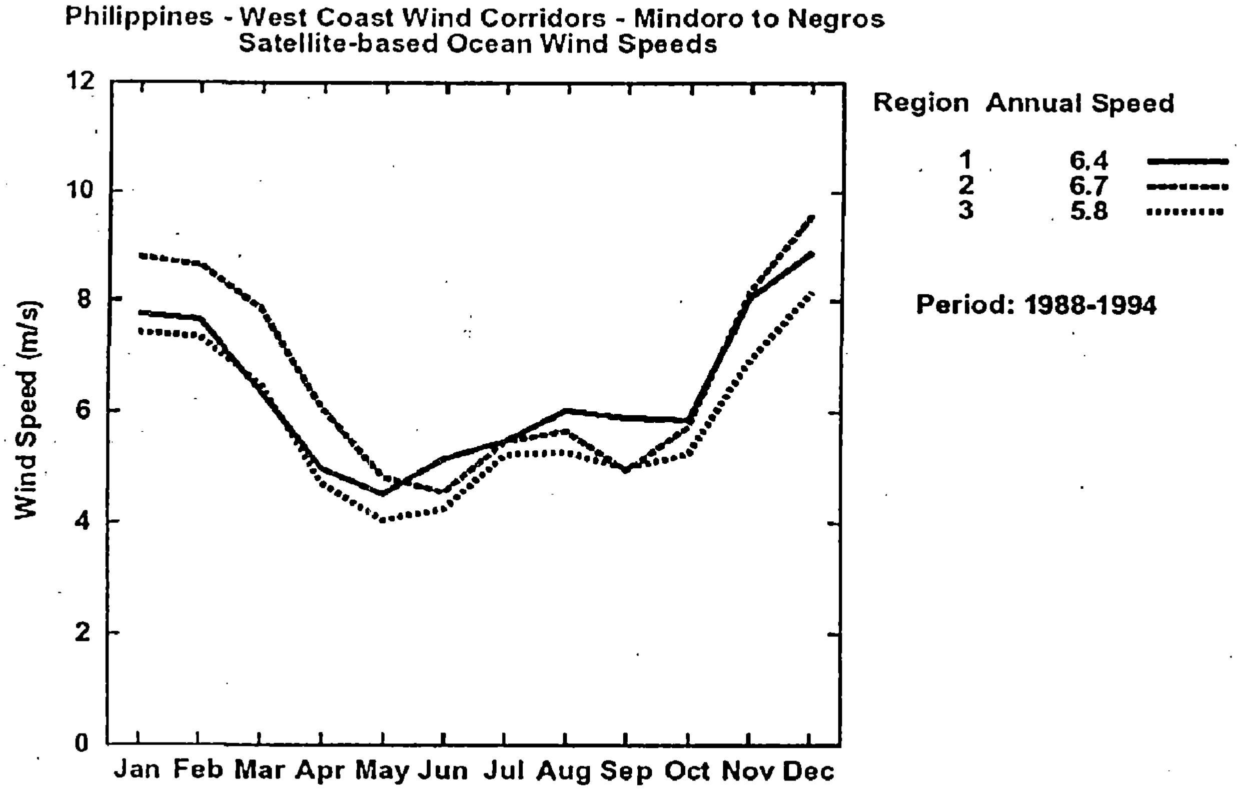


Figure 8-11: Average Monthly Mindoro Island Satellite Ocean Wind Speeds, 1988 – 1994

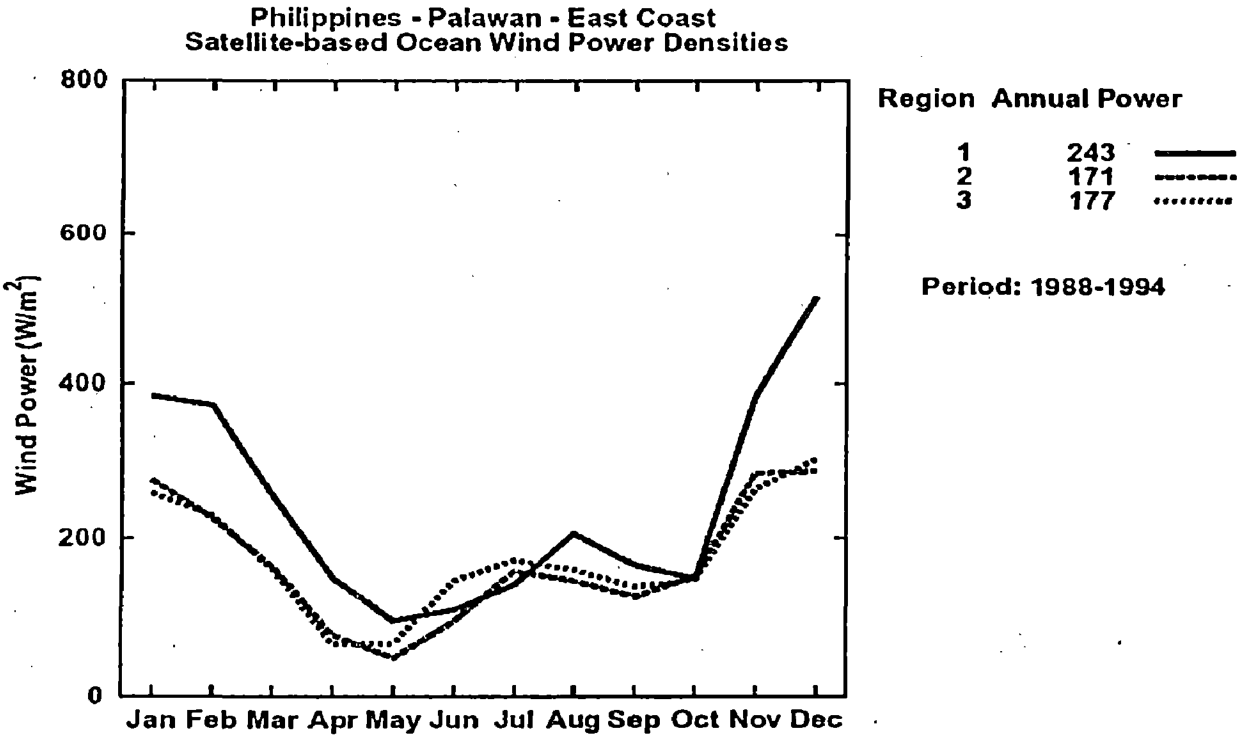


Figure 8-12: Average Monthly Palawan Island Satellite Ocean Wind Power Densities, 1988 - 1994

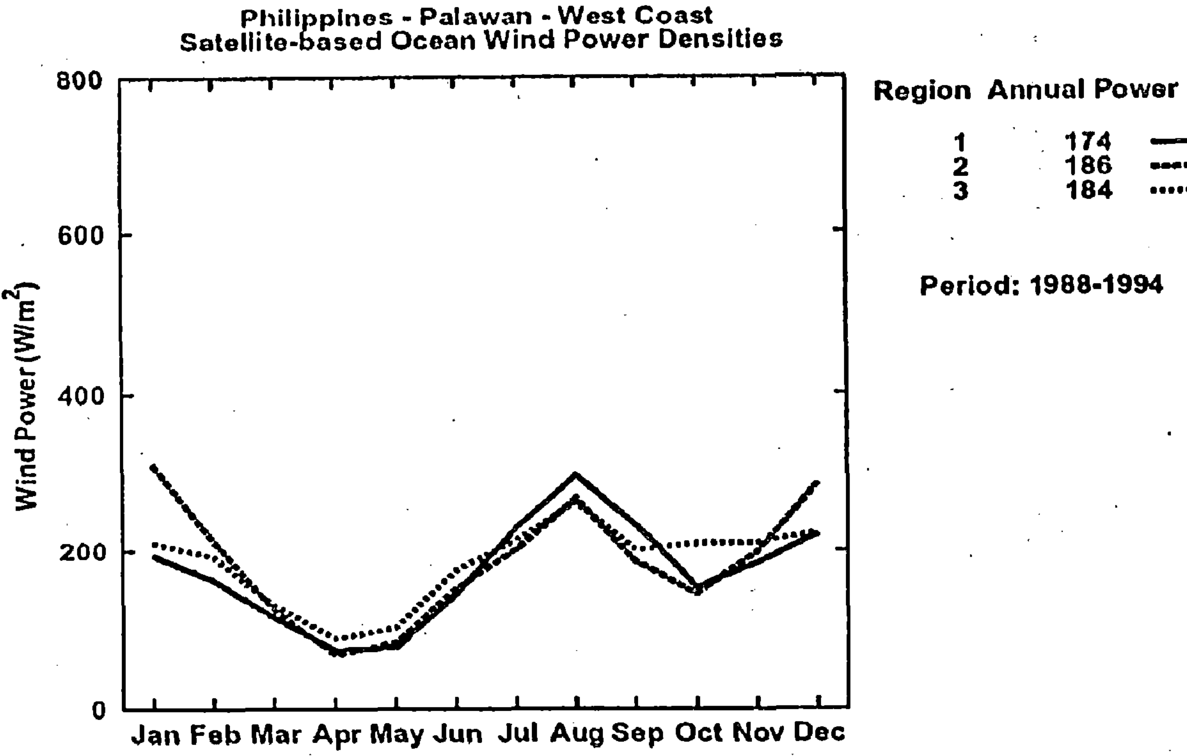


Figure 8-12: Average Monthly Palawan Island Satellite Ocean Wind Power Densities, 1988 - 1994

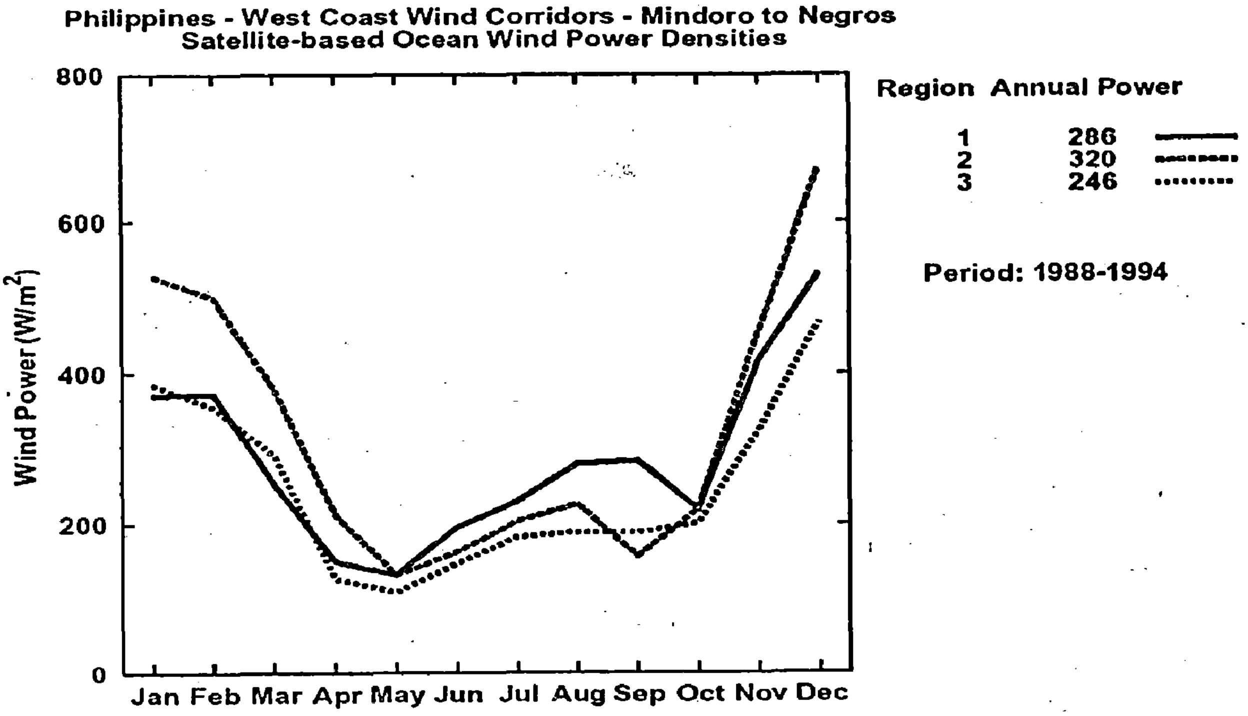


Figure 8-13: Average Monthly Mindoro Island Satellite Ocean Wind Power Densities, 1988 – 1994

Area	West Coast Wind Corridors - Mindoro to Negros			Palawan - East Coast			Palawan - West Coast		
Region	MN1	MN2	MN3	PE1	PE2	PE3	PW1	PW2	PW3
Jan	7.75	8.81	7.42	7.71	6.9	6.8	6.11	7.22	6.45
Feb	7.65	8.66	7.34	7.59	6.39	6.52	5.7	6.35	6.29
Mar	6.38	7.84	6.51	6.51	5.34	5.46	4.95	4.89	5.32
Apr	4.97	6.07	4.71	4.81	3.82	3.95	4.25	3.86	4.38
May	4.52	4.82	4.05	4.07	3.11	3.55	3.86	3.52	4.27
Jun	5.15	4.55	4.26	4.3	3.88	4.55	4.63	4.36	5.17
Jul	5.47	5.46	5.22	5.02	4.76	4.84	5.68	5.24	5.7
Aug	6.02	5.65	5.27	5.45	4.79	4.99	6.11	5.91	5.89
Sep	5.9	4.95	4.99	5.16	4.69	4.82	6.04	5.42	5.81
Oct	5.85	5.73	5.24	5.03	4.45	4.79	4.62	4.4	5.43
Nov	8.06	8.17	6.93	7.43	6.05	5.95	5.84	6.03	6.06
Dec	8.9	9.59	8.15	8.72	6.95	6.98	6.45	6.85	6.59
Weibull k	2.2	2	1.8	1.6	1.6	1.6	1.8	1.8	1.8
Autocorrelation factor	0.875	0.875	0.875	0.875	0.875	0.875	0.875	0.875	0.875
Diurnal Strength	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Hour of Peak Windspeed	14	14	14	14	14	14	14	14	14

Table 8-2: Average Monthly Wind Speed as Calculated for Philippine Ocean Regions from SSMI Satellite Ocean Wind Speed Data for Period *1988 – 1994*

8.2.3 Hydro Resource Potentials

The hydro resource potential of the Philippines is estimated at around 9,150 MW, aside from the existing 3,183.17 MW capacity already installed. Total large hydro potential stands at 4,400 MW, small at 1,150 MW and mini-hydro at 3,600 MW. The total existing hydropower plants in the Philippines comprise 2,953.1 MW of large hydro, 141 MW of small hydro and 89.07 MW of mini-hydro. More than 30% of the hydro potentials are located in the provinces of Cordillera Autonomous Region (CAR), 17% or 1,500 MW in Southern Tagalog region. In terms of Individual capacity, there are 28 large hydro potential sites with capacities ranging from 52 MW to 600 MW (**PEP 2002-2009**).

8.2.4 Hydro Resource Data

The hydro resource data used in this study was taken from the Philippine Hydropower Database, prepared and developed by the Mini-Hydro Division, Energy Utilization and Management Bureau, Philippine Department of Energy with the assistance and cooperation from the U. S. Agency for International Development (USAID) and the U. S. Department of Energy, National Renewable Energy Laboratory (NREL), U.S. Hydropower Council for International Development, and Winrock International. The information collection was funded under the Technology Cooperation Agreements Pilot Project (TCAPP), under which NREL provided assistance to nations supported by the United States Agency for International Development to encourage near-term private sector investment in renewable energy projects.

Table 3 and 4 from the Philippine Hydropower Database provide the potential hydroelectric projects studied in detail from 100 kW to 10 MW and 10 MW to larger hydropower potentials. The hydroelectric potentials for the study sites were extracted, summarized and tabulated in **Table 8-3** and **Table 8-4** for Mindoro and Palawan islands.

Project Name	Type	Installed Capacity (MW)	Head (m)	Hydraulic Capacity (m3/s)	Plant Factor	Ave. Annual Net Energy Production (GWh)	Project Construction Cost (Million)
Catuiran	R-O-R	18	158	15.8	0.37	58.7	$24.1
Dulangan	R-O-R	24	1,211	2.5	0.3	62.12	$34.8
Bongabong	R-O-R	28	102	36.4	0.51	124.1	$42.9
Alag	R-O-R	39.5	824	5.9	0.26	91.18	$39.6
Dulangan	R-O-R	1.6	34.5	6	0.35	4.891	N.A.
Dulangan 2	R-O-R	1	34.5	3.86	0.30	2.625	PhP 18.5
Bansud	R-O-R	1	54.5	2.38	0.49	4.288	N.A.
Buraboy	R-O-R	3.2	66.4	6.1			

Table 8-3: Mindoro Island Potential Major and Mini-Hydropower Development Projects with Feasibility Studies

Project Name	Type	Installed Capacity (MW)	Head (m)	Hydraulic Capacity (m3/s)	Plant Factor	Ave. Annual Net Energy Production (GWh)	Project Construction Cost (Million)
Langogan	R-O-R	6.8	98	8.9	0.46	27.12	$15.60
Babuyan	R-O-R	5.6	47	15.4	0.49	24.18	$17.70
Batang-Batang	R-O-R	3.59	80	5.46	0.65	20.44	PhP 161.55
Malatgao	R-O-R	3.13	70	5.6	0.65	17.82	PhP 140.85
Inagawan	R-O-R	2.32	50	5.8	0.65	13.21	PhP 104.40
Baraki	R-O-R	0.96	60	2.02	0.65	5.47	PhP 43.20
Talakaigan	R-O-R	0.84	80	1.32	0.65	4.78	PhP 37.80
Cabinbin	R-O-R	0.8	57	1.8	0.49	3.43	PhP 38.06

Table 8-4: Palawan Island Potential Mini-Hydropower Development Projects with Feasibility Studies

8.2.5 Streamflow Data

Streamflow discharge measurements are the only direct means of quantifying the amounts of water relevant to the utilization aspects of water resources development such as run-of-river hydropower scheme. For different types of renewable energy technology in a power generation load system management system, streamflow data were necessary for determination of the hourly baseload hydro power contribution of the runoff-river scheme to the hybrid power system in conjunction with the hourly wind farm power contribution to the mini-grid of the study sites. Since the streamflow data of the rivers used by the Department of Energy for the various completed feasibility studies of proposed hydropower projects which will be used in the simulation studies as shown in **Table 8-3** and 8-4 are not yet available for public, the mean daily streamflow data of selected river near the study site from the database of Philippines Department of Public Works and Highway, Bureau of Research Standards will instead be utilized in the Mindoro island integration wind and hydro power system simulation to be able to determine the annual mean monthly streamflow profile as shown in **Figure 8-14.**

This streamflow profile will then be matched with the average annual net energy production of the various run-of-river schemes that will be used in the hybrid power simulation. Streamflow input in the simulation program will be assumed to approximate the average annual net energy production.

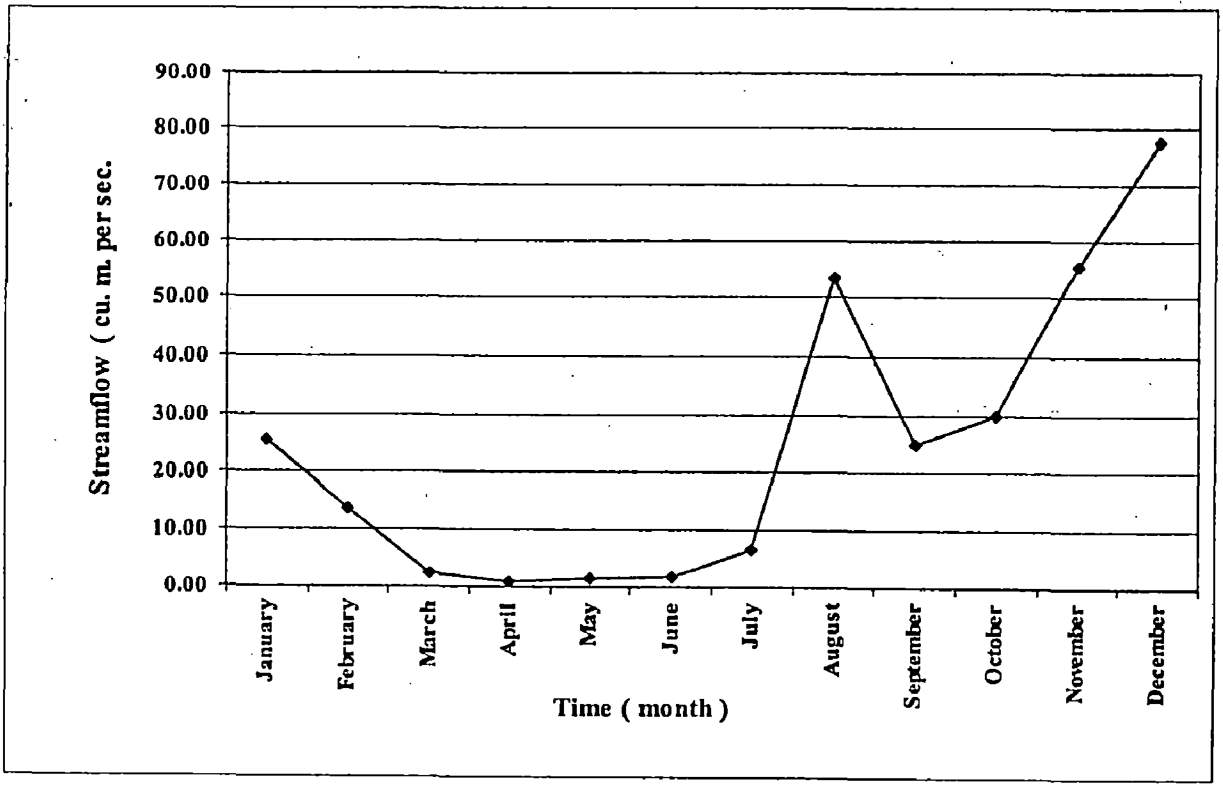


Figure 8-14: 1990 – 1993 Mean Monthly Streamflow Profile for Mag-Asawang Tubig, Naujan, Oriental Mindoro

For the Palawan, the necessary streamflow data for its run-of-river scheme hourly power computation are not also available. The Department of Public Works and Highway had not established any stream gaging station within the Palawan river basin. However, the Palawan Integrated Area Development Project (PIADP) had installed eight (8) stream gaging stations within the area. But these stations started operations only in 1981 and thus have insufficient historical streamflow record. In the absence of the run-off or steamflow data from within the Palawan island basins, the statistical mean monthly rainfall data from 1949 to 1973 of the existing rainfall station in Puerto Princesa shown in **Figure 8-15** which is within the study site shall be used as a reference for mean monthly streamflow characteristic to be used in the hourly simulation process. The mean monthly rainfall shall assume the basis for mean monthly streamflow variation for the run-of-river scheme input in the simulation process.

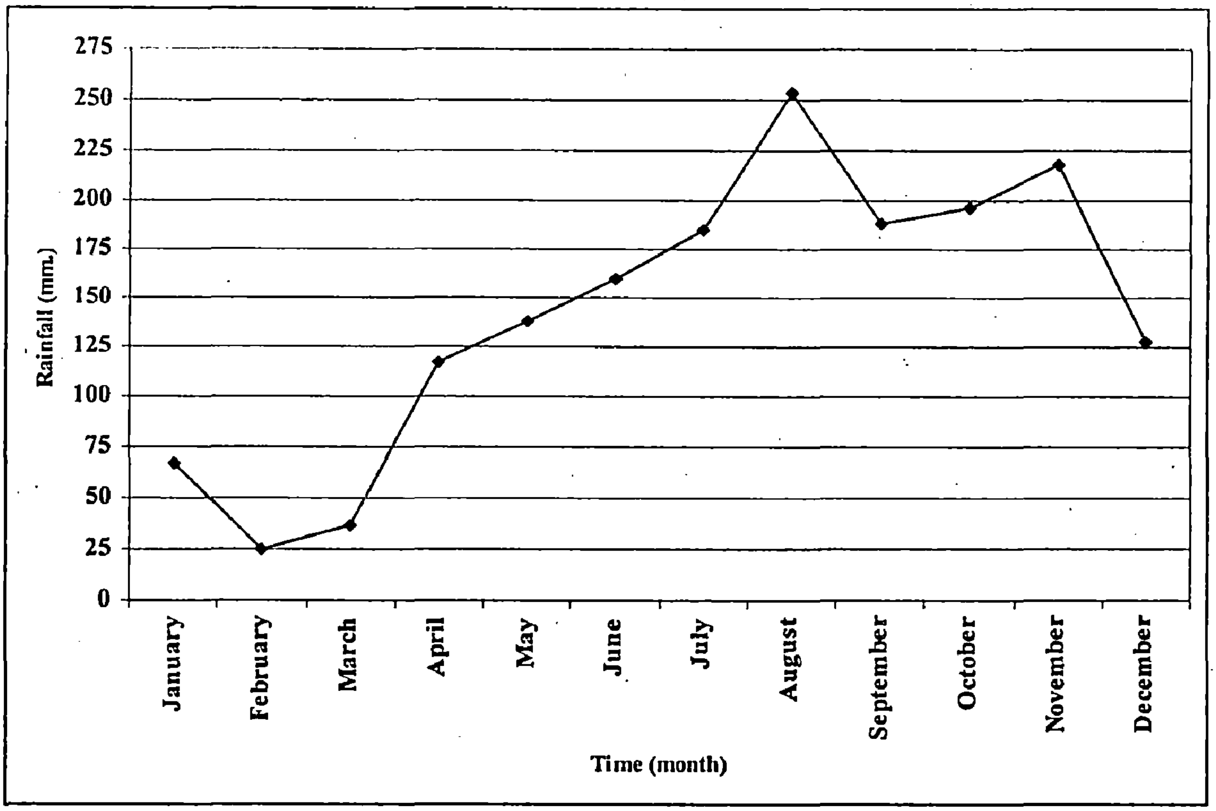


Figure 8-15: 1949 – 1973 Mean Monthly Rainfall Profile for Puerto Princesa, Palawan

8.2.5 Primary Load

The demand for electricity in the Philippines will continue to grow at an average annual rate of 7.54% based on the 10 year projected average GDP of 5.33% from 2003 to 2012. The forecasted system peak demand shall have an annual growth of 7.6% based on a low average GDP and 8.2% for high average GDP. The total Philippine forecasted base case power generation is around 55 TWh in 2003 to about 106 TWh in 2012. **(PEP, 2003-2012)**

Among the isolated island small power grids under NPC-SPUG operation, the Mindoro and Palawan island grid systems are the most dynamic in terms of load demand growth as shown in **Table 8-5. Table 8-6** and **8.7** shows the 24-hours load in 2001 for Mindoro and Palawan which will be used as the input primary load of the simulation.

Year	Oriental Mindoro			Occidental Mindoro			Palawan		
	MWH Demand	Peak Load, kW	MWH Generated	MWH Demand	Peak Load, kW	MWH Generated	MWH Demand	Peak Load, kW	MWH Generated
1981	7,308	2,250	9,770	2,277	1,292	3,339	6,018	2,107	7,362
1982	7,361	2,750	10,028	1,786	1,627	2,424	7,100	2,515	8,505
1983	10,577	2,750	13,637	1,136	1,627	1,619	7,499	2,515	9,156
1984	9,449	3,300	12,878	812	1,207	1,372	7,280	2,035	8,949
1985	10,162	3,500	14,465	1,445	1,177	2,124	7,499	2,716	9,273
1986	10,622	4,000	15,558	2,125	1,183	3,375	8,447	3,235	10,753
1987	8,209	3,900	11,366	2,965	1,256	4,736	10,406	3,943	13,990
1988	7,925	3,000	11,078	3,408	1,790	5,297	12,702	3,815	16,139
1989	11,512	3,500	14,058	5,108	2,017	6,899	14,927	4,120	18,460
1990	16,582	4,750	20,521	6,463	1,982	8,949	18,884	4,865	22,884
1991	17,079	5,500	21,535	7,674	2,362	9,579	23,108	5,720	27,980
1992	20,392	6,850	26,037	7,011	2,362	8,702	29,656	6,545	35,123
1993	24,509	7,620	29,739	9,188	2,600	11,287	34,321	7,816	40,458
1994	22,171	8,350	27,533	10,627	3,999	13,149	38,982	8,990	46,236
1995	27,663	11,450	34,960	13,069	5,250	15,843	45,351	10,350	52,344
1996	36,883	13,000	46,475	16,360	7,581	20,279	49,578	12,093	57,078
1997	46,058	15,900	56,505	19,819	8,999	24,498	58,602	13,780	67,600
1998	58,371	17,100	68,431	22,095	8,109	28,170	66,680	13,993	76,372
1999	61,860	18,310	72,168	25,087	8,064	30,019	69,248	15,400	78,614
2000	65,136	20,400	75,016	27,859	7,910	34,282	75,285	18,600	85,141
2001	74,733	21,500	87,200	30,475	7,878	36,475	78,091	18,600	88,487
2002	81,840	26,450	95,523	31,189	7,050	37,747	82,548	19,244	95,176

Table 8-5: Mindoro and Palawan Islands Electricity Load Demand, Supply and Peak Load, 1981 -2002

The typical 24-hour load profiles of Mindoro and Palawan small power grid system as provided by the NPC-SPUG is shown in **Figure 8-16a** and **8-16b**. Small island grids electricity demand will grow at an annual rate of 10.9 %, from 607.3 GWh in 2000 to 1,538 GWh in 2009. To meet the increasing demand, a total of 295 MW of additional capacity will be installed in small island grids.

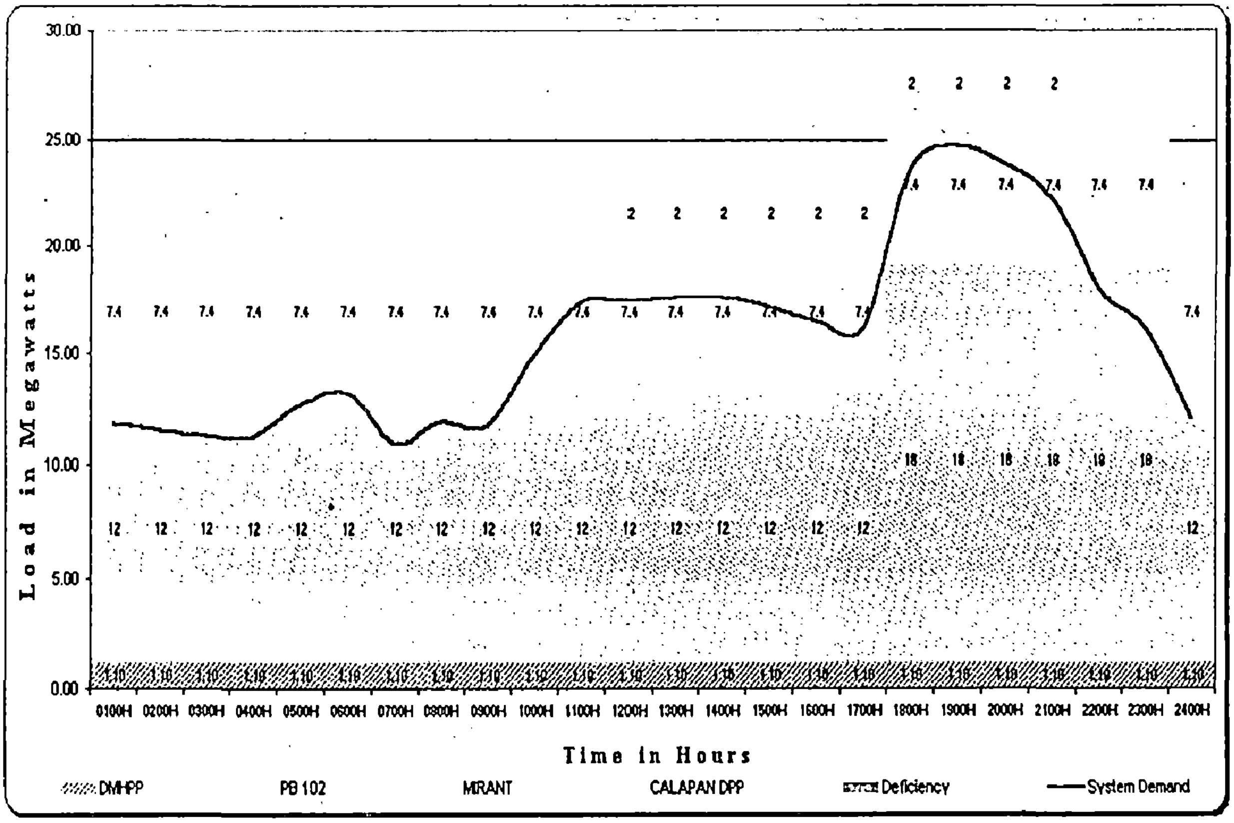


Figure 8-16a: Typical 24-hour Load Demand Profile of Mindoro Mainland

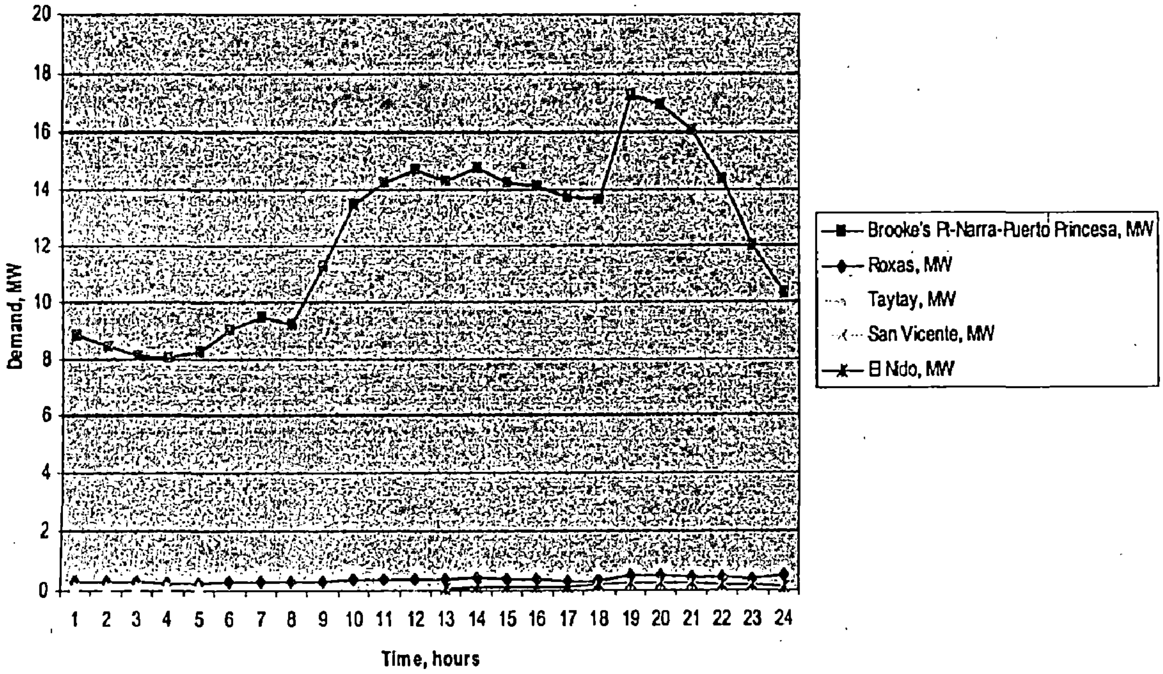


Figure 8-16b: Typical Load Demand Profile of Palawan Mainland

Time \ Month	January		February		March		April		May		June	
Hr:Mn:Sec	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend
00:00:00	5,711	5,112	6,165	5,496	5,113	4,576	5,670	5,216	7,185	6,431	6,533	5,840
01:00:00	5,547	4,965	5,988	5,338	4,966	4,445	5,508	5,067	6,979	6,247	6,346	5,673
02:00:00	5,445	4,874	5,878	5,240	4,875	4,364	5,407	4,974	6,851	6,132	6,230	5,569
03:00:00	5,384	4,819	5,812	5,181	4,820	4,314	5,345	4,918	6,773	6,063	6,159	5,506
04:00:00	6,141	5,497	6,630	5,910	5,498	4,921	6,098	5,610	7,726	6,916	7,026	6,281
05:00:00	6,346	5,680	6,850	6,107	5,681	5,085	6,301	5,797	7,984	7,146	7,260	6,490
06:00:00	5,219	4,672	5,634	5,023	4,673	4,183	5,182	4,768	6,567	5,878	5,971	5,338
07:00:00	5,772	5,167	6,231	5,555	5,168	4,626	5,731	5,273	7,262	6,500	6,603	5,903
08:00:00	5,671	5,076	6,121	5,457	5,077	4,544	5,630	5,180	7,134	6,386	6,487	5,799
09:00:00	7,370	6,596	7,955	7,092	6,598	5,906	7,317	6,732	9,272	8,299	8,431	7,537
10:00:00	8,720	7,805	9,413	8,392	7,807	6,988	8,658	7,965	10,971	9,820	9,976	8,918
11:00:00	8,741	7,824	9,436	8,412	7,825	7,004	8,678	7,984	10,997	9,843	9,999	8,939
12:00:00	8,823	7,897	9,524	8,491	7,899	7,070	8,760	8,059	11,100	9,936	10,093	9,023
13:00:00	8,829	7,903	9,531	8,497	7,904	7,075	8,766	8,065	11,108	9,943	10,100	9,030
14:00:00	8,598	7,696	9,281	8,274	7,697	6,890	8,537	7,854	10,817	9,682	9,836	8,793
15:00:00	8,229	7,366	8,883	7,919	7,367	6,594	8,170	7,517	10,353	9,267	9,414	8,416
16:00:00	8,208	7,347	8,861	7,899	7,349	6,578	8,150	7,498	10,327	9,244	9,390	8,395
17:00:00	17,401	15,576	18,785	16,746	15,579	13,944	17,277	15,895	21,893	19,596	19,907	17,796
18:00:00	17,884	16,008	19,306	17,211	16,011	14,332	17,757	16,336	22,500	20,140	20,459	18,290
19:00:00	16,990	15,208	18,341	16,350	15,211	13,615	16,869	15,519	21,375	19,133	19,436	17,376
20:00:00	11,319	10,132	12,219	10,893	10,134	9,071	11,239	10,340	14,241	12,747	12,949	11,577
21:00:00	9,048	8,099	9,767	8,707	8,100	7,251	8,983	8,265	11,383	10,189	10,351	9,254
22:00:00	8,065	7,219	8,707	7,762	7,221	6,463	8,008	7,367	10,147	9,083	9,227	8,249
23:00:00	5,813	5,204	6,276	5,595	5,205	4,659	5,772	5,310	7,314	6,547	6,650	5,945
Daily Total:	205,274	183,740	221,596	197,547	183,778	164,498	203,812	187,507	258,260	231,167	234,832	209,938

Table 8-6: Daily Weekday and Weekend Mean Monthly Primary Load Demand of Oriental Mindoro – 2001

Time \ Month	July		August		September		October		November		December	
Hr:Mn:Sec	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend
00:00:00	5,950	5,326	5,931	5,309	6,044	5,403	5,952	5,328	6,159	5,506	4,490	4,130
01:00:00	5,780	5,174	5,761	5,157	5,871	5,248	5,782	5,175	5,983	5,348	4,361	4,012
02:00:00	5,674	5,079	5,655	5,062	5,763	5,152	5,676	5,080	5,873	5,250	4,281	3,939
03:00:00	5,610	5,021	5,591	5,005	5,698	5,094	5,611	5,023	5,806	5,191	4,233	3,894
04:00:00	6,399	5,728	6,378	5,709	6,500	5,811	6,401	5,729	6,623	5,921	4,828	4,442
05:00:00	6,612	5,918	6,590	5,899	6,716	6,004	6,614	5,920	6,844	6,118	4,989	4,590
06:00:00	5,438	4,868	5,420	4,852	5,524	4,938	5,440	4,869	5,629	5,032	4,103	3,775
07:00:00	6,015	5,384	5,995	5,366	6,109	5,461	6,016	5,385	6,225	5,565	4,538	4,175
08:00:00	5,909	5,289	5,889	5,271	6,001	5,365	5,910	5,290	6,116	5,467	4,458	4,101
09:00:00	7,679	6,873	7,654	6,851	7,799	6,973	7,681	6,875	7,948	7,105	5,794	5,330
10:00:00	9,086	8,133	9,056	8,106	9,229	8,250	9,089	8,135	9,404	8,407	6,856	6,307
11:00:00	9,107	8,152	9,078	8,125	9,251	8,270	9,110	8,154	9,427	8,427	6,872	6,322
12:00:00	9,193	8,229	9,163	8,202	9,338	8,348	9,196	8,231	9,515	8,507	6,936	6,381
13:00:00	9,200	8,234	9,169	8,207	9,344	8,354	9,202	8,237	9,522	8,512	6,941	6,386
14:00:00	8,959	8,019	8,929	7,992	9,099	8,135	8,961	8,021	9,273	8,290	6,759	6,219
15:00:00	8,574	7,675	8,546	7,649	8,709	7,786	8,577	7,677	8,875	7,934	6,469	5,952
16:00:00	8,553	7,655	8,525	7,630	8,687	7,766	8,555	7,658	8,852	7,914	6,453	5,937
17:00:00	18,131	16,229	18,072	16,176	18,416	16,464	18,137	16,234	18,767	16,777	13,680	12,586
18:00:00	18,635	16,680	18,573	16,625	18,928	16,921	18,640	16,685	19,288	17,243	14,060	12,935
19:00:00	17,703	15,846	17,645	15,794	17,981	16,075	17,708	15,850	18,323	16,381	13,357	12,289
20:00:00	11,795	10,557	11,756	10,523	11,980	10,710	11,798	10,560	12,208	10,914	8,899	8,187
21:00:00	9,428	8,439	9,397	8,411	9,576	8,561	9,430	8,441	9,758	8,724	7,113	6,544
22:00:00	8,404	7,522	8,376	7,498	8,536	7,631	8,406	7,524	8,698	7,776	6,341	5,834
23:00:00	6,057	5,422	6,037	5,404	6,153	5,500	6,059	5,423	6,270	5,605	4,570	4,205
Daily Total:	213,890	191,450	213,186	190,822	217,250	194,219	213,952	191,507	221,384	197,915	161,382	148,471

Table 8-6: Daily Weekday and Weekend Mean Monthly Primary Load Demand of Oriental Mindoro – 2001

Time \ Month	January		February		March		April		May		June	
Hr:Mn:Sec	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend
00:00:00	7,699	3,808	9,001	4,892	7,398	3,659	8,656	4,422	8,281	4,095	8,501	4,343
01:00:00	7,359	3,639	8,603	4,675	7,071	3,497	8,273	4,226	7,915	3,914	8,126	4,151
02:00:00	7,072	3,498	8,267	4,493	6,796	3,361	7,950	4,062	7,606	3,762	7,809	3,989
03:00:00	7,023	3,473	8,210	4,462	6,748	3,337	7,895	4,033	7,553	3,736	7,755	3,962
04:00:00	7,109	3,516	8,310	4,517	6,831	3,378	7,992	4,083	7,646	3,781	7,850	4,010
05:00:00	7,675	3,796	8,972	4,876	7,375	3,647	8,628	4,408	8,255	4,082	8,474	4,329
06:00:00	7,990	3,952	9,341	5,077	7,678	3,797	8,983	4,589	8,594	4,250	8,823	4,507
07:00:00	7,793	3,854	9,111	4,952	7,489	3,704	8,762	4,476	8,382	4,146	8,606	4,396
08:00:00	9,544	4,720	11,157	6,064	9,171	4,536	10,730	5,481	10,265	5,077	10,539	5,384
09:00:00	11,344	5,610	13,261	7,207	10,901	5,391	12,753	6,515	12,201	6,034	12,526	6,399
10:00:00	12,024	5,947	14,057	7,640	11,554	5,714	13,518	6,906	12,933	6,396	13,277	6,783
11:00:00	12,438	6,152	14,541	7,903	11,952	5,911	13,984	7,144	13,378	6,616	13,734	7,017
12:00:00	12,191	6,029	14,251	7,745	11,714	5,794	13,705	7,002	13,112	6,485	13,461	6,877
13:00:00	12,652	6,257	14,791	8,039	12,158	6,013	14,224	7,267	13,608	6,730	13,971	7,137
14:00:00	12,220	6,044	14,286	7,764	11,743	5,808	13,738	7,019	13,144	6,500	13,494	6,893
15:00:00	12,085	5,977	14,128	7,678	11,613	5,743	13,586	6,941	12,998	6,428	13,344	6,817
16:00:00	11,756	5,814	13,743	7,469	11,297	5,587	13,217	6,752	12,645	6,254	12,981	6,632
17:00:00	11,877	5,874	13,884	7,546	11,413	5,644	13,352	6,821	12,774	6,318	13,114	6,700
18:00:00	15,207	7,521	17,778	9,662	14,613	7,227	17,097	8,734	16,356	8,089	16,792	8,578
19:00:00	14,973	7,405	17,504	9,513	14,388	7,116	16,833	8,599	16,104	7,965	16,533	8,446
20:00:00	14,239	7,042	16,646	9,047	13,683	6,767	16,008	8,178	15,315	7,574	15,723	8,032
21:00:00	12,739	6,300	14,893	8,094	12,242	6,054	14,322	7,317	13,702	6,777	14,067	7,186
22:00:00	10,661	5,272	12,463	6,773	10,244	5,066	11,985	6,123	11,466	5,671	11,772	6,014
23:00:00	9,247	4,573	10,810	5,875	8,886	4,395	10,396	5,311	9,946	4,919	10,211	5,216
Daily Total:	254,918	126,073	298,006	161,960	244,957	121,147	286,587	146,409	274,181	135,600	281,481	143,800

Table 8-7: Daily Weekday and Weekend Mean Monthly Primary Load Demand of Palawan – 2001

Time \ Month	July		August		September		October		November		December	
Hr:Mn:Sec	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend	Wkday	Wkend
00:00:00	7,620	3,769	7,544	3,731	8,608	4,397	8,079	3,996	8,384	4,283	8,089	4,001
01:00:00	7,283	3,602	7,210	3,566	8,227	4,203	7,722	3,819	8,014	4,094	7,731	3,824
02:00:00	6,999	3,462	6,929	3,427	7,906	4,039	7,421	3,670	7,701	3,934	7,430	3,675
03:00:00	6,951	3,438	6,881	3,403	7,851	4,011	7,369	3,645	7,648	3,907	7,378	3,649
04:00:00	7,036	3,480	6,965	3,445	7,948	4,060	7,460	3,689	7,741	3,955	7,469	3,694
05:00:00	7,596	3,757	7,520	3,719	8,580	4,383	8,053	3,983	8,357	4,270	8,063	3,988
06:00:00	7,908	3,911	7,829	3,872	8,933	4,564	8,384	4,147	8,701	4,445	8,395	4,152
07:00:00	7,714	3,815	7,636	3,777	8,713	4,451	8,178	4,045	8,487	4,336	8,188	4,050
08:00:00	9,446	4,672	9,351	4,625	10,670	5,451	10,015	4,953	10,393	5,310	10,027	4,959
09:00:00	11,227	5,553	11,115	5,497	12,682	6,479	11,903	5,887	12,353	6,311	11,918	5,894
10:00:00	11,901	5,886	11,781	5,827	13,443	6,868	12,618	6,240	13,094	6,689	12,633	6,248
11:00:00	12,311	6,089	12,187	6,027	13,906	7,104	13,052	6,455	13,545	6,920	13,068	6,463
12:00:00	12,066	5,967	11,945	5,907	13,629	6,963	12,792	6,327	13,275	6,782	12,808	6,334
13:00:00	12,523	6,193	12,397	6,131	14,145	7,226	13,277	6,566	13,778	7,039	13,293	6,574
14:00:00	12,095	5,982	11,973	5,922	13,662	6,980	12,823	6,342	13,307	6,798	12,839	6,350
15:00:00	11,961	5,916	11,841	5,856	13,511	6,902	12,681	6,272	13,160	6,723	12,697	6,279
16:00:00	11,636	5,755	11,519	5,697	13,144	6,715	12,336	6,101	12,802	6,540	12,351	6,109
17:00:00	11,755	5,814	11,637	5,755	13,278	6,783	12,463	6,164	12,933	6,607	12,478	6,171
18:00:00	15,051	7,444	14,900	7,369	17,002	8,686	15,958	7,892	16,560	8,460	15,977	7,902
19:00:00	14,819	7,329	14,670	7,255	16,740	8,552	15,711	7,770	16,305	8,330	15,731	7,780
20:00:00	14,093	6,970	13,951	6,900	15,919	8,133	14,941	7,389	15,506	7,921	14,960	7,399
21:00:00	12,609	6,236	12,482	6,173	14,243	7,276	13,368	6,611	13,873	7,087	13,384	6,619
22:00:00	10,551	5,218	10,445	5,166	11,919	6,089	11,187	5,533	11,609	5,931	11,200	5,539
23:00:00	9,152	4,526	9,060	4,481	10,338	5,282	9,703	4,799	10,070	5,144	9,715	4,805
Daily Total:	252,305	124,781	249,769	123,527	285,000	145,598	267,494	132,293	277,597	141,816	267,823	132,456

Table 8-7: Daily Weekday and Weekend Mean Monthly Primary Load Demand of Palawan – 2001

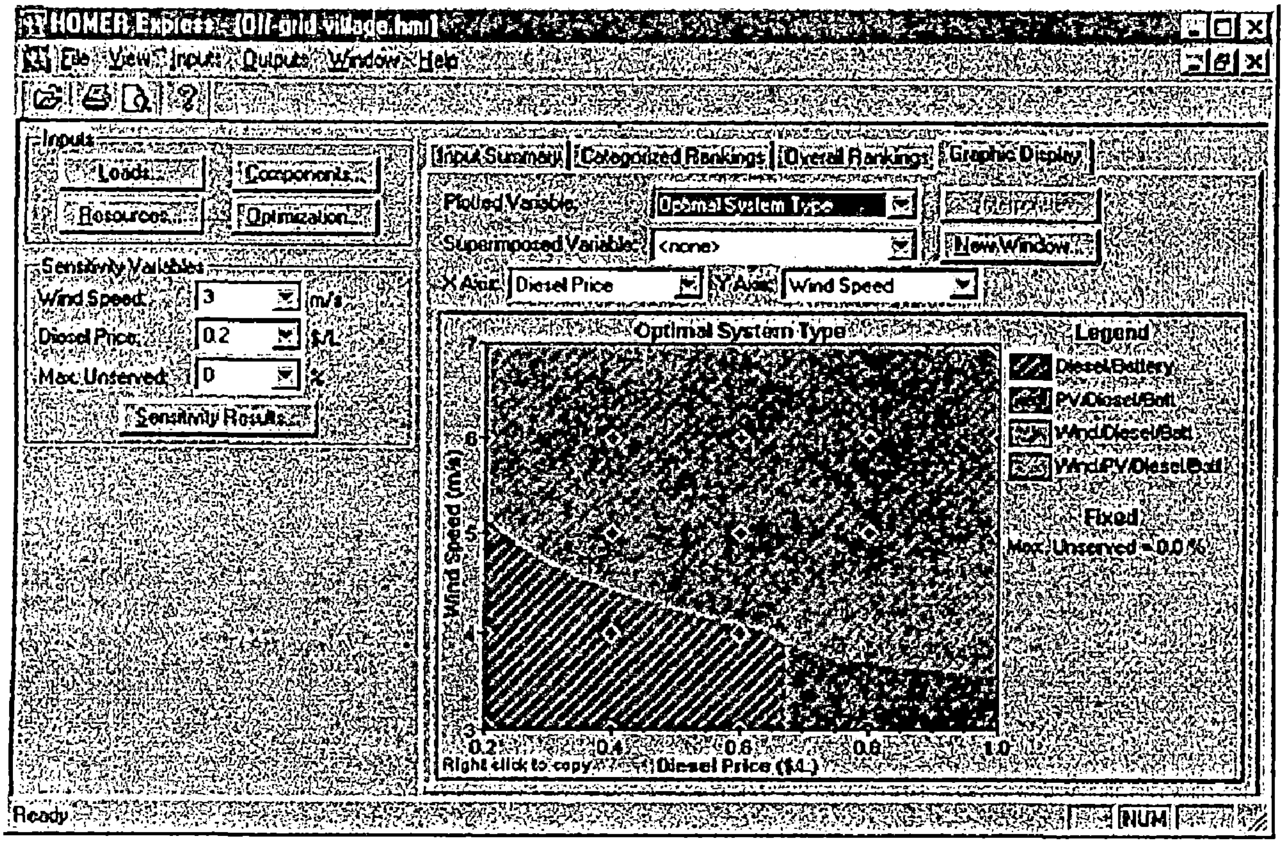
8.3 Optimization Model for Grid-Connected Wind/Hydro Power System

With hybrid power system, the degree of uncertainties due to weather conditions will be largely reduced. However, the degree of complexity in the system operation will be increased by many folds (Flowers, 1998). To design a system, which is characterized by non-linear and stochastic constraints, a large amount of combinatorial process must be checked and the system must be optimized. This is a typical case of a non-linear multi-objective decision making problem for sizing and operation strategy. To ease the work, a sound decision making tool is necessary. There are many computer programs available to optimize and/ or simulate the hybrid energy system such as ***HOMER*** (Lilliethal, 1995), ***Hybrid2***, (Baring-Gould et al., 1996), ***INSEL*** (Luther & Schumacher, 1991), ***RESAD*** (Jennings et al., 1996) etc.

Of the several optimization and simulation programs mentioned, this dissertation shall limit its selection to two options that of the ***Hybrid2*** and ***HOMER***. Both the programs can be downloaded free from the U.S. Department of Energy – National Renewable Energy Laboratory website for evaluating off-grid and grid-connected hybrid renewable energy technologies by power system designers, rural electrification program planners and researchers and market and technology analysts for distributed and small power technologies. ***Hybrid2*** is a hybrid power system simulation model developed by NREL and the University of Massachusetts. It performs an accurate simulation of the performance and the economics of a particular hybrid system. By contrast, ***HOMER*** is an optimization model which performs many hundreds or thousands of less-accurate simulations in order to determine the optimal hybrid system. Typically, a hybrid system designer will use ***HOMER*** to design an approximately optimal system, and then use ***Hybrid2*** to refine the system and further investigate its properties.

Hybrid2 has several capabilities that ***HOMER*** does not have. For example, it can use time steps smaller than one hour, and it can simulate many more dispatch strategies. On the other hand, ***HOMER*** has several capabilities that ***Hybrid2*** does not have. ***HOMER*** can perform optimization (search for the optimal system) and sensitivity analyses (determine the effect of changes to the inputs). It can also simulate grid-connected systems. Another capability is the integration of run-of-river hydropower technology in the power system model configuration to which is not present in ***Hybrid2*** computer model. The program is more simplified to run quickly, facilitating iterative computation to search the range of possible designs for the one leading to the lowest life-cycle cost.

Due to the absence of hydro in the ***Hybrid2*** configuration, this study will use ***HOMER*** hybrid system computer model for analysis and optimization of the proposed wind/hydro power system. ***HOMER*** stands for ***H****ybrid* ***O****ptimization* ***M****odel for* ***E****lectric* ***R****enewables* (Lilienthal 1995). ***HOMER*** is a time-series simulation optimization model program that was developed by U.S. DOE-NREL for distributed power generation and this simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. The program simulates the operation of a system by making energy balance calculations for each of the 8,760 hours in a year. Inputs are provided to the model, which describes the technology options, component costs, and resource availability.



Wind Speed: 3 m/s
Diesel Price: 0.2 $/L
Max. Unserved: 0 %
Plotted Variable: Optimal System Type
Superimposed Variable: <none>
X Axis: Diesel Price
Y Axis: Wind Speed
Max. Unserved = 0.0 %

Figure 8-17: Sample of HOMER Sensitivity Output for the Optimal System Type

The program uses these inputs to simulate different system configurations, or combinations of components, and generates results that can be view as a list of feasible configurations sorted by net present cost or sometimes called lifecycle cost that can be use to compare system design options. When sensitivity variables are defined as inputs, it repeats the optimization process for each sensitivity variable that is specified.

The following are some strengths of *HOMER* program:

- Compares different technologies including hybrids.
- Considers storage or deferrable load options such as water pumping, etc.
- Considers seasonal and daily variations in loads and resources.
- Designed as optimization model for sensitivity analyses.
- Performs dozens of 8760 hour annual simulations per second.
- Powerful graphic capability (shown in **Figure 8-17and 8-18)**

However, the program does not consider intra-hour variability and does not consider variations in bus-voltage.

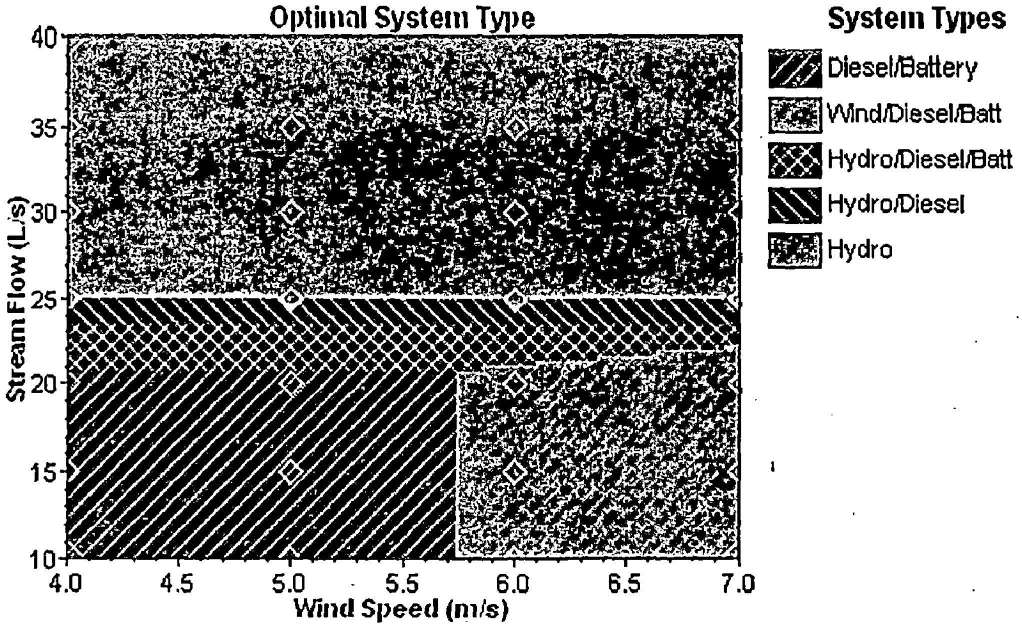


Figure 8-18: Sample of Graphical Results of an Analysis for Wind, Diesel, Hydro and Battery Energy Storage System Hybrid System by HOMER

HOMER had been studied and used in various hybrid power system architectures evaluation. Some of these studies, to name few, were used in evaluating feasibility of hybrid retrofits to off-grid diesel power plants in the Philippines[112], optimization of electric power systems for off-grid domestic applications: an argument for wind/photovoltaic hybrids[114], feasibility study wind/hybrid power system applications for New England islands[113], modeling the feasibility of using fuel cells and hydrogen internal combustion engines in remote renewable energy system[115], cost efficiency analysis of energy options for Dow Chemicals wetland building classrooms. [116] Some of these studies are not yet available on electronic publication but can be provided by U.S. DOE- National Renewable Energy Laboratory (NREL) upon request through Dr. Peter Lilienthal or Dr. Tom Lambert, in-charge of developing the ***HOMER*** program as these are still part of the on-going renewable energy research program of the U. S. Department of Energy..

8.3.1 Input Data

To design the optimal hybrid system, ***HOMER*** needs to know about the expected electrical demand, local energy costs, the available renewable energy resources, and the cost and performance of the various components. ***HOMER*** divides inputs into four categories:

- **load inputs**—the system's electrical and thermal loads,
- **resource inputs**—the available renewable energy resources (using monthly or hourly data) and the price and characteristics of fossil fuels,
- **component inputs**—the cost and performance of the power system components, and
- **optimization inputs**—the allowable size range for each system component and various constraints on the power system.

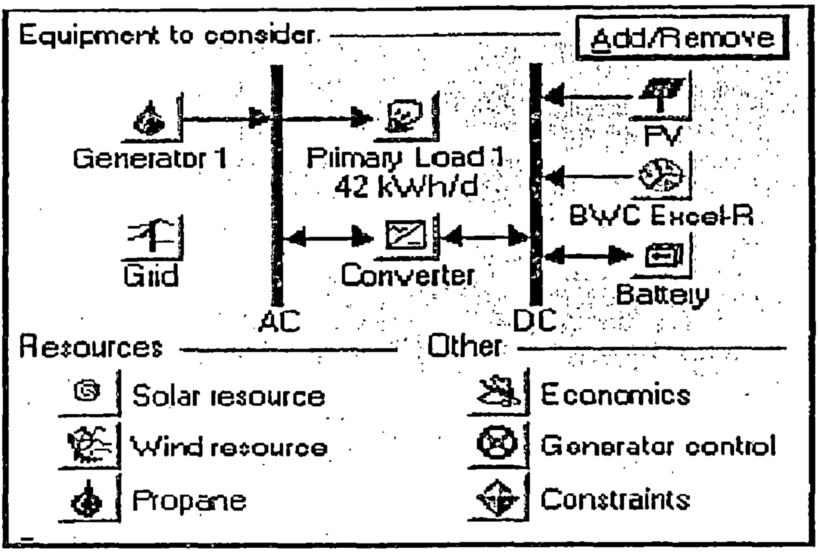


Figure 8-19: Window for HOMER Inputs Screenshot

HOMER also considers the local cost of fuel and the cost of grid extensions when evaluating options. Multiple values can be specified for most variables when the data is uncertain or the user is interested in a potentially wide range of applications. ***HOMER*** performs its optimization procedure for each sensitivity case, or combination of values.

8.3.2 Outputs

HOMER provides three levels of outputs. The results of a particular system simulation include:

- **summary results** like capital cost, net present cost, annual energy production, and fuel usage, as well as hourly data like power production or battery state of charge
- **optimization results,** which rank all of the different systems simulated for a particular sensitivity case according to net present cost; and
- **sensitivity outputs** that show the effects of changes in sensitivity variables, in tabular or graphic format.

CONCLUSION

9.1 Discussions and Analysis of the Study

All the available data for Mindoro and Palawan islands were processed, evaluated and elimination process was done to select the best possible potential sites for computer model simulation of the wind and hydro power hybrid system. The proximity of the potential wind farm sites to the nearest available potential hydropower projects of the island based on the various feasibility studies made by the Philippine Department of Energy on potential hydropower of both island was also considered in selecting the hydropower to matched the farm site since these two technologies will be complimenting each other. Connection to the existing diesel and bunker oil C power generators in the small power grid system was also necessary as the main objectives of this study are to reduce greenhouse gases (GHGs) caused by the combustion of fossil fuel dominated power generations of the islands and maximize the available identified sustainable renewable energy potentials of the island with low operational cost for integration to the power grid system thereby lowering the existing production cost of energy, which is beneficial to the consumers of the islands.

The conceptual purpose of the proposed system for small isolated island is to utilize the excess electricity generated by the potential wind farm during off-peak period, whenever there is enough power for hydro pump design capacity, to pump water to a higher elevation reservoir for various future utilization plan whether its for power generation as pump-storage hydropower unit, for agricultural irrigation for areas not reached by water, or as source for domestic water requirement for the island's population. This concept will maximize the utilization of water, a precious resource that is annually available for the island's water basin, now becoming scarce especially during dry season period, by circulating it back to the system and minimizing the return of these precious resources back to the salty sea water. This study will not deal with the more detail of what priority utilization plan that the island will do with the available water pumped to the higher elevation reservoir, but will assume that it will be use for additional power generation.

9.1.1 Analysis of Mindoro Study Site Wind/Hydro Power System

In Mindoro Island, the hourly satellite ocean wind data from NREL for the two potential wind farm sites were assessed and the data at the southern part of the island were selected to be the best possible site for wind farm electricity production because the area yields higher seven-year period annual mean wind speed and power density compared to the northern portion (see **Table 8-2** and **Figure 8-11**). The southern part of the island has annual wind speed of 6.7 meters per second (m/s) and wind power density of 320 Watts per square meter (W/m^2) compared to wind speed of 6.4 m/s and wind power density of 246 W/m^2 at the northern part during the same time period. Both potential sites have almost identical wind speed variation pattern during the year that is low during the dry months from April to beginning of July and high during the rest of the month for the same year as seen in **Figures 9-1**.

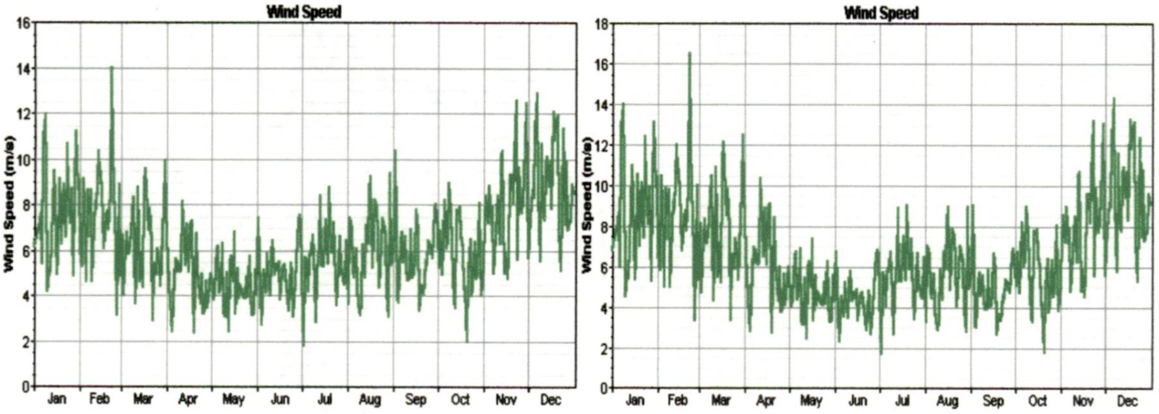


Figure 9-1: Comparative Profile of Mean Hourly Mindoro Island SSMI Satellite Ocean Wind Speed Data- Area 1 and 2, 1988-1994

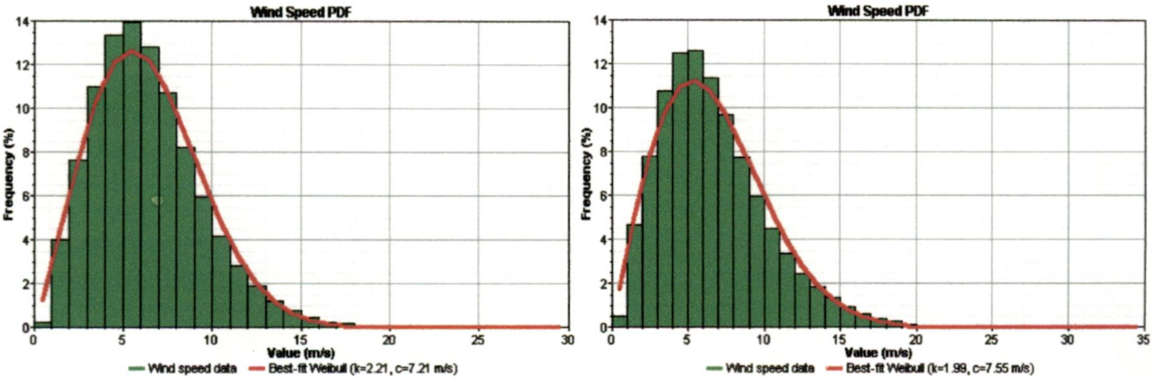


Figure 9-2: Wind Speed Probability Density Functions of the Two Potential Sites

Preliminary assessment of the electricity production of both sites using various wind farm capacities reveals that the site 2 at the southern part of the island provides more electricity production than site 1 at the northern part. **Tables 9-1** and **9-2** shows the comparative production of the two sites and its percent contribution to the total power system electricity production based on the 2001 load demand of Oriental Mindoro, the eastern part of the island. The wind farm electricity production at site 1 contribution to the power system of the grid for a 10.2 MW rated capacity is 19% while site 2 is 21%. For 39 MW wind farm, site 1 provides 50% while site 2 accounts to 54% of the total electricity productions of the system. **Vestas 600 kW** class wind turbine generators were used to simulate the wind power electricity production based on its rated power curve vs. wind speed.

Wind Capacity, MW	Total	Wind Turbines		Hydro Turbines		Grid Purchases	
10.2	110,002,744	20,999,528	(19%)	60,285,004	(55%)	28,718,210	(26%)
21.6	127,556,224	44,469,636	(35%)	60,285,004	(47%)	22,801,586	(18%)
24	131,696,400	49,410,596	(37%)	60,285,004	(46%)	22,000,802	(17%)
27	136,985,024	55,587,084	(41%)	60,285,004	(44%)	21,112,928	(15%)
30	142,399,120	61,763,308	(44%)	60,285,004	(42%)	20,350,812	(14%)
33	147,897,920	67,939,704	(46%)	60,285,004	(41%)	19,673,212	(13%)
36	153,466,784	74,116,032	(49%)	60,285,004	(39%)	19,065,756	(12%)
39	159,097,456	80,292,336	(50%)	60,285,004	(38%)	18,520,114	(12%)

Table 9-1: Annual Electrical Energy Production, kWh (% Share) at Site No. 1

Wind Capacity, MW	Total	Wind Turbines		Hydro Turbines		Grid Purchases	
10.2	110,235,792	23,663,940	(21%)	60,285,004	(55%)	26,286,850	(24%)
21.6	130,634,192	50,111,888	(38%)	60,285,004	(46%)	20,237,298	(16%)
24	135,441,664	55,679,924	(41%)	60,285,004	(45%)	19,476,728	(14%)
27	141,580,752	62,639,864	(44%)	60,285,004	(43%)	18,655,884	(13%)
30	147,840,224	69,599,832	(47%)	60,285,004	(41%)	17,955,384	(12%)
33	154,186,016	76,559,816	(50%)	60,285,004	(39%)	17,341,194	(11%)
36	160,595,376	83,519,744	(52%)	60,285,004	(38%)	16,790,634	(10%)
39	167,060,960	90,479,744	(54%)	60,285,004	(36%)	16,296,204	(10%)

Table 9-2: Annual Electrical Energy Production, kWh (% Share) at Site No. 2

As previously mentioned, the proximity of the potential wind farm site to the nearest available potential hydropower projects of the island will be the basis for the selection of the hydro component of the hybrid system. The proposed 18 MW Catuiran run-of-river hydropower project at Naujan, Oriental Mindoro was selected to provide the hydro component of the wind / hydro power system based on its proximity to the southern portion of the island and also the availability of interconnection to the small power grid system generated by diesel and bunker oil C generators, to which the proposed hybrid system will be connected so as to provide additional electricity source to serve load demand the eastern part of the island, the province of Oriental Mindoro. Another basis for selection of the proposed hydropower scheme is the presence of the natural lake, Naujan Lake, which can serve as the lower reservoir for the small 18 MW proposed pumped-storage hydropower scheme for the system. The only remaining part of the scheme to be constructed is the upper reservoir to which the elevation of the potential site of the reservoir is available at the upper part of the Mag-Asawang Tubig river basin area draining to Naujan Lake (see **Figure 8-3** of Chapter 8).

Since there is no gaging station at the Catuiran River and the available streamflow data used in the feasibility study of the run-of-river hydropower scheme is not available publicly, the study instead assumed streamflow data that was used in the computer simulation of the hybrid power system. The mean monthly streamflow variation of the Catuiran River was patterned after the 4-years mean daily to monthly discharge flow on the nearest rivers within the basin area. The Mag-Asawang Tubig River is located at the town of Naujan, Oriental Mindoro and there is a streamflow gaging station nearby monitored by the Department of Public Work and Highway's Bureau of Research and Standard. The available monthly 4-year streamflow data from 1990 to 1993 was plotted in a graph shown in **Figure 8-14,** which served as the pattern for the assumed monthly discharge flow variation used in the simulation process and this was matched with the estimated average annual net energy production based on the feasibility study already done by the Philippine Department of Energy. **Figure 9-3** shows the assumed monthly streamflow and **Figure 9-4**, the scatter graph for streamflow vs. wind speed of the potential site.

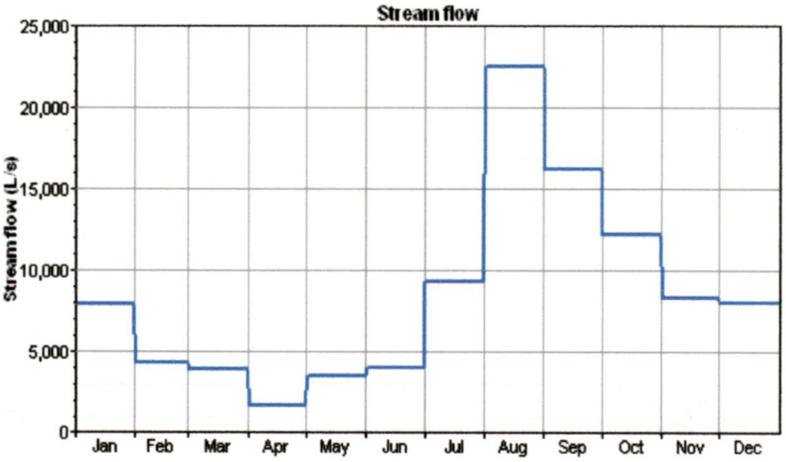


Figure 9-3: Assumed Monthly Streamflow for 18 MW Catuiran Hydropower Project

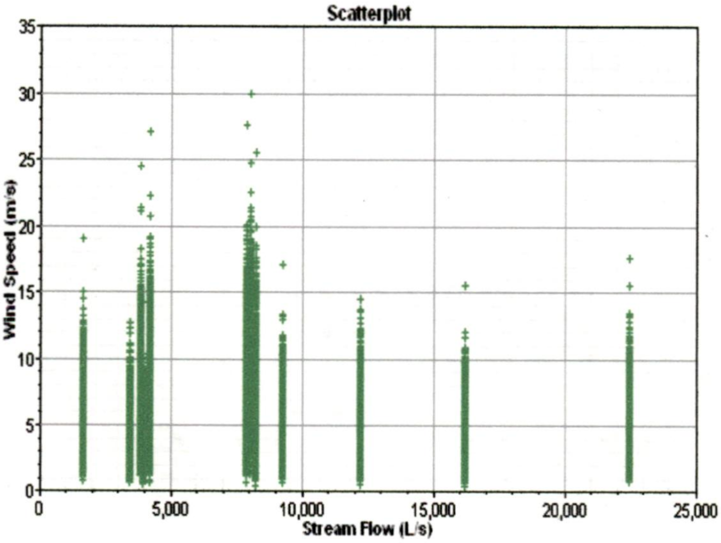


Figure 9-4: Scatter Graph for Wind Speed vs. Streamflow at the Proposed Wind / Hydro Power System Potential Site

Figure 9-5 provides the result of the simulation of both renewable energy technologies. The results of the simulation will provide an overview of how the proposed wind and hydro power system will operate in the proposed site in Mindoro island. The annual potential power generated from the proposed run-of-river hydropower scheme was matched with the annual power generated from the wind farm based on the 2001 load demand of Oriental Mindoro shown in **Figure 9-6**.

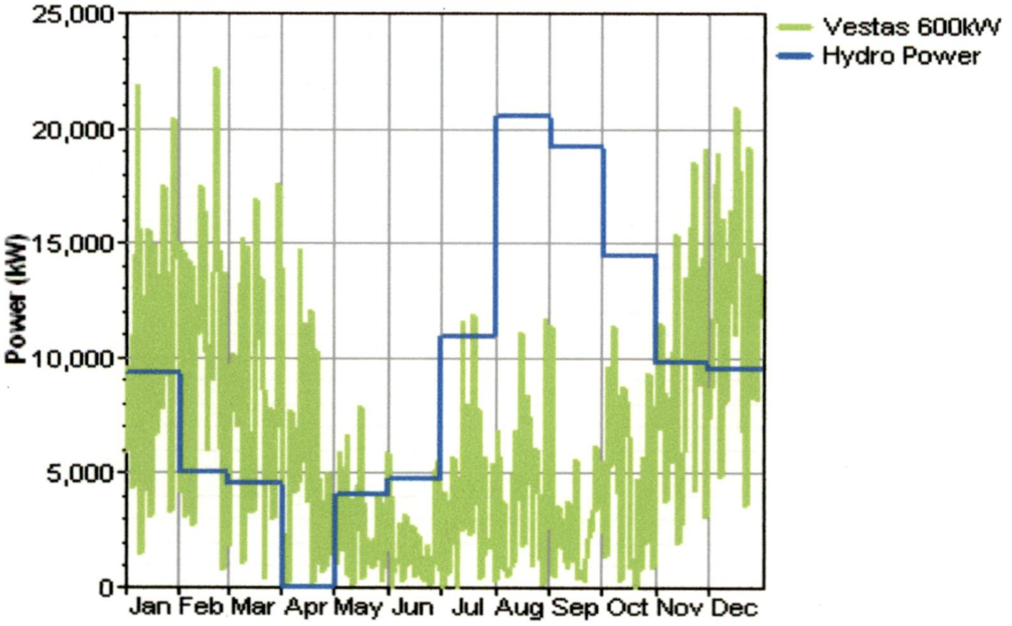


Figure 9-5: Simulation Graph for Wind Power vs. Hydropower at the Proposed Wind / Hydro Power System Potential Site in Mindoro Island

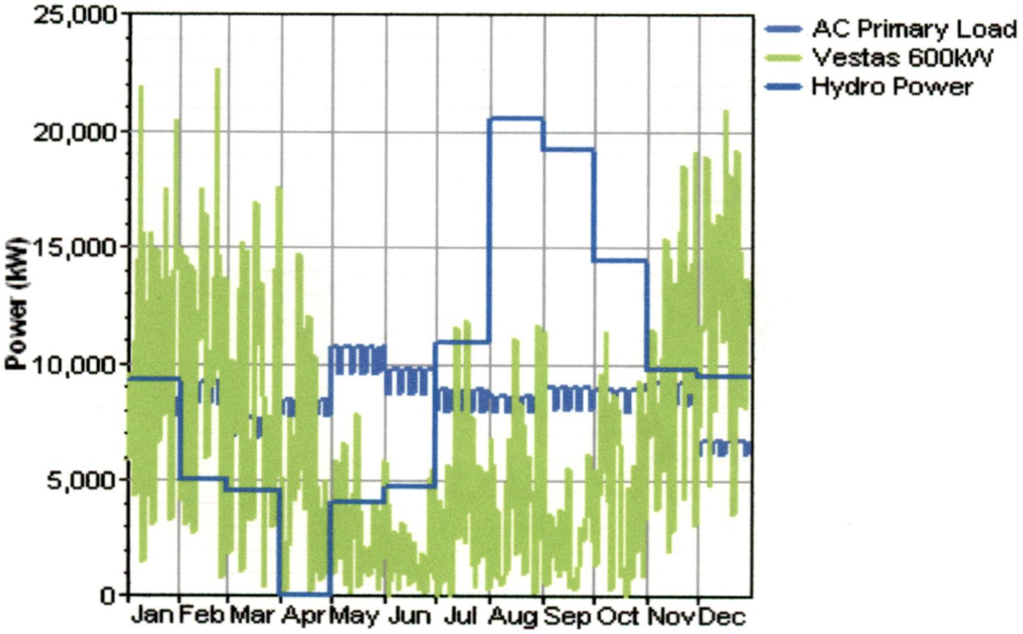


Figure 9-6: Simulation Graph of Wind Power and Hydropower vs. the 2001 AC Load Demand of Oriental Mindoro

Based simulation result graph at **Figure 9-5**, both technologies will not be able to contribute power substantially to the existing power grid system of the island during the dry season months of March to June due to low wind and water availability, which is the source of renewable energy fuel for the wind and hydro turbines. The existing diesel and bunker oil C fired power plants will be the main source of electricity for the island during these months and wind / hydro power system will only contribute minimally whenever renewable energy sources are available. Substantial power contribution from these two renewable energy technologies (RETs) can be observed from July up to February and during this period there are large excess wind as well as hydro power capacities in the whole system especially during off-peak period. **Figure 9-6** shows the period when diesel or bunker oil C generators will generate much power for the grid system and when there is excess electricity in the power grid system and during this period the diesel power generators will provide minimal electricity in the power grid system.

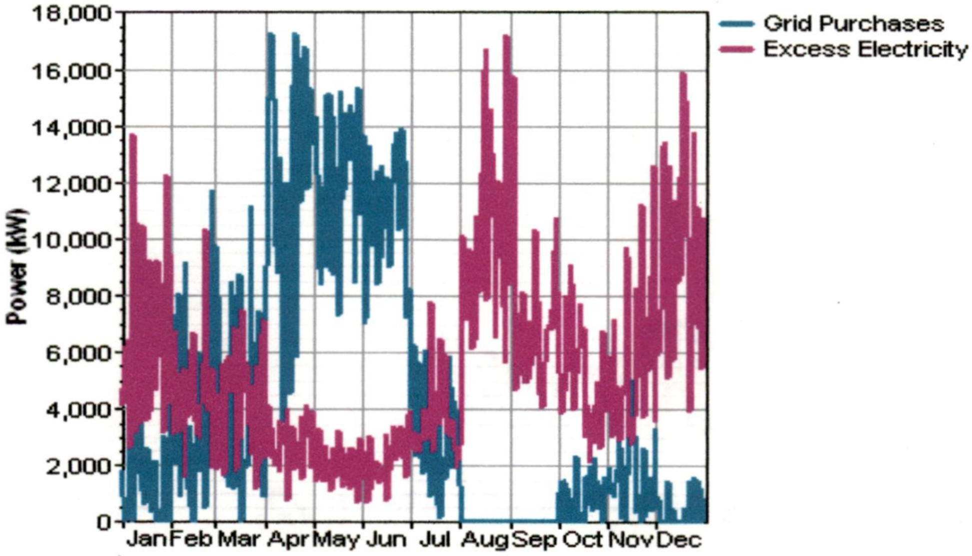


Figure 9-7: Simulation Graph of System's Period with Excess Electricity and Fossil Fuel-Based Optimum Generation Period in Mindoro

In the graph in **Figure 9-7**, fossil fuel-based generators will be the major source power to supply the small grid system during the months of March up to June and will only provide minimally or almost negligible power within the grid system during the month of August and September. This is due to abundant renewable energy resources such as water and wind during the rainy period with river discharge flow providing the rated power for the hydropower units and the higher wind density, compared to the dry season months, providing the descent capacity to the wind turbines at the wind farm site.

The summary of the different wind and hydro power simulation result for wind and hydro power system with hydropower capacity held at constant 18.708 MW, the grid's available capacity remained at 40 MW and the wind farm capacities were varied from 10.2 MW to 39 MW are is shown on the following **Tables 9-3** and **9-4**.

	System Architecture					Constraints Input				
	Input Capacity, MW			MWh / day				Operating Reserve		
Sim. No.	Wind	Hydro	Grid (Diesel)	Primary Load	Deferable Load	Max.Cap Short %	Min. RE Fraction	% of Hourly Load	% of Annual Peak Load	% of RE Output
1	10.2	18.708	40	203.731	150	0	0	10	10	50
2	21.6	18.708	40	203.731	150	0	0	10	10	50
3	24	18.708	40	203.731	150	0	0	10	10	50
4	27	18.708	40	203.731	150	0	0	10	10	50
5	30	18.708	40	203.731	150	0	0	10	10	50
6	33	18.708	40	203.731	150	0	0	10	10	50
7	36	18.708	40	203.731	150	0	0	10	10	50
8	39	18.708	40	203.731	150	0	0	10	10	50

Table 9-3: Grid-Connected Wind and Hydro Power System HOMER Simulation Input Variables and Constraints for Mindoro

Sim. No.	*Annual Electrical Energy Production, kWh (% Share)*							Annual Electricity Loads Served (Primary Load), kWh
	Total	Wind Turbines		Hydro Turbines		Grid Purchases		
1	120,840,880	23,663,940	(20%)	82,217,080	(68%)	14,459,859	(12%)	75,095,128
2	144,155,504	50,111,888	(35%)	82,217,080	(57%)	11,826,535	(8%)	75,095,128
3	149,318,432	55,679,924	(37%)	82,217,080	(55%)	11,421,436	(8%)	75,095,128
4	155,829,312	62,639,864	(40%)	82,217,080	(53%)	10,972,372	(7%)	75,095,128
5	162,394,448	69,599,832	(43%)	82,217,080	(51%)	10,577,535	(6%)	75,095,128
6	169,003,968	76,559,816	(45%)	82,217,080	(49%)	10,227,073	(6%)	75,095,128
7	175,649,232	83,519,744	(48%)	82,217,080	(47%)	9,912,413	(5%)	75,095,128
8	182,322,816	90,479,744	(50%)	82,217,080	(45%)	9,625,991	(5%)	75,095,128

Table 9-4: HOMER Simulation Result on Annual Electrical Energy Production, Various System Components Power Percent Contribution and Annual Electricity Load Served

As mentioned in Chapter 1, the wind-diesel system feasibility study for small island grid power system made by Barley, Flowers and the NPC-SPUG staff engineers in 1999 did not consider the possibility of deferrable loads, also known as productive dump loads. These deferrable or productive dump loads, due to excess wind energy in the system especially during off-peak period or when both hydropower and wind has excess capacity against the electricity demand in the system thereby using only hydropower as base load and a large portion of the wind power, can be temporarily diverted to maximum pumping operation so that substantial amount of water can be stored up to its available capacity of the upper reservoir which can be utilize in various manner as had mentioned in the first part of this chapter to which pump-storage hydropower scheme is one of them. Results of excess wind in the system using different wind farm capacity and its potential contribution to greenhouse gases (GHGs) reduction is summarized in **Table 9-5.**

Sim. No.	**Actual Renewable Energy Served, kWh**		Annual Reduced Carbon Dioxide Emissions (t/year)	Excess Renewable Energy, kWh	**Annual Additional RE Resources for Peak Hours, kWh**		
	Renewable Energy Contribution, kWh	Percent Fraction of Primary Load			Water Pumping Requirement, kWh	Pump-Stor. Hydro Cycle Effy.	Available Additional Annual Energy Contribution, kWh
1	60,635,269	80.74%	47,200	45,245,751	54,750,000	0.73	39,967,500
2	63,268,593	84.25%	49,249	69,054,512	54,750,000	0.73	39,967,500
3	63,673,692	84.79%	49,565	74,217,296	54,750,000	0.73	39,967,500
4	64,122,756	85.39%	49,914	80,728,368	54,750,000	0.73	39,967,500
5	64,517,593	85.91%	50,222	87,293,392	54,750,000	0.73	39,967,500
6	64,868,055	86.38%	50,494	93,903,064	54,750,000	0.73	39,967,500
7	65,182,715	86.80%	50,739	100,548,248	54,750,000	0.73	39,967,500
8	65,469,137	87.18%	50,962	107,222,056	54,750,000	0.73	39,967,500

Table 9-5: Summary of the Annual Actual RE Served, Excess RE, Additional Energy Available for Storage and CO2 Reduction

In **Table 9-5**, it is observed that oversizing the capacity of the potential wind farm to increase the contribution of wind power in the system will not contribute much to the system's overall efficiency as this will only provider more than enough excess renewable energy in the system assuming that deferrable dump load required for water pumping will be fix for a certain period of time due to the design capacity of the upper reservoir and the hydropower station. Based on this analysis, an optimum hybrid power system consisting of 24 MW wind farm, 18 MW run-of-river hydropower scheme and 18 MW pump-storage peaking hydropower plant for excess wind power capacity can provide the required load demand for the grid system of the island for the year 2001. **Table 9-6** shows an Excel hourly operation mode of the system in the month of July. **Table 9-7** shows the optimized result for site 2 in Mindoro Island at various wind farm capacities.

Time	Wind Speed	Stream Flow	AC Primary Load	Vestas 600kW	Hydro Power	Grid Purch	AC Prim. Served	Defer. Served	Excess Electricity	Unmet Load	Defer. Storage
hour	m/s	L/s	kW	kW	kW	kW	kW	kW	kW	kW	kWh
5021	3.809	9239.493	5917.995	326.783	10940.18	3651.032	5917.995	9000	0	0	4000
5022	4.175	9239.493	4867.996	546.029	10940.18	2381.787	4867.996	9000	0	0	6750
5023	3.691	9239.493	5383.996	279.341	10940.18	0	5383.996	0	5835.525	0	500
5024	3.151	9239.493	5288.996	60.928	10940.18	3287.889	5288.996	9000	0	0	3250
5025	3.616	9239.493	6872.995	249.004	10940.18	4683.811	6872.995	0	9000	3000	0
5026	3.895	9239.493	8132.994	361.447	10940.18	5831.367	8132.994	9000	0	0	2750
5027	5.733	9239.493	8151.994	2591.931	10940.18	3619.883	8151.994	9000	0	0	5500
5028	6.503	9239.493	8228.993	4252.986	10940.18	2035.826	8228.993	0	8999.999	750	0
5029	8.198	9239.493	8233.993	8881.77	10940.18	0	8233.993	9000	2587.956	0	2750
5030	7.311	9239.493	8018.994	6282.763	10940.18	0	8018.994	9000	203.95	0	5500
5031	7.503	9239.493	7674.994	6829.88	10940.18	0	7674.994	9000	1095.067	0	8250
5032	7.305	9239.493	7654.994	6265.283	10940.18	0	7654.994	9000	550.469	0	11000
5033	5.698	9239.493	16228.987	2526.033	10940.18	11762.77	16228.987	9000	0	0	13750
5034	5.091	9239.493	16679.986	1386.052	10940.18	13353.75	16679.986	9000	0	0	16500
5035	4.707	9239.493	15845.987	977.763	10940.18	12928.04	15845.987	9000	0	0	19250
5036	2.468	9239.493	10556.991	0	10940.18	0	10556.991	0	383.188	0	13000
5037	2.05	9239.493	8438.993	0	10940.18	0	8438.993	0	2501.187	0	6750
5038	2.158	9239.493	7521.994	0	10940.18	0	7521.994	0	3418.186	0	500
5039	1.449	9239.493	5421.996	0	10940.18	3481.816	5421.996	9000	0	0	3250
5040	2.198	9239.493	5949.995	0	10940.18	4009.815	5949.995	9000	0	0	6000
5041	1.971	9239.493	5779.996	0	10940.18	3839.816	5779.996	9000	0	0	8750
5042	1.893	9239.493	5673.996	0	10940.18	0	5673.996	0	5266.184	0	2500

Table 9-6: Hourly Operation Mode of a Grid-Connected Wind and Hydro Power System with Deferrable Load for Mindoro

Time	Wind Speed	Stream Flow	AC Primary Load	Vestas 600kW	Hydro Power	Grid Purch	AC Prim. Served	Defer. Served	Excess Electricity	Unmet Load	Defer. Storage
hour	m/s	L/s	kW	kW	kW	kW	kW	kW	kW	kW	kWh
5043	2.849	9239.493	5609.996	0	10940.18	3669.816	5609.996	9000	0	0	5250
5044	4.153	9239.493	6398.995	527.97	10940.18	3930.845	6398.995	9000	0	0	8000
5045	3.888	9239.493	6611.995	358.901	10940.18	0	6611.995	0	4687.085	0	1750
5046	3.008	9239.493	5437.996	3.051	10940.18	3494.766	5437.996	9000	0	0	4500
5047	3.663	9239.493	6014.995	267.703	10940.18	3807.112	6014.995	9000	0	0	7250
5048	3.834	9239.493	5908.995	337.12	10940.18	0	5908.995	0	5368.305	0	1000
5049	4.282	9239.493	7678.994	633.232	10940.18	5105.583	7678.994	9000	0	0	3750
5050	4.398	9239.493	9085.993	727.052	10940.18	6418.761	9085.993	0	8999.999	2500	0
5051	6.051	9239.493	9106.993	3209.376	10940.18	3957.437	9106.993	0	8999.999	6250	0
5052	6.927	9239.493	9192.992	5231.113	10940.18	2021.699	9192.992	9000	0	0	2750
5053	7.372	9239.493	9199.992	6457.639	10940.18	802.174	9199.992	9000	0	0	5500
5054	7.432	9239.493	8958.993	6626.876	10940.18	391.938	8958.993	0	8999.999	750	0
5055	8.47	9239.493	8573.993	9763.072	10940.18	0	8573.993	9000	3129.259	0	2750
5056	7.978	9239.493	8552.993	8177.338	10940.18	0	8552.993	9000	1564.524	0	5500
5057	7.613	9239.493	18130.986	7141.051	10940.18	9049.756	18130.986	9000	0	0	8250
5058	5.034	9239.493	18634.984	1279.783	10940.18	15415.021	18634.984	9000	0	0	11000
5059	3.321	9239.493	17702.986	129.513	10940.18	15633.294	17702.986	9000	0	0	13750
5060	3.796	9239.493	11794.99	321.507	10940.18	9533.303	11794.99	9000	0	0	16500
5061	3.707	9239.493	9427.992	285.755	10940.18	0	9427.992	0	1797.942	0	10250
5062	3.357	9239.493	8403.993	144.108	10940.18	0	8403.993	0	2680.295	0	4000
5063	3.434	9239.493	6056.995	175.439	10940.18	3941.377	6056.995	9000	0	0	6750

Table 9-6: Hourly Operation Mode of a Grid-Connected Wind and Hydro Power System with Deferrable Load for Mindoro

Sim. No.	Output / Optimization Result					Grid's Annual Carbon Emissions (t/year)
	Initial Total Capital ($)	Total Net Present Cost (NPC) ($)	Cost of Energy (COE) ($/kWh)	Renewable Energy Fraction	Cap. Short	
1	36,203,000	179,727,248	0.084	0.68	0	3,171
2	49,729,896	167,222,160	0.077	0.78	0	2,507
3	52,576,000	100,014,304	0.078	0.92	0	2,421
4	56,135,500	104,287,872	0.082	0.93	0	2,326
5	59,695,000	108,188,992	0.085	0.94	0	2,242
6	63,254,500	112,043,560	0.088	0.94	0	2,168
7	66,814,000	115,991,920	0.091	0.95	0	2,101
8	70,373,504	120,014,120	0.094	0.95	0	2,041

Table 9-7: HOMER Optimization Result of Grid-Connected Wind and Hydro Power System for Mindoro Island

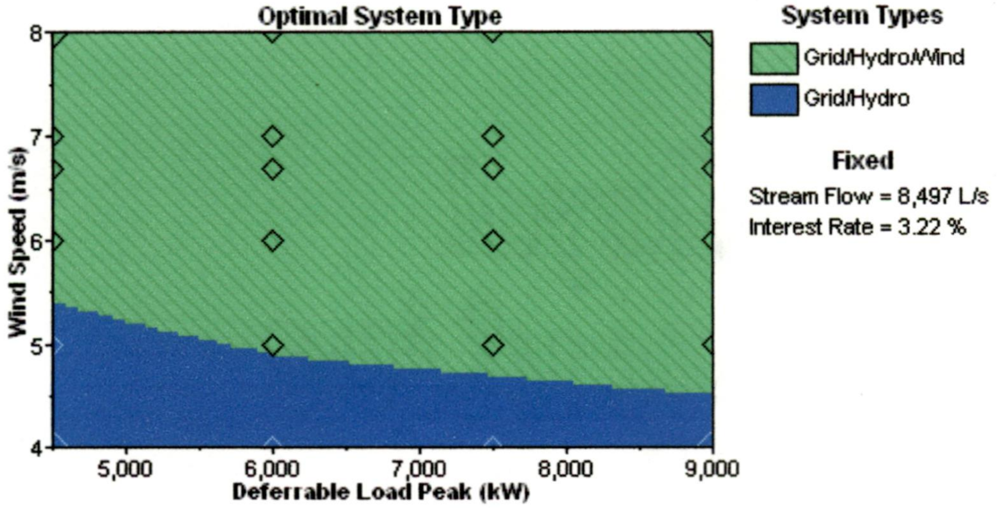


Figure 9-8: Optimal System Type for Mindoro Island Wind Farm Site 2 at Various Deferrable Load Capacities and Wind Speed Available

The comparative financial and economic aspect of the selected grid-connected wind/hydro power system for Mindoro Island based on the optimal system type from **Figure 9-8** for selected capacity of 40 units of 600 kW class Vestas WTG, 18 MW run-of-river hydropower plant, 18 MW pumped-storage hydro scheme requiring 54,750,000 kWh annually to pump water to upper reservoir at different deferrable load peak is summarized in **Table 9-8.**

Grid/Hydro/Wind				
Wind Speed (m/s)	Deferrable Load Peak (kW)			
	4500	6000	7500	9000
4	174,372,928	187,983,456	200,607,600	155,168,208
5	159,253,376	169,916,224	179,359,760	142,589,680
6	149,744,512	158,256,848	165,798,864	134,697,648
7	145,510,016	153,106,896	160,520,464	131,192,488
8	133,694,880	138,682,016	144,017,712	121,375,048
Grid/Hydro				
Wind Speed (m/s)	Deferrable Load Peak (kW)			
	4500	6000	7500	9000
4	175,860,544	193,573,888	211,383,776	149,884,336
5	175,860,544	193,573,888	211,383,776	149,884,336
6	175,860,544	193,573,888	211,383,776	149,884,336
7	175,860,544	193,573,888	211,383,776	149,884,336
8	175,860,544	193,573,888	211,383,776	149,884,336
Grid/Wind				
Wind Speed (m/s)	Deferrable Load Peak (kW)			
	4500	6000	7500	9000
4	305,188,640	335,338,464	364,247,552	273,137,792
5	271,904,928	298,870,240	324,343,776	242,219,424
6	249,957,376	274,090,368	296,840,352	222,052,896
7	239,923,216	263,144,192	284,518,304	212,885,856
8	210,783,632	230,494,160	247,878,720	186,490,896
Grid				
Wind Speed (m/s)	Deferrable Load Peak (kW)			
	4500	6000	7500	9000
4	334,086,144	358,916,896	388,210,272	299,699,744
5	334,086,144	358,916,896	388,210,272	299,699,744
6	334,086,144	358,916,896	388,210,272	299,699,744
7	334,086,144	358,916,896	388,210,272	299,699,744
8	334,086,144	358,916,896	388,210,272	299,699,744

Table 9-8: Total Net Present Cost (NPC), US$ of the Optimal System for Mindoro Island at Selected Deferrable Load Peak and Wind Speed

The total net present cost at different wind speed and deferrable pumping load capacities for combined grid-connected wind and hydro power system is much lower compared to other power system combination such as wind-grid, hydro-grid and purely grid source. As wind speed increases, the difference between the next least net present cost system, hydro-grid system, also increases. This however assumed that the hydropower power is fixed at 18 MW. The annual real interest rate used was 3.22% on a nominal interest rate of 9% and 2001 inflation rate of 5.6%.

Based on calendar year 2003 National Power Corporation-Small Power Utilities Group's (NPC-SPUG) result of operation, the production costs of the different diesel and bunker fuel oil C power plants for Mindoro Islands varies from as low as PhP 3.5714/ kWh (US$ 0.0712/ kWh) to as high as PhP 44.7716/kWh (US$ 0.895/ kWh) depending on the proximity of the various plant from the oil refinery and depot at the main island of Luzon, efficiency of the plant, load factor and the volatile cost of crude oil in the international market. Based on the available data, the approximate power grid cost was assumed at PhP 7.7156/ kWh or around $ 0.154/ kWh using Peso to US Dollar exchange rate of PhP 50 per US$ 1 in 2000-2001, which is the Puerto Princesa, Palawan power production cost and is more realistic. The levelized cost of energy and total annualized cost are shown in **Figures 9-9** and **9-10** for the proposed optimal system in Mindoro Island and summarized in **Table 9-9.**

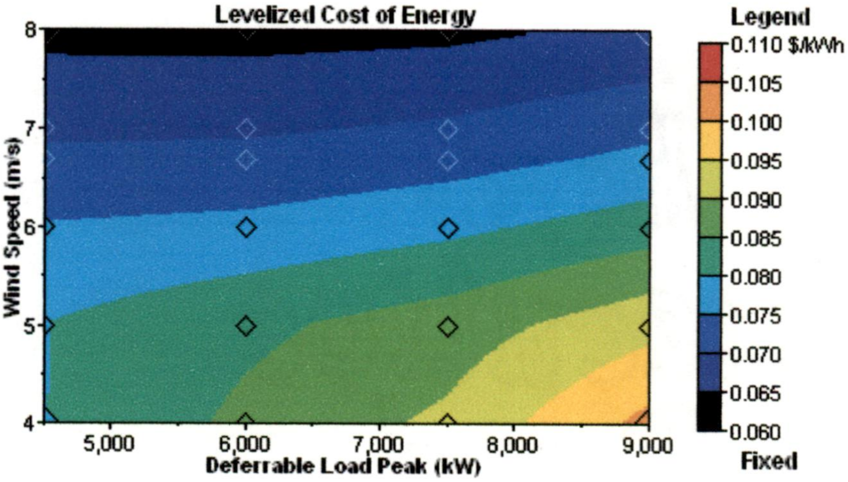


Figure 9-9: HOMER Simulation Levelized Cost of Energy for the Optimal System

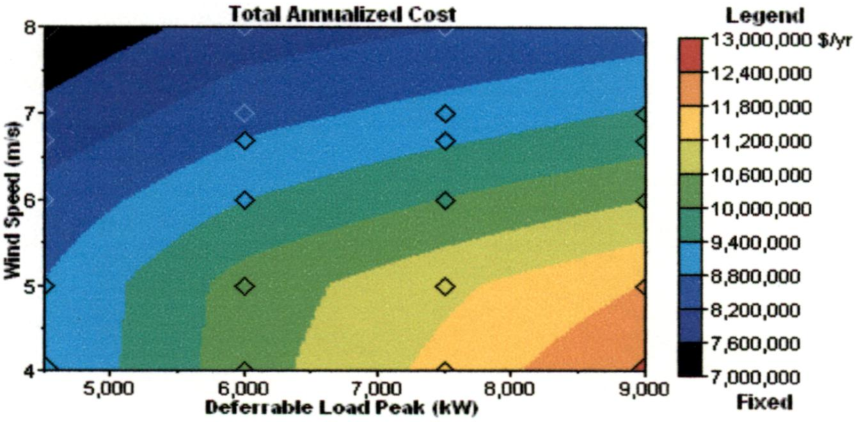


Figure 9-10: Homer Simulation Annualized Cost for the Optimal System

Wind Speed (m/s)	Levelized Cost of Energy ($/kWh)				Total Annualized Cost ($/yr)			
	Deferrable Load Peak (kW)				Deferrable Load Peak (kW)			
	4500	6000	7500	9000	4500	6000	7500	9000
4	0.083828	0.087456	0.093369	0.079895	10,260,926	11,061,834	11,804,698	8,819,902
5	0.076089	0.078612	0.082545	0.075149	9,371,220	9,998,672	10,554,375	8,390,650
6	0.071272	0.073033	0.076186	0.070807	8,811,674	9,312,580	9,756,388	7,926,246
7	0.069206	0.070673	0.073781	0.068937	8,562,496	9,009,532	9,445,782	7,719,985
8	0.063258	0.063778	0.065872	0.063515	7,867,238	8,160,704	8,474,682	7,142,281

Table 9-9: Levelized Cost of Energy and Total Annualized Cost of the Optimal Grid-Connected Wind / Hydropower System for Mindoro

The optimization result indicates that as wind speed increases in combination with the hydro and grid-connected, levelized cost of energy decreases at different level of pumping load. This is because the levelized cost of energy is directly proportional to the total annualized cost and inversely proportional to the sum of the primary load served, deferrable load served and total grid sales, if there is provision that excess energy can be sold back to the grid during peak period. Thus, deferrable load such as pumping water to higher elevation reservoir and selling back to grid excess electricity during peak period are beneficial to the grid system economic and financial operation as this utilize the excess power capacity of the system that will be dumped and at the same time lowers the cost of energy as providing higher load efficiency to the system.

9.1.1 Analysis of Palawan Study Site Wind/Hydro Power System

Palawan's annual wind speed for 7-year period from 1988-1994, based on NREL's Special Sensor Microwave Imager (SSMI) satellite ocean wind data, are presented in **Table 8-2** and **Figures 8-9** and **8-10** of the previous chapter. NREL's *Wind Atlas of the Philippines* has divided Palawan into 2 areas; Palawan East Coast and Palawan West Coast. Each area has 3 regions; Region 1 covers the northern part of the island, Region 2 for the mid-portion and Region 3 at the south. Palawan East Coast Region 1 was selected as the best possible study site for utility-scale wind farm development simulation. Referring to **Figure 8-10**, Palawan East Coast Region 1 yields the highest mean wind speed for 7-year period at 6 m/s compared to the other five regions. This type of wind speed is classified as class 2 type, which is suitable for moderate utility-scale wind power development (see **Table 8-1** wind speed class classification in Chapter 8). The wind power density of the selected site varies from 250 – 300 W/m^2. The mean hourly wind speed variations and probability density function of the potential site is shown in **Figure 9-11**.

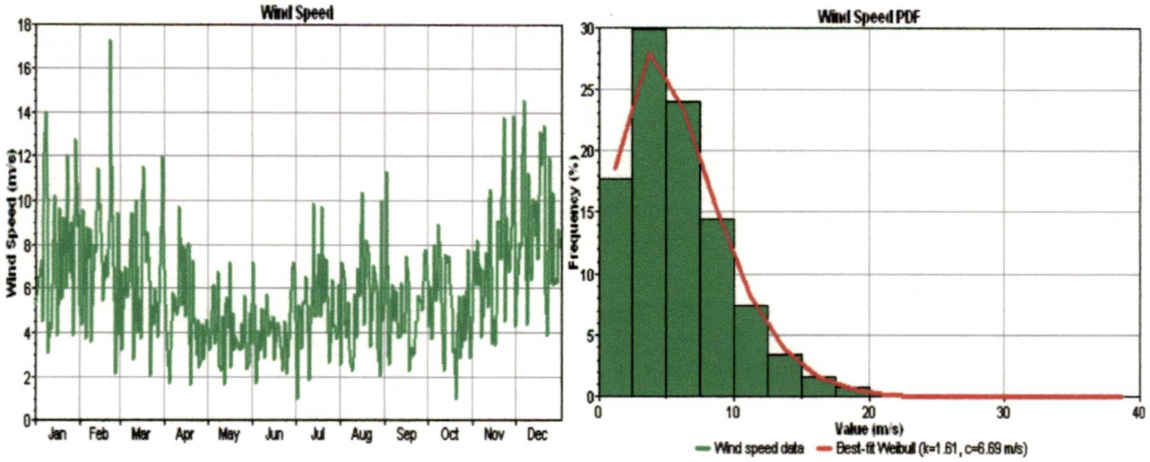


Figure 9-11: Variation and PDF of Mean Hourly Palawan East Coast Region 1 SSMI Satellite Ocean Wind Speed Data, 1988-1994

Sim. No.	Wind Power Capacity, MW	Annual Electrical Energy Production, kWh (% Share)							Annual Electricity Loads Served (AC Primary), kWh
		Total	Wind Turbines		Hydro Turbines		Grid Purchases		
1	10.2	129,334,624	19,719,216	(15%)	38,583,580	(30%)	71,031,824	(55%)	84,506,024
2	20.4	136,770,144	39,438,432	(29%)	38,583,580	(28%)	58,748,124	(43%)	84,506,024
3	24.6	141,627,280	47,558,048	(34%)	38,583,580	(27%)	55,485,648	(39%)	84,506,024
4	27	145,516,032	52,197,976	(36%)	38,583,580	(27%)	54,734,472	(38%)	84,506,024
5	30	149,323,760	57,997,680	(39%)	38,583,580	(26%)	52,742,500	(35%)	84,506,024
6	33	153,950,912	63,797,368	(41%)	38,583,580	(25%)	51,569,956	(33%)	84,506,024
7	36	158,483,456	69,597,072	(44%)	38,583,580	(24%)	50,302,804	(32%)	84,506,024
8	39	163,247,312	75,396,992	(46%)	38,583,580	(24%)	49,266,744	(30%)	84,506,024
9	42	167,760,128	81,196,880	(48%)	38,583,580	(23%)	47,979,664	(29%)	84,506,024

Table 9-10: Annual Electrical Energy Production, kWh (% Share) at Palawan East Coast Region 1

Simulation process using **HOMER** for the electricity production of potential wind farm site was done using various wind farm capacities and utilized **Vestas 600 kW** class wind turbine generators to provide the required capacity based on its rated power curve vs. wind speed. Result of the simulation is shown in **Table 9-10**. The simulation was done based on the 2001 load demand of Puerto Princesa city and towns of Narra and Brooke's Point, which are currently inter-connected to each other by 69 kV transmission line.

Using the same criteria in selection of the available potential hydropower component for wind / hydro power system concept for Mindoro, the nearest potential hydropower project for development in Palawan East Coast Region 1 is the 6.8 MW Langogan run-of-river with 3-hour peaking hydropower plant. The proposed hydro scheme has a gross head of 98 meters, turbine designed head of 91.2 meters on a designed hydraulic capacity of 8.9 m^3/s and a plant factor of 0.46 with an estimated average annual net energy production of about 27.12 GWh. The powerhouse will utilize two horizontal Francis turbines at 3.4 MW each for hydraulic flow of 4.45 m^3/s. The plant was estimated to cost around US$ 15.6 based on 1992 feasibility study with an IRR of 18%. The site is also within the interconnection to the small power grid system of the island.

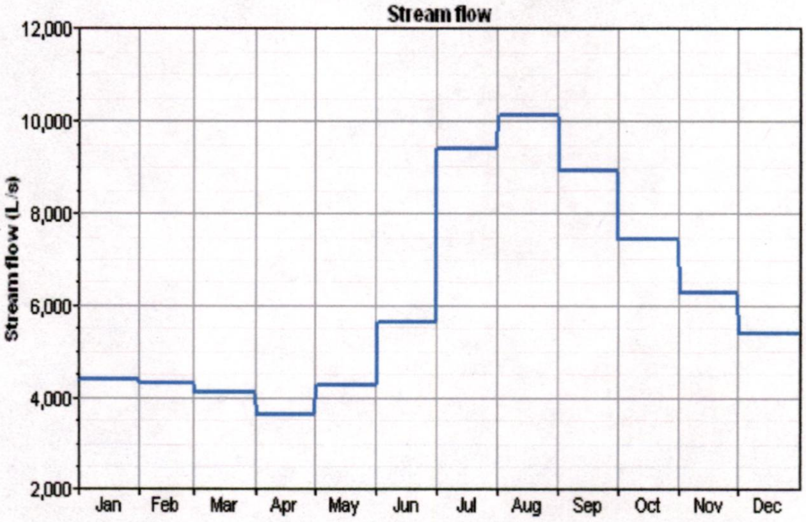


Figure 9-12: Assumed Monthly Streamflow for 6.8 MW Langogan Hydropower Project in Puerto Princesa, Palawan

As mentioned in Chapter 8, since there is no streamflow gaging station at the potential site in Langogan river and thus no reliable data, the statistical mean monthly rainfall data from 1949 to 1973 of the existing rainfall station in Puerto Princesa was utilized in the HOMER simulation process as reference for mean monthly streamflow characteristic of the river for hydro power computation (see **Figure 8-15** in Chapter 8). Based on this characteristic, the monthly streamflow input was assumed and matched with the estimated average annual net energy production of the potential hydropower project. The assumed monthly streamflow is shown in **Figure 9-12**.

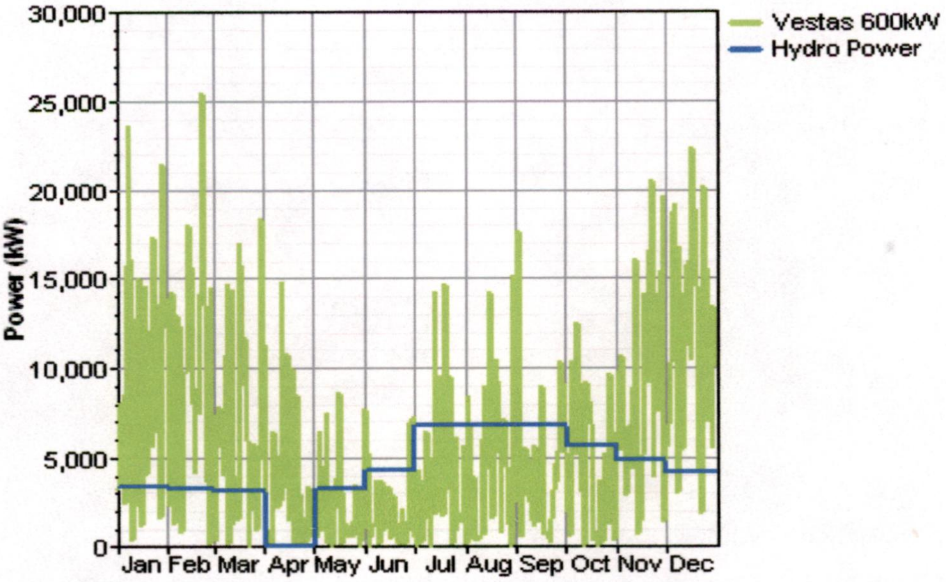


Figure 9-13: Simulation Graph for Wind Power vs. Hydropower at the Proposed Wind / Hydro Power System Potential Site in Palawan

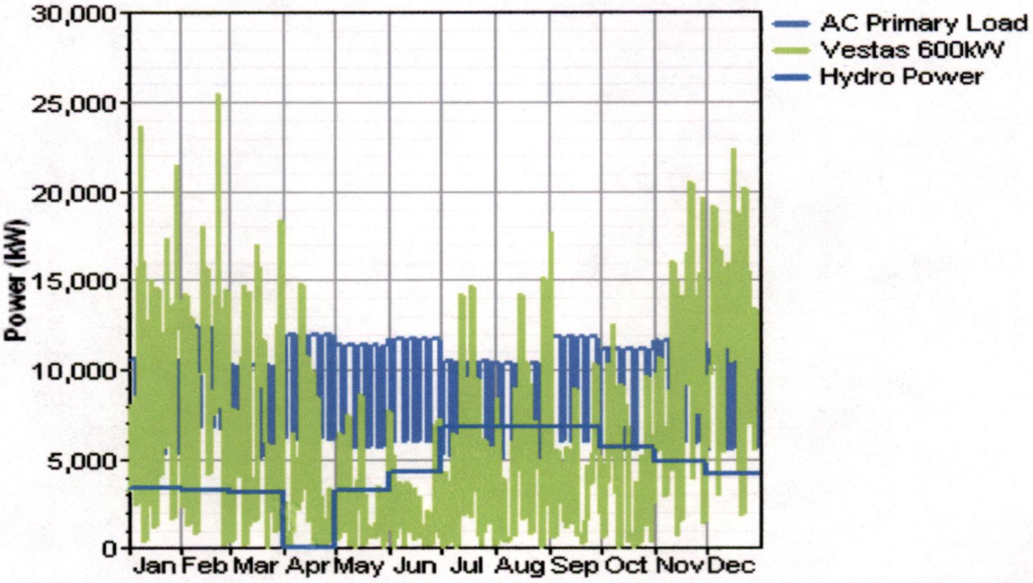


Figure 9-14: Simulation Graph of Wind Power and Hydropower vs. the 2001 AC Load Demand of Puerto Princesa, Palawan

Based simulation result graph at **Figures 9-13** and **14**, both technologies will not be able to contribute substantial power to the existing power grid system of the island during the dry season months due to low wind and water availability, which is the source of renewable energy fuel for the wind and hydro turbines. The existing diesel and bunker oil C fired power plants will be the main source of electricity for the island during these months and wind / hydro power system will only contribute minimally whenever renewable energy sources are available. Substantial power contribution from these two renewable energy technologies (RETs) can be observed from August up to February and during this period there are large excess wind as well as hydro power capacities in the whole system especially during off-peak period. **Figure 9-15** shows the period when diesel or bunker oil C generators will generate much power for the grid system and when there is excess electricity in the power grid system and during this period the diesel power generators will provide minimal electricity in the power grid system.

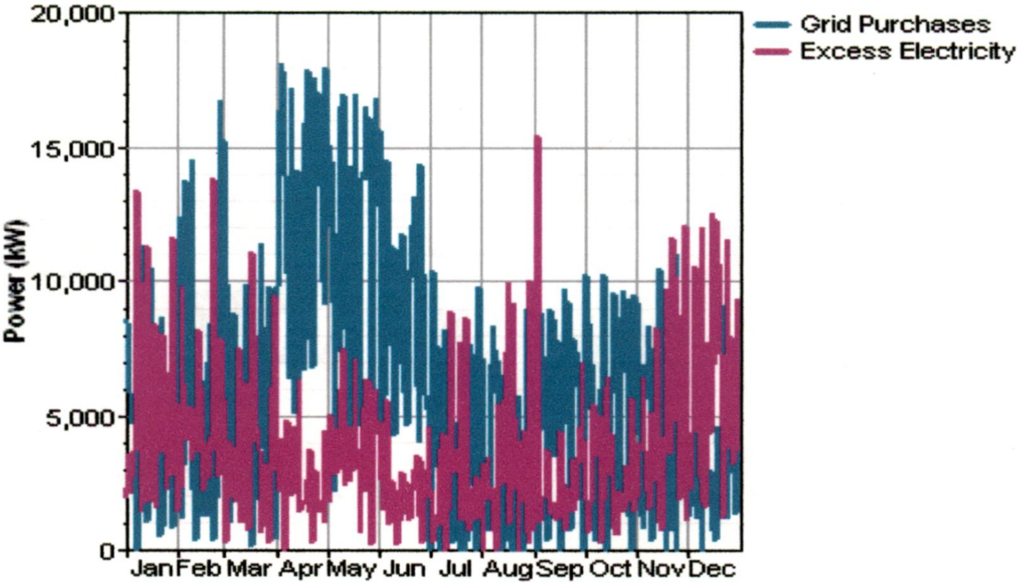


Figure 9-15: Simulation Graph of System's Period with Excess Electricity and Fossil Fuel-Based Optimum Generation Period in Palawan

In the graph in **Figure 9-15**, fossil fuel-based generators will be the major source of power to supply the small grid system during the months of March up to June and will also provide substantial power within the grid system during the rest of the year. This is because large amount renewable energy resource such as wind can generate up to its rated capacity during the months from August, November up to February but the considerable portion of this is available only during off-peak period when there is less load in the system with water pumping load operating only in its designed capacity and the excess wind capacity supplied to the system may have to be dumped after meeting all the required load. The summary of the different wind and hydro power simulation result for wind and hydro power system with hydropower capacity held at constant 6.84 MW, the grid's available capacity remained at 26 MW and the wind farm capacities were varied from 10.2 MW to 42 MW are is shown on the following **Tables 9-11** and **9-12.**

Sim. No.	System Architecture					Constraints				
	Input Capacity, MW			MWh /day				Operating Reserve		
	Wind	Hydro	Grid (Diesel)	Primary Load	Defer. Load	Max.Cap Short %	Min. RE Fraction	% of Hourly Load	% of Annual Peak Load	% of RE Output
1	10.2	6.84	26	231.515	75	0	0	10	10	50
2	20.4	6.84	26	231.515	75	0	0	10	10	50
3	24.6	6.84	26	231.515	75	0	0	10	10	50
4	27	6.84	26	231.515	75	0	0	10	10	50
5	30	6.84	26	231.515	75	0	0	10	10	50
6	33	6.84	26	231.515	75	0	0	10	10	50
7	36	6.84	26	231.515	75	0	0	10	10	50
8	39	6.84	26	231.515	75	0	0	10	10	50
9	42	6.84	26	231.515	75	0	0	10	10	50

Table 9-11: Grid-Connected Wind and Hydro Power System HOMER Simulation Input Variables and Constraints for Palawan

Sim. No.	Annual Electrical Energy Production, kWh (% Share)							Annual Electricity Loads Served (AC Primary), kWh
	Total	Wind Turbines		Hydro Turbines		Grid Purchases		
1	129,334,624	19,719,216	(15%)	38,583,580	(30%)	71,031,824	(55%)	84,506,024
2	136,770,144	39,438,432	(29%)	38,583,580	(28%)	58,748,124	(43%)	84,506,024
3	141,627,280	47,558,048	(34%)	38,583,580	(27%)	55,485,648	(39%)	84,506,024
4	145,516,032	52,197,976	(36%)	38,583,580	(27%)	54,734,472	(38%)	84,506,024
5	149,323,760	57,997,680	(39%)	38,583,580	(26%)	52,742,500	(35%)	84,506,024
6	153,950,912	63,797,368	(41%)	38,583,580	(25%)	51,569,956	(33%)	84,506,024
7	158,483,456	69,597,072	(44%)	38,583,580	(24%)	50,302,804	(32%)	84,506,024
8	163,247,312	75,396,992	(46%)	38,583,580	(24%)	49,266,744	(30%)	84,506,024
9	167,760,128	81,196,880	(48%)	38,583,580	(23%)	47,979,664	(29%)	84,506,024

Table 9-12: HOMER Simulation Result on Annual Electrical Energy Production, Various System Components Power Percent Contribution and Annual Electricity Load Served for Palawan

Since the annual electricity load requires only 84,506,024 kWh and diesel power generators from grid system still contributes a considerable amount of power, there will be excess wind energy in the system especially during off-peak period or when both hydropower and wind has excess capacity against the electricity demand in the system thereby using only hydropower as base load and a large portion of the wind power, and this can be temporarily diverted to maximum pumping operation so that substantial amount of water can be stored up to its available capacity of the upper reservoir which can be utilize in various manner as had mentioned in the first part of this chapter to which pump-storage hydropower scheme is one being assumed. Results of actual renewable energy served for primary load, excess wind in the system using different wind farm capacity and its potential contribution to greenhouse gases (GHGs) reduction is summarized in **Table 9-13.**

Sim. No.	Actual Renewable Energy Served, kWh		Annual Reduced Carbon Dioxide Emissions (t/year)	Excess Electricity, kWh	Annual Additional Energy Resources for Peak Load Hours, kWh		
	Renewable Energy Contibution, kWh	Percent Fraction of Primary Load			Water Pumping Requirement, kWh	Pump-Stor. Hydro Cycle Effy.	Available Additional Annual Energy Contribution, kWh
1	13,474,200	15.94%	40,168	7,070,282	27,375,000	0.73	5,161
2	25,757,900	30.48%	44,367	21,446,702	27,375,000	0.73	15,656,092
3	29,020,376	34.34%	45,389	28,262,912	27,375,000	0.73	19,983,750
4	29,771,552	35.23%	45,878	32,278,796	27,375,000	0.73	19,983,750
5	31,763,524	37.59%	46,415	37,394,620	27,375,000	0.73	19,983,750
6	32,936,068	38.97%	46,886	42,593,864	27,375,000	0.73	19,983,750
7	34,203,220	40.47%	47,299	47,865,928	27,375,000	0.73	19,983,750
8	35,239,280	41.70%	47,672	53,191,012	27,375,000	0.73	19,983,750
9	36,526,360	43.22%	48,008	58,561,356	27,375,000	0.73	19,983,750

Table 9-13: Summary of the Annual Actual RE Served, Excess RE, Additional Energy Available for Storage and CO2 Reduction for Palawan

In **Table 9-13,** the tabulated different optimized system result indicates that oversizing the capacity of the potential wind farm to increase the contribution of wind power in the system will not provide much to the system's overall efficiency as this will only increase excess renewable energy in the system assuming that deferrable dump load required for water pumping will be fix for a certain period of time due to the design capacity of the upper reservoir and the hydropower station. Based on this analysis, an optimum hybrid power system consisting of 27 MW wind farm, 6.8 MW run-of-river with 3-hour peaking hydropower scheme and 9 MW pump-storage peaking hydropower plant for excess wind power capacity can provide the required load demand for the grid system of the island for the year 2001. **Table 9-14** shows the optimized result selected wind and hydro power system capacities in Palawan at various wind farm capacities. **Table 9-15** shows an Excel hourly operation mode of the system in the month of August.

Sim. No.	Optimization Result					Grid Carbon Emissions (t/year)
	Initial Total Capital ($)	Total Net Present Cost (NPC) ($)	Cost of Energy (COE) ($/kWh)	Ren'ble Energy Fraction	Cap. Short	
1	27,703,000	144,412,496	0.126	0.45	0	15,059
2	39,806,000	144,405,840	0.120	0.57	0	12,455
3	44,787,900	145,091,152	0.121	0.61	0	11,763
4	47,635,500	147,331,344	0.122	0.62	0	11,604
5	51,195,000	148,387,344	0.123	0.65	0	11,181
6	54,754,500	150,801,088	0.125	0.66	0	10,933
7	58,314,000	153,057,872	0.127	0.68	0	10,664
8	61,873,500	155,697,584	0.129	0.70	0	10,445
9	65,433,000	157,921,424	0.131	0.71	0	10,172

Table 9-14: HOMER Optimization Result of Grid-Connected Wind and Hydro Power System for Palawan Island

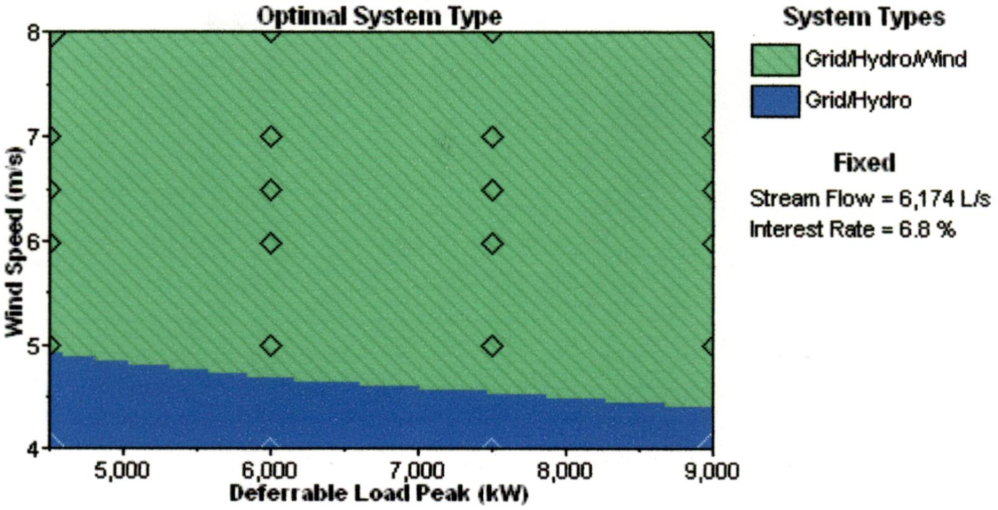


Figure 9-16: Optimal System Type for Palawan Island Wind Farm Site 2 at Various Deferrable Load Capacities and Wind Speed Available

Time	Wind Speed	Stream Flow	AC Primary Load	Vestas 600kW	Hydro Power	Grid Purch.	AC Prim. Served	Defer. Served	Excess Electricity	Unmet Load	Defer. Storage
Hour	m/s	L/s	kW	kW	kW	kW	kW	kW	kW	kW	kWh
5024	2.229	9409.958	4672.004	0	6845.026	0	4672.004	0	2173.022	0	4000
5025	2.621	9409.958	5553.005	0	6845.026	0	5553.005	0	1292.021	0	875
5026	2.9	9409.958	5886.005	0	6845.026	3540.979	5886.005	4500	0	0	2250
5027	4.89	9409.958	6089.005	1267.111	6845.026	2476.868	6089.005	4500	0	0	3625
5028	5.719	9409.958	5967.005	2885.996	6845.026	0	5967.005	0	3764.017	0	500
5029	8.059	9409.958	6193.006	9483.992	6845.026	0	6193.006	4500	5636.013	0	1875
5030	6.699	9409.958	5982.005	5293.53	6845.026	0	5982.005	4500	1656.551	0	3250
5031	7.018	9409.958	5916.005	6133.807	6845.026	0	5916.005	4500	2562.829	0	4625
5032	6.812	9409.958	5755.005	5587.437	6845.026	0	5755.005	4500	2177.458	0	6000
5033	4.93	9409.958	5814.005	1303.78	6845.026	0	5814.005	0	2334.801	0	2875
5034	4.25	9409.958	7444.007	682.546	6845.026	4416.435	7444.007	4500	0	0	4250
5035	3.914	9409.958	7329.007	415.295	6845.026	4568.686	7329.007	4500	0	0	5625
5036	1.6	9409.958	6970.006	0	6845.026	4624.98	6970.006	4500	0	0	7000
5037	1.329	9409.958	6236.006	0	6845.026	0	6236.006	0	609.021	0	3875
5038	1.399	9409.958	5218.005	0	6845.026	0	5218.005	0	1627.021	0	750
5039	0.897	9409.958	4526.004	0	6845.026	2180.978	4526.004	4500	0	0	2125
5040	1.512	9409.958	7620.007	0	6845.026	5274.98	7620.007	4500	0	0	3500
5041	1.34	9409.958	7283.007	0	6845.026	4937.98	7283.007	4500	0	0	4875
5042	1.252	9409.958	6999.006	0	6845.026	4653.98	6999.006	4500	0	0	6250
5043	2.239	9409.958	6951.006	0	6845.026	4605.98	6951.006	4500	0	0	7625
5044	3.397	9409.958	7036.006	180.574	6845.026	4510.406	7036.006	4500	0	0	9000
5045	3.114	9409.958	7596.007	51.699	6845.026	5199.282	7596.007	4500	0	0	10375
5046	2.19	9409.958	7908.007	0	6845.026	5562.981	7908.007	4500	0	0	11750
5047	2.762	9409.958	7714.007	0	6845.026	5368.98	7714.007	4500	0	0	13125
5048	2.932	9409.958	9446.009	0	6845.026	7100.982	9446.009	4500	0	0	14500
5049	3.319	9409.958	11227.01	144.762	6845.026	8737.222	11227.01	4500	0	0	15875
5050	3.403	9409.958	11901.011	183.329	6845.026	9372.655	11901.011	4500	0	0	17250

Table 9-15: Hourly Operation Mode of a Grid-Connected Wind and Hydro Power System with Deferrable Load for Palawan

Time	Wind Speed	Stream Flow	AC Primary Load	Vestas 600kW	Hydro Power	Grid Purch.	AC Prim. Served	Defer. Served	Excess Electricity	Unmet Load	Defer. Storage
Hour	m/s	L/s	kW	kW	kW	kW	kW	kW	kW	kW	kWh
5051	5.213	9409.958	12311.01	1816.509	6845.026	8149.476	12311.01	4500	0	0	18625
5052	6.316	9409.958	12066.01	4298.077	6845.026	5422.907	12066.01	4500	0	0	20000
5053	6.746	9409.958	12523.01	5415.195	6845.026	4762.79	12523.01	4500	0	0	21375
5054	6.852	9409.958	12095.01	5689.587	6845.026	0	12095.01	0	439.603	0	18250
5055	8.486	9409.958	11961.01	11041.26	6845.026	0	11961.01	4500	1425.274	0	19625
5056	7.795	9409.958	11636.01	8616.119	6845.026	0	11636.01	0	3825.135	0	16500
5057	7.362	9409.958	11755.01	7230.353	6845.026	0	11755.01	0	2320.368	0	13375
5058	4.178	9409.958	15051.01	616.817	6845.026	12089.17	15051.01	4500	0	0	14750
5059	2.479	9409.958	14819.01	0	6845.026	12473.99	14819.01	4500	0	0	16125
5060	2.956	9409.958	14093.01	0	6845.026	11747.99	14093.01	4500	0	0	17500
5061	2.914	9409.958	12609.01	0	6845.026	10263.99	12609.01	4500	0	0	18875
5062	2.643	9409.958	10551.01	0	6845.026	8205.983	10551.01	4500	0	0	20250
5063	2.799	9409.958	9152.009	0	6845.026	6806.982	9152.009	4500	0	0	21625
5064	3.141	9409.958	7620.007	64.123	6845.026	5210.857	7620.007	4500	0	0	23000
5065	3.664	9409.958	7283.007	301.648	6845.026	4636.333	7283.007	4500	0	0	24375
5066	4.072	9409.958	6999.006	520.406	6845.026	0	6999.006	0	366.426	0	21250
5067	3.245	9409.958	6951.006	111.44	6845.026	0	6951.006	0	5.46	0	18125
5068	4.724	9409.958	7036.006	1115.86	6845.026	0	7036.006	0	924.88	0	15000
5069	5.451	9409.958	7596.007	2320.215	6845.026	0	7596.007	0	1569.234	0	11875
5070	4.887	9409.958	7908.007	1265.191	6845.026	0	7908.007	0	202.209	0	8750
5071	5.972	9409.958	7714.007	3418.594	6845.026	0	7714.007	0	2549.613	0	5625
5072	6.909	9409.958	9446.009	5838.301	6845.026	0	9446.009	0	3237.318	0	2500
5073	5.496	9409.958	11227.01	2414.793	6845.026	6467.189	11227.01	4500	0	0	3875
5074	8.1	9409.958	11901.01	9633.229	6845.026	0	11901.01	4500	77.245	0	5250
5075	8.78	9409.958	12311.01	12113.46	6845.026	0	12311.01	4500	2147.479	0	6625
5076	8.72	9409.958	12066.01	11893.02	6845.026	0	12066.01	4500	2172.04	0	8000

Table 9-15: Hourly Operation Mode of a Grid-Connected Wind and Hydro Power System with Deferrable Load for Palawan

The comparative financial and economic aspect of the selected grid-connected wind/hydro power system for Palawan Island based on the optimal system type graph shown in **Figure 9-16** for selected capacity of 45 units of 600 kW class Vestas WTG, 6.8 MW run-of-river with 3-hour peaking hydropower plant, 9 MW pumped-storage hydro scheme requiring 27,375,000 kWh annually to pump water to upper reservoir at different deferrable load peak is summarized in **Table 9-16.**

Wind Speed (m/s)	**Grid/Hydro/Wind**			
	Deferrable Load Peak (kW)			
	4500	6000	7500	9000
4	154,583,968	159,174,608	163,292,480	149,892,384
5	140,253,136	144,221,792	147,331,344	136,066,448
6	139,831,200	143,288,224	146,423,568	135,774,528
7	127,249,976	130,776,048	133,084,320	124,189,960
8	117,844,160	120,296,456	122,489,344	114,897,640
Wind Speed (m/s)	**Grid/Hydro**			
	Deferrable Load Peak (kW)			
	4500	6000	7500	9000
4	160,057,808	167,019,552	173,815,552	151,243,232
5	160,057,808	167,019,552	173,815,552	151,243,232
6	160,057,808	167,019,552	173,815,552	151,243,232
7	160,057,808	167,019,552	173,815,552	151,243,232
8	160,057,808	167,019,552	173,815,552	151,243,232
Wind Speed (m/s)	**Grid/Wind**			
	Deferrable Load Peak (kW)			
	4500	6000	7500	9000
4	196,142,560	199,731,904	201,728,032	192,294,480
5	177,175,088	180,115,680	182,614,400	173,048,928
6	176,021,152	179,113,456	181,833,488	172,407,312
7	158,404,720	161,116,672	163,329,200	154,948,704
8	143,854,960	146,181,664	148,622,192	139,939,440
Wind Speed (m/s)	**Grid**			
	Deferrable Load Peak (kW)			
	4500	6000	7500	9000
4	198,866,912	202,625,600	205,030,208	196,971,040
5	198,866,912	202,625,600	205,030,208	196,971,040
6	198,866,912	202,625,600	205,030,208	196,971,040
7	198,866,912	202,625,600	205,030,208	196,971,040
8	198,866,912	202,625,600	205,030,208	196,971,040

Table 9-16: Total Net Present Cost (NPC), US$ of the Optimal System for Palawan Island at Selected Deferrable Load Peak and Wind Speed

The result of power operation of the NPC-SPUG for the calendar year 2003 in the island of Palawan indicates that the production costs of the different diesel and bunker fuel oil C power plants varies from as low as PhP 4.475/ kWh (US$ 0.0894/ kWh) to as high as PhP 13.2161/kWh (US$ 0.2643/ kWh) depending on the proximity of the various plant from the oil refinery and depot at the main island of Luzon, efficiency of the plant, load factor and the volatile cost of crude oil in the international market. Based on the available data, the approximate power grid cost was assumed at PhP 7.7156/ kWh or around $ 0.154/ kWh using Peso to US Dollar exchange rate of PhP 50 per US$ 1 in 2000-2001, which is the Puerto Princesa, Palawan power plants's production cost and is more realistic. The levelized cost of energy and total annualized cost of the wind and hydro power system with deferrable water pumping load in Palawan are shown in **Figures 9-17** and **9-18** and summary of selected deferrable load against the variable wind speed is tabulated in **Table 9-17.**

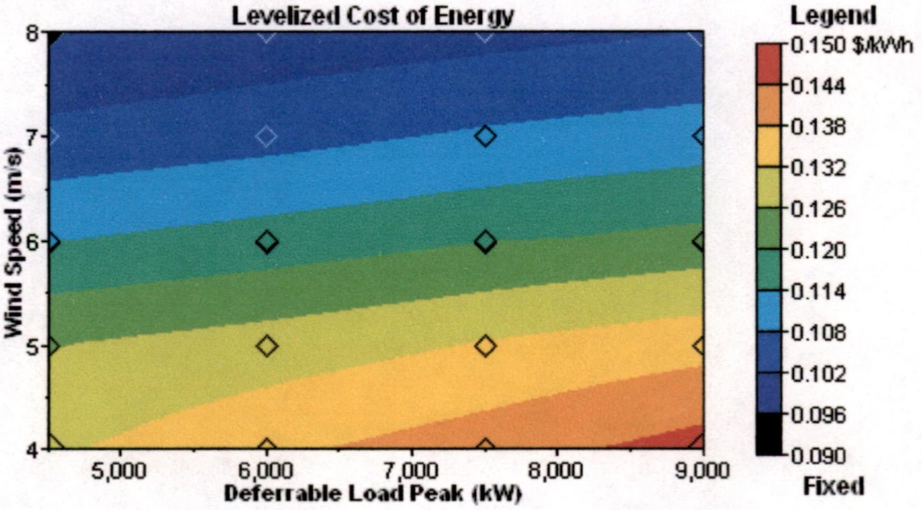


Figure 9-17: HOMER Simulation Levelized Cost of Energy for the Optimal System for Palawan

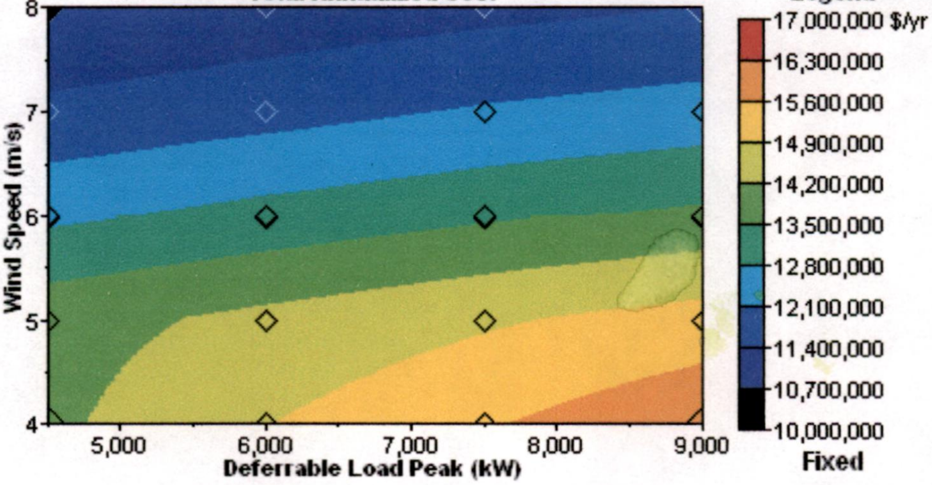


Figure 9-18: Homer Simulation Annualized Cost for the Optimal System for Palawan

9.2 Discussions on the Results

The two study sites provided different results in terms of total penetration to the existing power grid system. The result of the study in Mindoro Island indicates that the selected grid-connected wind and hydropower system (WHPS) architecture of 24 MW wind farm, 18 MW run-of-river hydro scheme and 40 MW fossil fuel generating capacity from the grid system can provide as much as 85% generation from both renewable energies to meet the required annual load demand of the island. Both renewable energy technologies were able to contribute 63,673,692 kWh of the required 75,095,128 kWh annual load demand required by Oriental Mindoro in 2001. The fossil fuel generators of the grid system contributed 11,421,436 kWh, which was translated to 8,877 tons per year of CO_2 emission. The power grid system was able to avoid 49,565 tons per year of carbon dioxide emission. The wind and hydro power system concept contributed substantially to the reduction of this greenhouse gas (GHG), which is one of the causes of global warming. Using the excess electricity of 74,217,296 kWh from both renewable energies in the system during off-peak period and during monsoon season to pump water to a higher reservoir for future use such as pumped-storage hydropower scheme can maximize the penetration of both technologies in the power grid system and further enhance its load efficiency. For the selected WHPS architecture, 18 MW of pumped-storage hydropower capacity can be added to the system from the excess energy of the WHPS. Although, this may cause additional increase in the levelized cost of energy for the system due to the cost of construction of the scheme and is deemed as net energy user in the system because it needs approximately 4 MW of energy for pumping operation to provide additional 3 MW power to the system, but this will provide additional capacity that will be available anytime when needed and can smoothen the system's power load fluctuations. The WHPS concept for Mindoro island can be cost competitive to the current predominantly fossil fuel power plants in the system because it was able to reduce the levelized cost of energy from US$ 0.154 per kWh to US$ 0.078 per kWh, which almost the same cost of energy of the most efficient diesel generator plant of the island's power system in 2003 operation at US$ 0.0712 per kWh.

For Palawan Island, the result of the study shows that the selected grid-connected wind and hydropower system (WHPS) architecture of 27 MW wind farm, 6.8 MW run-

Wind Speed (m/s)	Levelized Cost of Energy ($/kWh)					
	Deferrable Load Peak (kW)					
	4500	6000	7500	8000	8500	9000
4	0.128556	0.132249	0.133202	0.134332	0.135663	0.125571
5	0.116557	0.119818	0.120580	0.121982	0.122403	0.113726
6	0.116200	0.119034	0.120029	0.121004	0.121639	0.113468
7	0.105711	0.108640	0.109016	0.109830	0.110566	0.103477
8	0.097886	0.099934	0.100589	0.101100	0.101756	0.095488
Wind Speed (m/s)	Total Annualized Cost ($/yr)					
	Deferrable Load Peak (kW)					
	4500	6000	7500	8000	8500	9000
4	14,365,592	14,792,204	14,899,665	15,027,341	15,174,880	13,929,600
5	13,033,818	13,402,629	13,485,926	13,644,737	13,691,601	12,644,747
6	12,994,608	13,315,872	13,425,263	13,536,438	13,607,241	12,617,618
7	11,825,426	12,153,106	12,196,061	12,286,365	12,367,616	11,541,057
8	10,951,337	11,179,231	11,253,240	11,309,797	11,383,017	10,677,515

Table 9-17: Levelized Cost of Energy and Total Annualized Cost of the Optimal Grid-Connected Wind / Hydropower System for Palawan

The optimized system result for the selected grid-connected wind and hydro power system for Palawan indicates that as wind speed increases, levelized cost of energy as well as the total annualized cost of the system also decreases. This is because the levelized cost of energy is directly proportional to the total annualized cost and inversely proportional to the sum of the primary load served, deferrable load served and total grid sales, if there is provision that excess energy can be sold back to the grid during peak period. Thus, deferrable load such as pumping water to higher elevation reservoir and selling back to grid excess electricity during peak period are beneficial to the grid system economic and financial operation as this utilize the excess power capacity of the system that will be dumped and at the same time lowers the cost of energy as providing higher load efficiency to the system. However, the result of the levelized cost of energy and total annualized cost in terms of increasing deferrable load at same level of wind speed tends to increase but decreases as deferrable pumping peak load reaches around 9,000 kW.

of-river hydro scheme and 26 MW fossil fuel generating capacity from the grid system can provide as much as 35.23% generation from both renewable energies to meet the required annual load demand of the island. Both renewable energy technologies were able to contribute only 29,771,552 kWh of the required 84,506,024 kWh annual load demand required by Palawan in 2001. The fossil fuel generators of the grid system contributed 54,734,472 kWh, which was translated to 42,548 tons per year of CO_2 emission. The power grid system was able to avoid only 23,174 tons per year of carbon dioxide emission. The wind and hydro power system concept had only reduced less than half of the CO_2 emission compared to what the Mindoro WHPS has done in its grid system and this is due to low capacity contribution from the hydro from the Palawan WHPS. The maximum hydropower power scheme available for the island is only 6.8 MW. Large hydropower based power system is a big factor in term of levelizing the overall cost of energy in the system. Using the excess electricity of 32,278,796 kWh from both renewable energies in the system during off-peak period and during monsoon season to pump water to a higher reservoir for future use such as pumped-storage hydropower scheme, it can maximize the penetration of both technologies in the power grid system and further enhance its overall load efficiency. For the selected WHPS architecture, 9 MW of pumped-storage hydropower capacity can be added to the system from the excess energy of the WHPS. The WHPS concept for Palawan island can only be a marginally cost competitive project compared with the current predominantly fossil fuel power plants in the system. It was only able to marginally reduce the levelized cost of energy from US$ 0.154 per kWh to US$ 0.122 per kWh, or savings of around US$ 0.032 per kWh. This is comparatively less attractive in investment compared to the WHPS for Mindoro Island but overall this more better than the current levelized cost of energy from the existing power grid system that utilizes 100% fossil fuel.

9.3 Conclusion

In final analysis, the two study sites selected show that grid-connected wind and hydro power system (WHPS) concept for existing small power grid system in selected isolated islands in the Philippines is most likely to be most cost effective and economically competitive alternative hybrid power system compared to other systems such as hydro-grid, wind-grid or purely grid system that is power generated by 100% fossil fuel. The concept has the least environmental impact compared to the existing fossil fuel generating plants of the power grid system. Utilizing the excess wind energy available during off-peak period to pump water in a higher reservoir can further enhance the overall load efficiency of the grid-connected wind and hydro power system in the system and at the same time can provide additional power capacity that can augment the existing peaking plants of the system. The most important of all is that proposed WHPS concept was able to reduce production of greenhouse gases like CO_2 and at the same time the dependence of the island to imported fossil fuel.

There are several limitations in this study. Some of the data used in the simulation process was purely based on assumptions because no actual data are available for public access but otherwise some data was based on the actual technical and financial operations of the power system of the selected study sites. The hour to hour simulation of the system studied may vary to the actual because some data were only synthesized based on the average monthly data required by the simulation program as the hour to hour data is difficult to obtain from the selected island. The present technical capability of the grid's transmission system used in the WHPS study was not covered in the study. This study has not actually simulated the contribution of the pump-storage hydropower scheme operation in the whole WHPS due to the limitation in the existing computer model program used, **HOMER**, which can only simulate one unit of run-of-river hydro for renewable energy hybriding to other technologies such as wind, solar, biomass, diesel and the grid system. The possibility of pumped-storage hydropower scheme intra hour to hour operation as well as its power contribution to the system should be included in any subsequent studies for the WHPS in the isolated islands in the Philippines.

Overall, the whole WHPS concept is a very attractive investment project for small isolated islands in the Philippines that depends wholly in fossil fuel for generating system. If the non-financial benefits, like the environmental protection, release from total dependence on the imported oil of the isolated island and the creation of tourist attraction made by the system which can be replicated to other small islands in the Philippines, then the implementation of the concept in existing small grid system is strongly recommended.

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