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Worldwide Wind/Diesel Hybrid Power System Study: Potential Applications and Technical Issues

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TABLE OF CONTENTS

Page

1.0 World Markets for Wind/Diesel Hybrid Applications 1

1.1 Global Diesel Generator Set Markets 2

1.2 Opportunities for Wind/Diesel Hybrid Applications 3

1.2.1 Market Potential in Countries Screened for High Potential 4

1.2.2 Corollary Markets for Wind/Diesel Hybrids 4

1.3 Priming Wind/Diesel Market Growth 8

1.4 Dealing with Barriers to Market Growth 9

1.4.1 Barriers Common to New Technology Markets 9

1.4.2 Barriers Specific to LDC and Remote Markets 11

2.0 Wind/Diesel Hybrid Power Research 13

2.1 Impact of Application-Related Technical Requirements on Research Priorities 13

2.2 Impact of Market Sector Potential on Research Priorities 16

3.0 World Potential for Wind/Diesel Hybrid Applications (Task 1) 19

3.1 Assessing Country-Specific Wind Potential and Diesel Gen Set Markets 19

3.2 Ranking Countries by Wind Energy Applications Potential 20

3.2.1 Ranking Methodology 20

3.2.2 Countries Selected for Task 2 Analysis 20

4.0 Specific Application Requirements (Task 2) 24

4.1 Alaska 24

4.1.1 Wind Resource Characterization 25

TABLE OF CONTENTS

Page

4.1.2 Market Opportunity: Village Electrification 25

4.1.3 Market Opportunity: Military Installation Power 28

4.1.4 Corollary Opportunities 29

4.2 Canada 30

4.2.1 Wind Resource Characterization 30

4.2.2 Energy Market Characterization 31

4.2.3 Business Conditions 32

4.2.4 Market Opportunity: Village Electrification 33

4.2.5 Market Opportunity: Private Industry Power 35

4.2.6 Corollary Opportunities 35

4.3 Republic of Chile 37

4.3.1 Wind Resource Characterization 37

4.3.2 Energy Market Characterization 37

4.3.3 Business Conditions 39

4.3.4 Market Opportunity: Remote Utility Power 39

4.3.5 Market Opportunity: Private Industry Power 39

4.3.6 Corollary Opportunities 40

4.4 People s Republic of China 41

4.4.1 Wind Resource Characterization 42

4.4.2 Energy Market Characterization 42

4.4.3 Business Conditions 45

TABLE OF CONTENTS

Page

4.4.4 Market Opportunity: Water Pumping 46

4.4.5 Market Opportunity: Village Power 46

4.4.6 Market Opportunity: Industrial Power 47

4.4.7 Market Opportunity: Telecommunications 47

4.4.8 Corollary Opportunities 47

4.5 Dominican Republic 49

4.5.1 Wind Resource Characterization 50

4.5.2 Energy Market Characterization 50

4.5.3 Business Conditions 50

4.5.4 Market Opportunity: Corporacion Dominicana de Electricidad and Large Industrial and Commercial Customers 52

4.5.5 Market Opportunity: Residential Customers 53

4.5.6 Market Opportunity: Tourist Hotels 54

4.5.7 Corollary Opportunities 54

4.6 Arab Republic of Egypt 55

4.6.1 Wind Resource Characterization 56

4.6.2 Energy Market Characterization 56

4.6.3 Business Conditions 57

4.6.4 Market Opportunity: Red Sea Coast Development 58

4.6.5 Market Opportunity: Village Power Systems 59

TABLE OF CONTENTS

Page

4.6.6 Market Opportunity: Diesel-Supplied Electric Grids 60

4.6.7 Market Opportunity: Water Pumping 60

4.6.8 Corollary Opportunities 60

4.7 Hellenic Republic (Greece) 61

4.7.1 Wind Resource Characterization 61

4.7.2 Energy Market Characterization 62

4.7.3 Business Conditions 62

4.7.4 Market Opportunity: Small Grids 64

4.7.5 Market Opportunity: Remote Resorts and Other Commercial Applications 64

4.7.6 Corollary Opportunities 65

4.8 Republic of India 66

4.8.1 Wind Resource Characterization 67

4.8.2 Energy Market Characterization 67

4.8.3 Business Conditions 69

4.8.4 Market Opportunity: Village Electrification, Package Systems 69

4.8.5 Market Opportunity: Village Electrification, Retrofit Turbines ... 71

4.8.6 Market Opportunity: Water Pumping 72

4.8.7 Market Opportunity: Private Industrial and Agricultural Power ... 73

4.8.8 Corollary Opportunities 73

TABLE OF CONTENTS

Page

4.9 Republic of Korea 75

4.9.1 Wind Resource Characterization 76

4.9.2 Energy Market Characterization 76

4.9.3 Business Conditions 77

4.9.4 Market Opportunity: Utility Grid Power 77

4.9.5 Corollary Opportunities 78

4.10 Republic of the Sudan 79

4.10.1 Wind Resource Characterization 80

4.10.2 Energy Market Characterization 80

4.10.3 Business Conditions 81

4.10.4 Market Opportunity: Village Electrification 82

4.10.5 Market Opportunity: Isolated and Grid-Connected Utility Diesel Units 83

4.10.6 Market Opportunity: Water Pumping 84

4.10.7 Corollary Opportunities 85

Appendices 86

Wind/Diesel Database 87
Contacts 93
List of Acronyms 95

References 96

1.0 World Markets for Wind/Diesel Hybrid Applications

Wind/diesel generation systems combine wind turbine technology with diesel generator sets. Such systems could be an attractive energy-producing technology option in many areas of the world that currently depend on diesel generator sets for electricity. Advantages of these hybrid systems over conventional diesel generator sets include the systems' ability to

- reduce consumption of expensive diesel fuel in remote locations ("fuel-saver" capacity),
- extend the diesel fuel supply in locations where fuel delivery is infrequent, and
- provide electricity at a cost that is lower than diesel generator set electricity.

The world market potential for wind/diesel hybrid technology is a function of the need for electric power, the availability of sufficient wind resource to support wind/diesel power, and the existence of buyers with the financial means to invest in the technology. This study includes data related to each of these three factors. This study does not address market penetration, which would require analysis of application specific wind/diesel economics. Buyer purchase criteria, which are vital to assessing market penetration, are discussed only generally.

Countries were screened for a country-specific market analysis based on indicators of need (e.g., diesel fuel prices, number of existing diesel generator sets) and wind resource (at least 250 W/m^2). Both developed countries (e.g., United States and Canada) and "less developed countries" (LDCs) were screened for wind/diesel market potential. This screening process is described in Section 3. Based on the results of the screening, ten countries showing high market potential were selected for more extensive market analyses. These analyses provide country-specific market data to guide wind/diesel technology developers in making design decisions that will lead to a competitive product. Section 4 presents the country-specific data developed for these analyses, including more extensive wind resource characterization, application-specific market opportunities, business conditions, and energy market characterizations. An attempt was made to identify the potential buyers with ability to pay for wind/diesel technology required to meet the application-specific market opportunities identified for each country. Additionally, the country-specific data are extended to corollary opportunities in countries not covered by the study. Section 2 gives recommendations for wind/diesel research based on the findings of the study.

Wind/diesel generation systems can serve both "retrofit" and "new" electricity generation markets. The conventional retrofit market includes the numerous existing stock of diesel generator sets in the world to which wind turbines could be added as fuel-savers. The new market covers packaged wind/diesel systems that meet the growing global demand for expanded electricity generation, offering a new electricity supply where none has existed before.

1.1 Global Diesel Generator Set Markets

The diesel generator set serves a critical role in supplying the power needs of many users throughout the world. For users in remote villages not served by a central electric grid, these generators provide the only source of electric power. For industrial and commercial users in much of the developing world (e.g., the People's Republic of China and the Dominican Republic), diesel generator sets ("gen sets") provide back-up power to supplement unreliable central utility power. Diesel gen sets also provide uninterruptible power service for remote military, telecommunications, and navigational aid facilities.

Table 1.1 gives an overview of the number of diesel gen sets in the world that are currently serving prime power needs. Prime power applications cover the range of potential uses from village electrification to industrial and commercial loads. Table 1.1 indicates that about 75% of these gen sets are in sizes up to 70 kW, a range that covers a variety of village power and commercial loads. The largest markets are in the Asian/Pacific (about 40% of the gen sets) and African (about 18% of the gen sets) regions. In this study, Asian/Pacific countries are illustrated by country-specific analyses of China, India, and Korea; African countries analyzed include Egypt and Sudan.

TABLE 1.1: NUMBER OF DIESEL GENERATOR SETS IN PRIME POWER MARKETS

1990

		Size Range (kW)						
Region	Total	0-5	5.1-30	31-70	71-150	151-300	301-500	501-1000
Africa	24,640	272	13,887	3,824	2,666	2,324	972	695
Asia/ Pacific	54,552	554	30,458	13,571	4,269	3,919	1,054	727
Europe	22,777	341	13,297	3,346	2,373	1,809	829	782
N. America	14,650	280	7,414	2,145	1,901	1,572	1,054	284
S. America	17,197	135	7,236	3,530	2,454	2,203	1,272	367
World	133,816	1,582	72,292	26,416	13,663	11,827	5,181	2,855

Source: Extrapolated from Power Systems Research data for 1982.

The growth of diesel gen set installations is closely related to the health of a country's economy; thus, the frail economies of LDCs make market growth in such countries less likely. However, near-term growth of diesel generator set sales in countries around the world is expected to be good. World gen sets sales from 1982 to 1990 were estimated to grow at an annual rate of about 3% [1-5]. This new applications market growth trend is expected to continue and should provide many prospects for sales of packaged wind/diesel systems.

1.2 Opportunities for Wind/Diesel Hybrid Applications

Promising world-wide markets are defined by several factors. Those examined in this study include overall market size, degree of uncertainty in the future market's existence, development time frames, physical climates, trade relations, amount of effort required to tap the market, options for financing purchases, and whether the market is for equipment or services. The country-specific data presented in Section 4 illustrate how these factors can impact market potential and form the basis for the following discussion.

Data on internationally installed diesel capacity and village electrification indicate that the largest markets, based solely on total existing or expected plant capacity, are most likely

- retrofits for
  - remote, private industry
  - village electrification
  - larger, remote, diesel-supplied grids
- retrofits and package systems for small, diesel generator-based grids on islands
- hybrid packages for new village electrification.

Small and moderate markets may be

- retrofits for
  - remote U.S. military installations
  - village electrification in cold climates
- package and retrofit installations for large resort hotels
- water pumping (a large mechanical and electrical wind pump market, but a much smaller wind/diesel hybrid market).

1.2.1 Market Potential in Countries Screened for High Potential

The 10 countries listed in Table 1.2 are thought to have high wind/diesel sales potential based on market indicators (wind class, number of installed diesel gen sets over 10 kW, delivered diesel fuel cost, and diesel market growth rate). These countries were chosen for an in-depth assessment of the market conditions that may be encountered by a wind/diesel developer. The installed diesel capacity in these countries serves loads ranging from 5 to 10 kW for village power to 1 to 2 MW for hotel/resort complexes. Table 1.2 indicates a global diesel gen set retrofit market of 15 GW, offering potential for significant wind turbine sales. Furthermore, the 15 GW estimate of installed capacity is probably conservative, since installed capacity estimates were unavailable for many countries (e.g., China).

Estimates of new village electrification potential indicated in Table 1.2 provide a feel for the size of a potentially very large new applications market (26 GW). These estimates are based on the percent of a country's rural population without electricity, the total country rural population, and an estimate of 30 W/capita for newly electrified areas. (This estimate is believed to be conservative [9-9].)

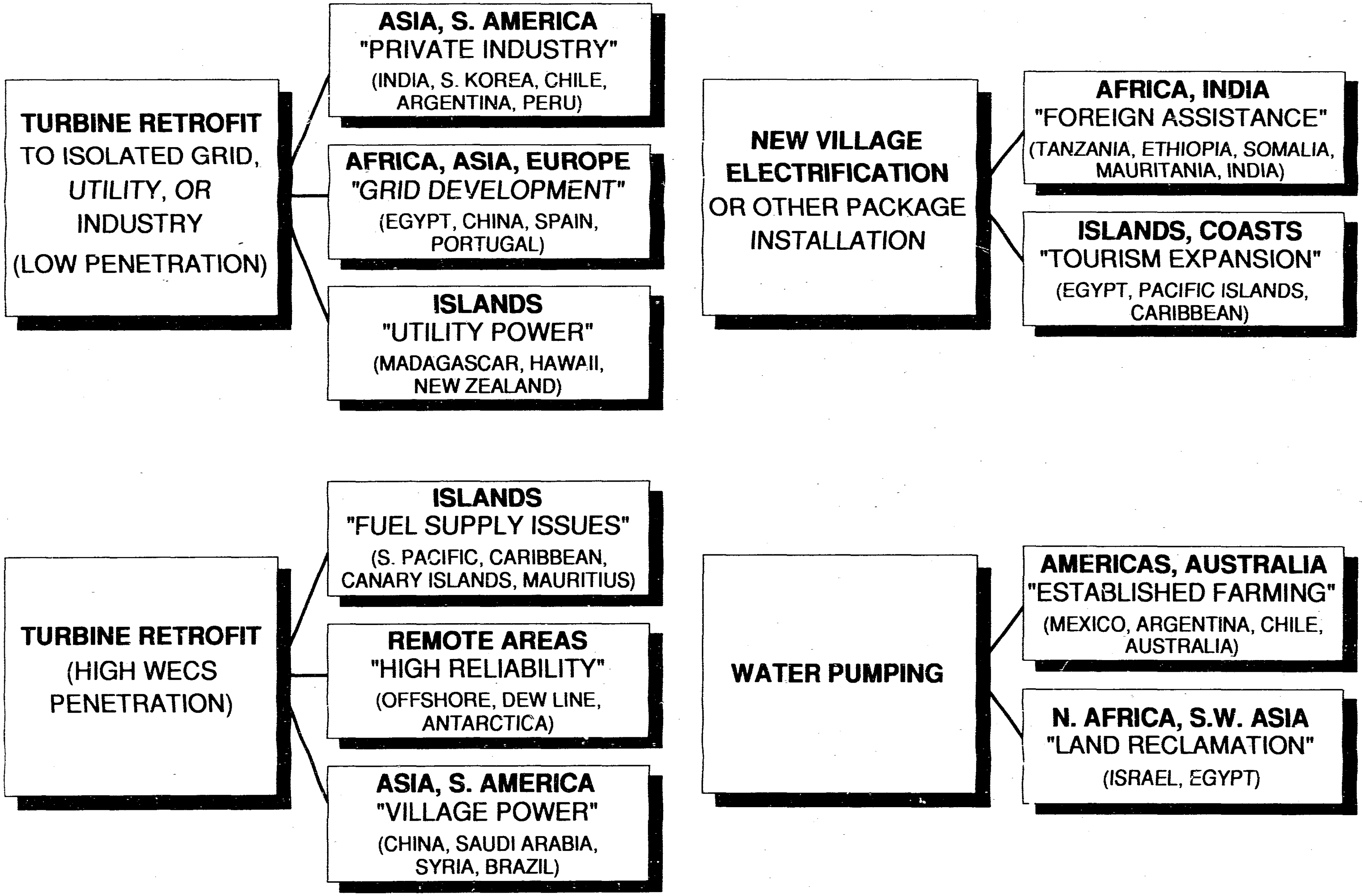
TABLE 1.2: WIND/DIESEL OPPORTUNITIES IN COUNTRIES WITH HIGH POTENTIAL

	Installed Capacity (MW)		Village Electrification Potential (MW)	
Alaska	260	(2%)	N/A	
Canada	300	(2%)	350	(1%)
Chile	740	(5%)	40	(<1%)
China	N/A		3,820	(15%)
Dominican Republic	200	(1%)	60	(<1%)
Egypt	220	(1%)	500	(2%)
Greece	350	(2%)	Negl.	(<1%)
India	2,000	(13%)	14,490	(55%)
Korea	1,160	(8%)	50	(<1%)
Sudan	240	(2%)	410	(2%)
Other Database Countries	9,530	(64%)	6,680	(25%)
World Market	15,000	(100%)	26,400	(100%)

N/A -- Not Available

1.2.2 Corollary Markets for Wind/Diesel Hybrids

Figure 1.1 gives some examples of important application market segments for countries highlighted in this report and extends the wind/diesel market assessment to other countries having similar application opportunities. The examples illustrate the wide variety of potential wind/diesel applications and corresponding regional and country-specific market locations. The applications are discussed in more detail below, including examples of countries where they might be useful.



World-Wide Wind/Diesel Applications: Broad Relationships

Figure 1.1

Wind/Diesel Package Systems for New Village Electrification

Package systems may be a very important part of the future market, once high reliability systems appropriate to this application have been introduced. Village electrification market growth will depend on availability of buyers, yet the villagers in greatest need of the systems have the least hard currency to purchase them. Wind/diesel electrification may still have potential in countries where the government is committed to supplying electricity to remote rural communities without major electric grid access, even when wind speeds are only moderate. Leaders of many LDCs recognize that the costs to the country of not electrifying these areas are greater than costs of electrification at a premium, since lack of electricity is one factor that causes rural poor to migrate to city slums. Alternatively, reliable electricity supply helps local industry to develop, reduces population growth, facilitates the raising of health standards, and unites the country through the electronic media. Also, perceptive leaders and governments recognize the importance of using renewable sources of energy to displace imported fossil fuels in order to improve their balance of trade. India's installation of photovoltaic systems in rural communities shows these principles at work.

Donor agencies (e.g., U.S. Agency for International Development [USAID], The World Bank, United Nations Development Program [UNDP]) provide another avenue for facilitating wind/diesel market growth. Limits on project funding are more motivational than economic. The key to project success is to get field-based donor agency mission directors interested, since they are responsible for developing projects proposed by electricity supply authorities in the country hosting the mission.

Given LDC government and donor agency interest in expanded village electrification, good opportunities for wind/diesel package systems or retrofits present themselves in many regions, including much of northern and central Africa (e.g., Ethiopia, Tanzania, Mauritania, Morocco, Senegal, Zambia), the Near and Middle East (e.g., Turkey, Pakistan, Saudi Arabia, Syria, Jordan), coastal and mountain areas in South America (e.g., Argentina and Peru), and island nations with moderate wind resources (e.g., Sri Lanka, Fiji, Madagascar). However, opportunities are not necessarily equally open to all countries selling wind technology. Developing nations with a history of strong European presence may be less likely to contract with the U.S. wind industry because of continued strong marketing ties to Europe.

Wind Turbine Retrofits (Low and High Penetration of Turbine into the Grid)

Technical requirements for wind turbine retrofits to existing diesel gen sets are similar to those for package systems, with an additional need to consider the impact of wind turbine electricity generation on the stability of existing local or regional electricity grids. Grid stability is less likely to be a problem where wind turbines supply a low percentage of electricity relative to diesel generators (low penetration) than where the percentage of wind turbine electricity is high (high penetration).

Climates, rural industries, and remote communities similar to those in Alaska and Canada, where diesel gen sets are already in place, can be found in the Soviet Union and mainland China. Even if the direct sale of U.S. equipment to these countries is limited by trade barriers, there could be many opportunities to sell system designs and provide services. A joint diesel generator operation study by the University of Alaska and Brazil has demonstrated the great similarities between small community power systems in the two countries [2-4]. These similarities suggest that the basic design and operational experience gained in the installation of wind/diesel systems in Canada and Alaska can be transferred to village power applications in many other areas of the world.

Corollary markets to the diesel gen set Greek and Dominican Republic island sites are abundant, including the Hawaiian Islands and others in the higher wind regions of the South Pacific, the Azores, Cape Verde Islands, islands of the United Kingdom, Canary Islands, Falkland Islands, Turks and Caicos Islands, Barbados, and parts of the Bahamas.

Argentina shares applications in water pumping and larger diesel installations with Chile. Excellent wind regimes and U.S. presence would benefit wind/diesel market development. One estimate is that 90% of Patagonia contains Class 5 winds. Other factors supporting market development include populated areas corresponding to areas with good wind and problems with power reliability. A number of wind energy projects are under way in Argentina. For instance, the State of Chebut is promoting the use of wind turbines. This state operates 62 diesel-electric facilities totaling 8.4 MW, with sizes varying from 20 kW to 1.3 MW [4-1]. Estimated electricity costs are as high as $0.50/kWh. Additionally, private business interests (e.g., cattle ranchers) need power and have hard currency from exports to pay for wind/diesel technology [4-4]. Such groups may be more immune to the extremely poor economic situation, the major drawback to the marketing of wind/diesel systems in Argentina. The economy exhibits slow growth, triple digit inflation, and external debt that has doubled since 1978.

Opportunities for interconnection with diesel grids are not limited to South America. Excellent winds are found along the Siberian coast, with good winds (Class 4) in areas of both North and South Korea. Although North Korea has not recently been considered an export opportunity for U.S. firms, it is now rapidly and inconspicuously making efforts to import Western technology. The head of the Ministry of Foreign Trade recently stated that the North Koreans "favor expanded trade with Western countries irrespective of their own economic systems" [10-1]. A number of North Korean firms are now actively trading with western European countries and Canada, as well as Japan and Hong Kong. A future potential market is possible, given an increasing trade deficit, due in part to major imports of petroleum from the U.S.S.R. and China, and given wind regimes of the same order as those found in South Korea (Class 4) [7-2]. However, the United States ban on trade with North Korea will have to be lifted before direct U.S. - North Korean trade is possible. The

UNDP has been one avenue for trade in recent years and has the potential for being the means of introducing wind/diesel hybrid systems.

Water Pumping

This application is currently served by small diesels (<20 kW). While the need for low-cost, low-maintenance water pumping systems is extraordinarily large, it is not clear how retrofit wind turbines for diesel connection could have a significant role. The simplest and most economically efficient method of water pumping may well be to use very inexpensive, locally manufactured wind pumps when wind is available and existing mechanical diesel pumps when it is not. However, if wind/diesel systems do prove cost effective for water pumping applications, the market will be enormous, including vast areas of South America (Argentina, Brazil, Chile), Africa, and Asia.

1.3 Priming Wind/Diesel Market Growth

Wind/diesel technology acceptance by world markets will be most successful if it is designed to match the user's level of technical expertise. Users in LDC markets are especially sensitive to these technology design requirements. The term "appropriate technology" has been adopted by developers of LDC economies to describe technologies that have a design simplicity that enables often uneducated and nontechnical users to make repairs easily. Preferred designs might maximize the use of modularity. For instance, the design might enclose all electronic controls in a box that could be disconnected and replaced when it failed. Appropriate technology designs also account for installation site characteristics. Is the structure modular enough to be assembled on-site if road access makes it impossible to deliver a preassembled structure? Could system components withstand extreme weather conditions? Is the system too expensive for the market because it was "over-designed"? Is system reliability high, to minimize repairs in remote locations where repair capabilities are limited? For instance, diesel generation systems for remote military and telecommunications uninterruptible power services increase reliability by having a redundant back-up, often another diesel or battery storage. However, users in remote villages may be unable to afford the significant investment in electricity storage or the high operating costs of back-up diesel generation capacity and would benefit from technology that would increase the reliability of existing diesel gen sets.

Appropriate technology is also technology that can be supported by the existing country infrastructure. Businesses may exist to manufacture part or all of an appropriate technology, including spare parts. As an example, India and Egypt have diesel generator set manufacturers. Service organizations also exist to maintain installed systems and to provide spare parts. For instance, most provinces in China have an agricultural machinery service company that supplies spare parts and repairs and maintains machinery, including diesel engines and water pumps. The infrastructure may not be developed sufficiently to provide the kind of service expected in developed countries, but it has over time adapted to the appropriate technology. Diesel gen sets have attained a degree of infrastructure support in many LDCs that make them the best available appropriate technology. Wind turbine technology would represent a new challenge to such existing infrastructures. In China, the challenge has already been addressed; China has wind turbine developers (e.g., Wind Energy Research Institute) and manufacturers (factories in several provinces) making 50, 100, and 150 watt turbines.

This study provides country-specific market information to guide wind/diesel system designers in developing appropriate technology. It also provides developers with insights needed to help them enter specific markets.

1.4 Dealing with Barriers to Market Growth

Wind/diesel market development is subject to many barriers, some encountered by new technology entering today's competitive world market and some unique to LDC and remote markets. Successful market developers will recognize barriers and develop creative solutions. The following discussion examines both the barriers and possible avenues to solutions. Solutions may be borrowed from related experience in developing autonomous, dispersed electrical grids based on power generation technologies such as photovoltaics, small-scale hydroelectric, and cogeneration. New strategies for financing, operation and maintenance, control systems, load management, and energy storage are being developed to meet the special needs of such technologies.

1.4.1 Barriers Common to New Technology Markets

Technical requirements of wind/diesel technology must be understood for successful application. In particular, site-specific wind resources need to be assessed; and control and operational strategies need to be defined.

Buyers may reject technology that is not currently cost effective in favor of more cost effective options (e.g., hydroelectric). Wind/diesel technology developers can gain exposure to potential technology users by donating technology to demonstration projects sponsored by donor agencies and governments. Through this mechanism, they can gain "real world" application experience that will help them achieve technical advances needed to improve technology economics and to prime sales. Application-specific economic analyses should accompany such demonstrations.

Low buyer awareness can be overcome by funding demonstration projects and by marketing the benefits of wind/diesel technology. Target buyer groups fall into two categories: (1) electricity supply authorities and organizations, government departments, and industrial and commercial buyers in individual countries; and (2) donor organizations, which often facilitate project development for LDC buyers. Trade development groups, such as the Committee on Renewable Energy Commerce and Trade (CORECT), could sponsor demonstrations.

Poor understanding of how to benefit from existing related technology sales distribution systems may stand in the way of developing any new technology market. Distribution systems of possible use to the wind/diesel market include agricultural, industrial, and commercial machinery sales and service companies, and possible use of the existing world-wide diesel gen set distribution systems. System integrators, who might put customized wind/diesel generation systems together, need to be educated regarding the profit potential of a wind/diesel business.

High import duties and tariffs need to be recognized as a cost of doing business; however, wind turbine imports often receive favorable treatment. Under the current United States-Canada Free Trade Agreement (January 1, 1989), tariff relief schedules are set for goods and services. South Korea plans to cut average tariffs from 18% (1988) to 8% (1993). India has given wind turbines an Open General License that waives the need for approval of imports. Currently, no tariffs are levied on wind turbine imports; however, significant duties may be reintroduced. The Dominican Republic has high tariffs that discourage imported technology; however, it also has industrial development policies. Its private investment incentives and Industrial Free Zones have attracted U.S. manufacturers; development of U.S. sales of wind/diesel technology in the Dominican Republic would benefit from a similar manufacturing presence.

Project bidding procedures may favor non-U.S. bidders. For instance, Greece is a member of the European Economic Community (EEC); and energy projects sponsored by the EEC open only to bids from member countries. The United States is not, however, excluded from doing business in Greece. Buyers who favor U.S. technology, such as the military, do exist. U.S. wind technology developers may also face established spheres of influence in parts of the world. For instance, the French have colonial connections to North Africa. Danish development efforts have included East Africa and India. European companies have a strong presence in South America (e.g., Daimler-Benz in Argentina). Japan's proximity to Pacific Rim countries gives it a potential geographical advantage that could lead to a lower cost of doing business. Japan has developed a broad technology distribution system for diesel engines and generator sets in the Pacific Rim region. The United States has a comparable advantage in the Caribbean.

Weak patent protection laws are often encountered in developing countries. China is a prime example of this potentially unfavorable situation. U.S. technology developers need to incorporate this risk into their plans for conducting business in such countries.

1.4.2 Barriers Specific to LDC and Remote Markets

LDC and remote markets lack the numbers of financially able and technically knowledgeable buyers found in developed economies. Thus, developers have difficulty in identifying interested buyers, even though the need for electric power is great. Major buyers will be donor agency mission directors in the country, responding to interest expressed by the host country, and the host country's government. Industrial and commercial (e.g., resort) developers represent a much smaller near-term market. The U.S. Department of Commerce (USDOC), through the International Trade Administration, offers assistance programs (e.g., trade missions and buyer identification services).

Buyer sensitivity to the capital costs of high technology often dampens interest in capital-intensive new energy technologies such as wind/diesel. Part of the problem is that some countries either lack or are unwilling to spend the hard currency (e.g., U.S. dollars or other convertible currencies) needed to buy U.S. technology. Ironically, "up-front" expenditures on wind/diesel technology could help such countries achieve even larger reductions in hard currency expenditures for diesel fuel purchases. China, the Dominican Republic, and Sudan are examples of countries with hard currency problems. In the past, up to 30% of the Dominican Republic's import expenditures have been for oil. One solution might be the use of barter transactions to overcome initial reluctance of the developing country to part with hard currency. Such transactions can be arranged by international trade companies. An example transaction would involve trading wind/diesel technology for a good manufactured in China, which is in turn sold to a consumer outside of China who can pay hard currency.

Diesel fuel and electricity price subsidies lead to an artificially low electricity price for diesel generation capacity. Developing countries often use subsidized prices to make electricity affordable, thus increasing the potential for rural development. Subsidized electricity prices paid by industrial and commercial users may encourage growth in those sectors and may benefit development of the country's infrastructure. Diesel fuel prices are heavily subsidized in Egypt and Sudan. The Dominican Republic lets its major utility purchase petroleum products at subsidized rates. In India, electricity prices for agricultural and irrigation uses are particularly low. Governments also could reduce the impact of diesel fuel expenditures on users by supporting wind/diesel technology (a fuel-saver). Subsidy funds could then be diverted to higher priority projects. Egypt is attempting to achieve fuel savings by stimulating renewable energy development. Donor agencies and regional development banks could assist developing countries with financial planning to assess the benefits of using wind/diesel technology to reduce energy price subsidies.

Incorrectly identified buyer needs may lead to a technology design that is more expensive than needed for the developing country. Wind/diesel systems should be designed for the power quality, reliability, and safety standards of these countries, which may result in a less expensive design than required in the United States or Western Europe.

Nontechnical users will probably be the primary wind/diesel system operators. System acceptance would benefit from a modular design that lets an operator with no technical knowledge remove and replace defective system components (e.g., use of color-coded parts and of packaged electronic controls). Donor agency programs designed to train nontechnical operators to maintain wind/diesel systems would be useful. Experience in LDC market acceptance of technology suggests that nontechnical users can become accustomed to a new technology over time. LDC users accept the "familiar" diesel technology, even if fuel use and maintenance are problems. In China, wind turbine technology has already gained a similar footing.

Weak commercial and manufacturing infrastructures in developing countries make it difficult to obtain local servicing and replacement of diesel technology, and wind technology servicing and replacement capabilities are even less likely to be well developed, except perhaps in China, where there has been experience with wind turbines. Developing countries usually lack the transportation infrastructure (e.g., roads, airports), communications systems, and financial services needed to maintain power generation technology, especially in remote locations. Japan has addressed this problem partly by selling diesel and gasoline engines and generator sets at prices low enough to make them very replaceable. They support the technology with a widespread distributor system.

Favorable financing from foreign donor agencies can put U.S. technology at a disadvantage. This problem area needs to be addressed by U.S. donor agencies, the Export-Import Bank, and CORECT. The World Bank, through the Energy Sector Management Assistance Program (ESMAP), does offer an avenue for financing energy projects that are smaller than the central station power projects that they have financed traditionally. Wind/diesel projects are candidates for ESMAP support.

Lack of bilateral trade agreements may hinder the sale of wind technology to countries with which the United States has not had a strong trade relationship. Such agreements between the United States and other governments are useful in promoting acceptance of U.S. technology. The recently adopted United States-Canada Free Trade Agreement is an example.

2.0 Wind/Diesel Hybrid Power Research

Current federally supported wind/diesel research includes (1) computer modeling of wind/diesel systems and (2) collection and evaluation of actual diesel performance data for model validation. Research topics have centered primarily on resolving problems with wind/diesel generation system stability under both grid-connected and non-grid-connected (stand-alone) operating modes. Nongovernment U.S. organizations involved in this research include Atlantic Orient Corporation, Northern Power Systems, and the University of Massachusetts (Amherst).

Research into the stability of small grids is critical to all types of wind/diesel applications and does not require large amounts of funding. Therefore, it is recommended that this area of study continue and be expanded to include development of necessary control electronics and strategies. These efforts, combined with the creation of software tools for optimization of system sizing and site-specific economic projections, should make it possible for industry to identify and design for opportunities on island and mainland small grids, remote private industries, military installations, and resort hotels.

Pursuit of the village electrification markets will require a more intense research effort, primarily because of the requirement for high reliability in a high wind penetration system. However, cooperative R&D programs with the wind industry could provide a valuable source of leveraged R&D funding. A logical first step would be to perform a preliminary study to establish the level of research effort required to produce a viable package system for village electrification, followed by a decision regarding longer-term commitments to research.

Finally, benefits from technical research supported by the U.S. Department of Energy (DOE) and industry will be significantly reduced if there are no parallel efforts to encourage such organizations as USAID to assist in conducting demonstration projects for the systems developed and to coordinate international market planning with the U.S. Export Council for Renewable Energy (ECRE) and other key export and renewable energy organizations.

2.1 Impact of Application-Related Technical Requirements on Research Priorities

Wind/diesel system technical requirements are dictated by the types of applications. The following discussion illustrates the variety of technical requirements for a broad range of applications. It does not cover low load, high power quality, high availability systems for such uses as remote telecommunications, since a growing commercial market is already being established (e.g., Northern Power Systems).

Wind/Diesel Package Systems for New Village Electrification

Package systems ranging in size from about 5 kW to 50 kW appear to have a large future market potential because of power market growth and the number of unelectrified communities worldwide. Package systems are attractive to the wind industry because product cost can be reduced by designing technology that fits the needs of many similar sites.

R&D/Design Considerations: Package systems must perform reliably in remote sites with repair or maintenance personnel who may not be skilled, achieve very high availability, and be low cost. The systems will probably require self-diagnostic and temperature-tolerant modular electronics, modularity in other subsystems, and short-term storage (e.g., flywheel storage of 5-10 minutes or batteries). Alternative turbine and tower designs must withstand conditions as diverse as dust and ice storms. Towers must be sectional, with only a four-wheel-drive vehicle required for erection. Furthermore, compromises in wind energy capture for the sake of a long, repair-free wind turbine life may be an overall cost of service reduction strategy. Batteries can provide effective energy storage in wind/diesel systems (e.g., Cape Clear, Ireland experience and systems provided by SMA Regelsysteme [Germany], EB Energi [Norway], and Chalmers [Sweden]). However, R&D is needed to decrease the cost and increase the performance of commercial battery systems that are suitable for the deep discharge cycles seen in wind/diesel service. Research areas include increased battery life, improved heat tolerance, and reduced power electronics cost.

Other village electric research requirements include: (1) investigate the effects of wind penetration on relatively small diesel generator systems and the resulting issues of power quality (system stability and voltage fluctuation), control hardware, and control strategy and (2) develop system sizing optimization software, based on system load characteristics and wind power distributions.

Applied village electrification research could lead to a DOE/industry cost-shared partnership to (1) develop, install, and test a prototype system and (2) extend the prototype experience to a geographically diverse range of demonstration projects. To demonstrate the technology in cold, remote-access conditions, a cost-shared venture could take advantage of the continuing interest that the Alaska Energy Authority (AEA) has expressed in wind and other hybrid systems to demonstrate a packaged or retrofit wind/diesel system for community power in an Alaskan village. Recorded data regarding system characteristics could be used for the validation of computer models currently being developed. The AEA has also expressed interest in intelligent power systems (e.g., United Kingdom Fair Isle wind/diesel system), which offer direct load control of appliances or give the user source and cost of energy data.

Alaskan applied research experience could be extended to other regions of the world. Research to solve icing and other cold climate problems could lead to marketing of both the technology and the expertise in dealing with cold climate markets. A DOE/industry cooperative venture (in consultation with USAID mission officers) could adapt the Alaskan package system for use in an LDC such as India. This type of joint effort attacks both technical and marketing problems and provides for immediate technology transfer to industry. The effort would be able to highlight differences in package system design requirements, other than climate-related, between India and Alaska. For instance, a very small, simple system may be acceptable in previously unelectrified Indian villages; but higher quality power is needed for applications requiring uninterruptible power supply (e.g., computers and telecommunications) and for villages with developed mini-grids (e.g., Canada and Alaska).

Wind Turbine Retrofits to Small Diesel Grids

This category includes the addition of wind turbines to both diesel generators for village electrification applications and diesel-electric water pumps. This application will face the same hurdles as package systems.

R&D/Design Considerations: Develop optimum configurations for an integrated wind turbine/diesel system with low cost, very high availability (skilled maintenance never required), and fair wind energy capture at moderate (Class 4) wind speeds; analyze the impact of high wind (or high turbulence) regimes or load curve shape variation on optimum system configuration; and develop wind/diesel systems that allow very high grid penetration of wind turbine electricity (to minimize diesel stop/starts) without adversely affecting grid stability. Additionally, improve control of the diesel gen sets in a wind/diesel system, possibly by adapting the system to incorporate mechanical governors. The requirement for high machine availability may be relaxed if it is feasible to train local technicians in system maintenance and repair. For example, the wind/diesel installation on the Taiwanese island of Que Moy is benefiting from local maintenance and repair expertise.

Wind Turbine Retrofits for Industries and Isolated Grids

Wind/diesel systems for private industries will have performance requirements that differ substantially from those for small community power applications. For instance, system frequency must be stable. Also, capacity ratings will be higher than for village electrification; and load curves for industrial operations will differ greatly from community power applications.

R&D/Design Considerations: The most economically attractive turbine retrofits will be in process industries that can store energy in the form of product (e.g., ice making, desalination, grain grinding and drying). Energy storage processes provide dump loads for wind turbines, thus reducing the impact of large turbine installations on grid stability. Development of control strategies for multiple diesel systems may be critical. If industry-specific applications are targeted, research should focus on one or two types of industries, dealing with some of the same questions that apply to village power systems and with investigation of industry-specific control strategies and hardware. For instance, research might address optimum system design (relative rotor and generator sizes, relative turbine and diesel sizes, minimum voltages) and operating strategy for a large reverse-osmosis desalination system or an ice-making facility.

Remote industrial or other large isolated grids may benefit from high penetration of wind turbines on the grid to reduce the amount of diesel fuel needed. Such grids must still provide electricity at a high availability factor. Thus, depending on wind availability, the generation system may switch frequently from diesel generation to wind generation. Research is needed to develop operating strategies that minimize diesel maintenance and extend diesel life under frequent start/stop conditions. Low wind penetration systems on stable grids with only fuel savings as their economic advantage are comparable to other utility-connected wind turbines that act as fuel savers and will not require much additional research. Research might be needed to meet the aesthetic requirement of large resort hotels (of several megawatts demand) that turbines be equipped with airfoils designed for low noise production.

2.2 Impact of Market Sector Potential on Research Priorities

Some knowledge of the nature of specific promising markets is needed to rank opportunities and determine research objectives. For example, if the high-priority markets are in Alaska or Canada, the program should conduct cold climate wind/diesel retrofit research. Similarly, a market focus on resort hotels would place research priority on high-reliability systems for warm climates. A choice not to focus on new village electrification because of the difficulty in getting project financing might shift research away from design and demonstration of packaged wind/diesel systems and toward research for ways to retrofit wind turbines to existing diesel generator sets.

Island Markets

Island markets have been the earliest wind/diesel markets pursued, largely because of high prices of diesel generation and good winds. Continued development of this large market will depend on the early reputation that wind hybrids establish.

Market-Motivated Research Direction: Focus on grid penetration and stability issues, system cost reduction, and reliability. Assess the research required to achieve economic system costs for many locations.

Remote Grid Mainland Diesel-Generating Capacity Owned by Utilities

The worldwide utility-owned diesel market amounts to thousands of megawatts. A large portion of this capacity is remote from national or major grids. System capacities range from a few megawatts to substantially larger. This opportunity is distinguished from that of islands more because of trade issues than technical considerations. For comparison, the installed diesel capacity in South Korea equals the total of that found in hundreds of islands; thus, it offers a much more concentrated potential trading market.

Market-Motivated Research Direction: Research issues are much the same as for the island and private industry markets. Addressing grid stability alone, through ongoing electrical systems applied research and through industry-cooperative development of appropriate electronics and control strategies, could make remote grids a viable wind option.

New Village Electrification

Markets for packaged wind/diesel systems are driven primarily by political and social realities rather than the economic forces of an open commercial market. Project funding will come primarily from development banks and international aid organizations, with cofinancing from commercial banks. The United States government, through USAID, offers one channel for facilitating village electrification. Because this type of funding is available, even LDCs with great financial difficulties are working toward rural electrification, though at various rates. An enormous market exists now in India; however, the Indian government is working rapidly toward self-sufficiency in photovoltaic cell supply. The Sudanese market will only develop if there is a substantial change in the political climate.

Market-Motivated Research Direction: Develop and demonstrate a very reliable package system that will be more attractive, where good wind resources exist, than other available alternatives (e.g., photovoltaics, micro-hydro). First, establish the technical feasibility of this effort. Use results of current R&D tests as the basis for a next-step study to identify potential conceptual designs and unresolved technical issues.

Wind Turbine Retrofits for Village Electrification

Wind turbine retrofits for village electrification represent a substantial market; however, market growth rates may be reduced to the extent that villages already have a modest amount of power. Government programs for power systems improvement in such villages will be less urgent than for new systems in villages with no electrification because of lower economic or political motivation. Priority is particularly low if the existing systems are already based on renewable energy technologies or other sources that do not require imported fossil fuels. Market opportunities are more likely in developed nations, such as those communities in Alaska and Canada that are not in extremely cold areas.

Market-Motivated Research Direction: Retrofit systems, including wind turbine and electronics, require research to address some of the problems caused by lack of control over the choice of diesel generator. Research in control electronics and strategies could put the United States in a position of dominance in the component and service market (e.g., a long-term Chinese market).

Village Electrification Hybrid Systems for Cold Climates

This market is smaller than others because of low population densities associated with the climate. The equipment market includes northern Alaska, Canada, and the Soviet Union. The Alaskan and Canadian markets of several hundreds of megawatts may not be sufficient by themselves to justify the expense of the research required. The Soviet Union may in the long term be an excellent market for sale of designs and joint ventures, electronics sub-systems, and expertise, just as they have purchased U.S. aerospace and computer technology.

Market-Motivated Research Direction: Power technology design requirements must include ability to withstand cold and icing conditions and the need for foundations suited to permafrost.

Retrofit Systems for Remote, Private Industry

Remote industry markets are a large and promising commercial market. Wind/diesel systems have already been installed in ice-making and desalination facilities. These types of industries are superbly suited to wind turbines because ice or other products can be produced whenever winds are highest, in effect storing energy in the form of the finished good. A related, smaller application is resort hotels (e.g., Egyptian Red Sea area, Greece, Dominican Republic). Industries, particularly in Greece, have shown a reluctance to commit to an unproven technology. Substantial market growth is expected as industry perceptions of wind change and as the systems are proven economically and technically.

Market-Motivated Research Direction: Technical problems are like those for island and other small grids. Low wind grid penetration opportunities will require lesser amounts of research related to grid stability. Because of the predictability of industrial power requirements, R&D for remote industrial applications could be widely applicable across international boundaries with little adaptation.

3.0 World Potential for Wind/Diesel Hybrid Applications (Task 1)

3.1 Assessing Country-Specific Wind Potential and Diesel Gen Set Markets

Task 1 of the wind/diesel market assessment used a two-step screening of countries throughout the world for market potential. This process resulted in the identification of 10 countries with high potential for wind/diesel market development, which were selected for more detailed market analysis in Task 2. Factors indicative of a potentially strong wind/diesel market were used to screen countries.

Preliminary Screen for Countries with Wind Potential of Class 5 or Greater -- This screen selected countries with at least a Class 5 wind resource (average annual wind speed between 6.0 and 6.4 m/s at 10 meters measuring height), enabling concentration on those countries with the best wind resource for wind/diesel systems. A table showing wind class to wind speed conversions is included in the Appendix. The wind resource assessment for each country was based on reported data and on discussions with researchers at Pacific Northwest Laboratories (PNL) about their country-specific data. Figure 3.1 shows that most countries have regions with wind potential of Class 5 or greater.

Secondary Screen to Target Markets with Diesel Gen Sets over 10 kW for Class 5 Countries -- This screen was based on data indicative of high wind/diesel market potential for each country passing the preliminary screen. Four variables were viewed as the most important indicators of wind/diesel market potential:

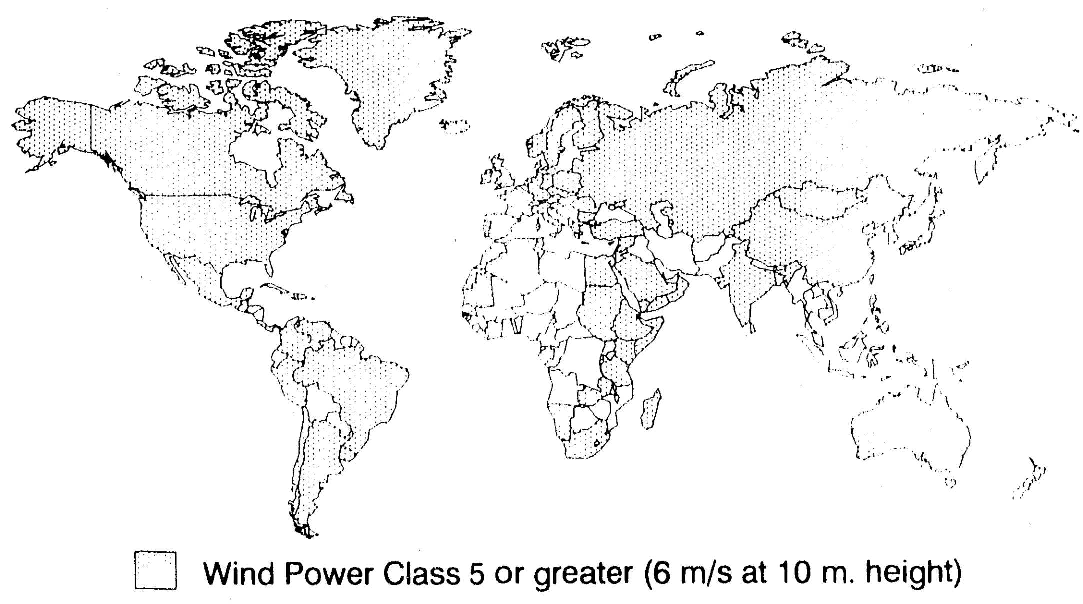


FIGURE 3.1: COUNTRIES WITH WIND POTENTIAL AREAS OF CLASS 5 OR GREATER

- Wind class -- Obtained for the preliminary screen
- Number of installed diesel gen sets larger than 10 kW
- Delivered diesel fuel cost
- Diesel market growth rate -- Historical growth rates were collected. Such rates are not critical in market analyses focusing on the diesel retrofit market; however, they are needed to assess market potential for the new village electrification market.

Electric energy cost was not included in the data base because electricity cost from a diesel gen set would be driven largely by diesel fuel cost, which was included in the screening. The data collected for these screens are presented in the Appendix.

3.2 Ranking Countries by Wind Energy Applications Potential

3.2.1 Ranking Methodology

Each country in the secondary screen was given a wind/diesel market potential score using the indicator data collected for the screening process. The data were converted into unitless standard normal Z statistics. The score was calculated by summing the four Z statistics for each country to form a single indicator of wind/diesel market potential. These scores are shown in the Appendix.

3.2.2 Countries Selected for Task 2 Analysis

Ten countries were selected for the Task 2 market analysis based on examination of the Z statistics as indicators of high market potential and on the country's ability to highlight important aspects of wind/diesel market potential. First, countries were ranked based on their total Z statistic score. High total scores indicated countries that had any combination of the indicator variables that were significantly above average. The ten highest ranking countries, in decreasing magnitude of the total Z statistic score, were India, Chile, Mexico, South Korea, Portugal, Argentina, New Zealand, Iceland, St. Lucia, and Spain.

Next, the individual Z statistic components of the total Z statistic score were examined to make certain that the total score did represent high wind/diesel market potential. This step was critical for three reasons:

- First, a country might not have been ranked as highly as possible because data were unavailable for certain market indicators (e.g., the number of installed diesel gen sets over 10 kW, delivered diesel fuel cost). Qualitative information available for such countries was used to justify their addition to the list. For instance, the People's Republic of China was added because of its large village electrification potential and its experience in wind turbine technology. Canada, the United States, and Greece were added based on qualitative information for installed diesel capacity and high fuel prices in specific remote markets.

- Second, the available data were not always accurate enough to provide the best indication of significant wind/diesel market potential. Data accuracy was affected by factors including lack of ranges on data such as fuel costs, fuel price subsidies that masked the true economic cost of fuel, and a single country estimate of wind class, which did not reflect the number of sites. The Dominican Republic and Egypt were added partly to recognize the higher ranking they would have had if the delivered diesel fuel cost had not reflected a subsidized price. Similarly, Sudan was added to reflect the reality of high fuel costs, fuel shortages, and significant need for village electrification. In the long-term, once the political situation in Sudan improves, its proximity to Egypt should enable it to benefit from development of the Egyptian market. Wind/diesel developers could establish a base market in Egypt, which has a better technical support infrastructure and more buyers with capital to invest. The developers could then pursue projects with Sudanese buyers. The Sudan is expected to have a slow growth market because of a lack of buyers with investment capital. However, World Bank data do indicate a 6% annual diesel market growth rate. Countries eliminated based on qualitative information included New Zealand (suspected low installed diesel generator capacity and high hydropower potential), Iceland (small population and large geothermal resource), Spain (small installed diesel gen sets capacity relative to grid extension potential), and Argentina (in favor of Chile's stronger economy).

- Third, St. Lucia, Portugal, and Mexico were eliminated because a high total Z statistic score was caused by one component variable with a very high Z statistic, while other component variable Z statistics indicated a potentially weaker market. St. Lucia and Portugal each have a high total Z statistic score because of a high delivered diesel cost; yet each country also has marginal or widely scattered wind resources and low installed diesel capacity relative to other countries. Mexico has a high installed diesel capacity that can be fueled by inexpensive indigenous oil resources and has limited total land area with high winds.

Figure 3.2 shows the 10 countries selected for Task 2 analysis.

Table 3.1 summarizes the major factors influencing country selection. The selected countries were chosen partly to help extend the market analysis to other similar countries. For instance, Alaska and Canada represent markets that are close to potential U.S. suppliers and are not subject to some of the trade restrictions that increase the cost of doing business in other parts of the world. South Korea represents countries that are newly industrialized and technically advanced. They have a growing need for reliable power in areas without grid access and possess the technical expertise to manufacture and maintain diesel generators and advanced power generation technology such as wind/diesel systems. The

Dominican Republic and Greece provide examples of island markets. Analysis of Chile's market is analogous to markets in Argentina and other South American countries. The People's Republic of China, Arab Republic of Egypt, and India represent developing countries that have the technical infrastructure to manufacture and maintain diesel systems. China already has experience in developing, manufacturing, and maintaining wind turbines. The Sudan exemplifies the poorest LDCs, which are targets of donor agency electrification programs.

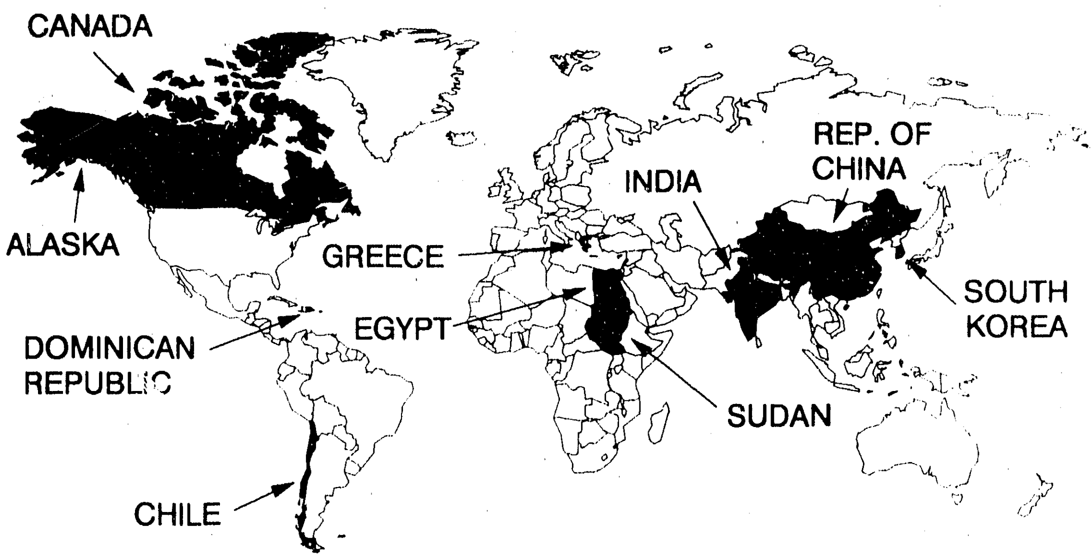


FIGURE 3.2: COUNTRIES SELECTED FOR TASK 2 ANALYSIS

TABLE 3.1: COUNTRIES SELECTED FOR TASK 2 ANALYSIS

Country	Major Factors Influencing Selection
Alaska	Class 7 winds in Aleutians and coastal areas; technically advanced; close to U.S. wind technology suppliers; no export barriers; high fuel costs; many diesel-supplied islands.
Canada	Class 7 winds; technically advanced; close to U.S. wind technology suppliers; remote areas with high fuel costs; government funding of wind/diesel research.
Chile	Class 5/7 winds on coast (up to Class 10 in southern Chile, including areas of off-grid capacity); 741 MW installed diesel generating capacity.
People's Rep. of China	Class 6/7 winds in Zhejiang, Shandong, and Fujian provinces of China; infrastructure to manufacture and maintain wind technology; large village electrification potential (4 GW); urgent need for electrical expansion to support commercial development; not practical to grid connect all areas.
Dominican Republic	Class 5/7 winds; island market; 200 MW diesel gen capacity; government encourages private power; close to U. S. wind technology suppliers; commercial development hindered by unreliable grid electricity and dependence on high-priced imported oil.
Egypt	Class 7 winds on Red Sea coast; infrastructure to manufacture and maintain diesels; historical diesel market growth of 10% per year; consistent government interest in wind energy, with funding available.
Greece	Class 5/7 winds on islands with diesel power; ongoing government-sponsored wind/diesel and other renewable energy projects; infrastructure to maintain wind turbines and diesel.
India	Installed diesel capacity of about 2 GW; about 145,000 villages need to be electrified (grid connection not feasible for many); technically advanced for design/production, but not remote maintenance.
South Korea	1158 MW installed diesel gen capacity; technically advanced; economically healthy.
Sudan	241 MW installed diesel gen capacity; unverified Class 4 and 5 winds in north and central Sudan; prime candidate for donor agency assistance; high fuel prices; diesel fuel shortages; 92% of population has no electricity.

4.0 Specific Application Requirements (Task 2)

4.1 ALASKA

ALASKA WIND/DIESEL MARKET SUMMARY

Opportunities:

- Village electrification: Alaska Energy Authority has strong near-term interest in wind/diesel systems applicable to the many isolated communities that help make up the state's 259 MW of installed diesel generating capacity.

- Military installation power: Wind turbine retrofits for diesel units serving remote military facilities.

- Private industry power: Large, unexplored market in mines, fish hatcheries, logging operations.

- Remote, high reliability power: Established market in small load facilities for military.

Advantages:

- Trade environment: No export barriers, close to U.S. mainland, no capital repatriation problems.

- Wind resources: Very good wind regimes in coastal and mountainous areas, and islands (Class 5-7).

- Power environment: High installed diesel gen set capacity, high fuel costs.

Disadvantages:

- Wind/diesel system operation: Icing and other potential climate-related problems need to be addressed. Research needs to be conducted into system configurations for small villages that may include load control strategies and modular components to reduce potentially high operating and maintenance costs.

4.1.1 Wind Resource Characterization

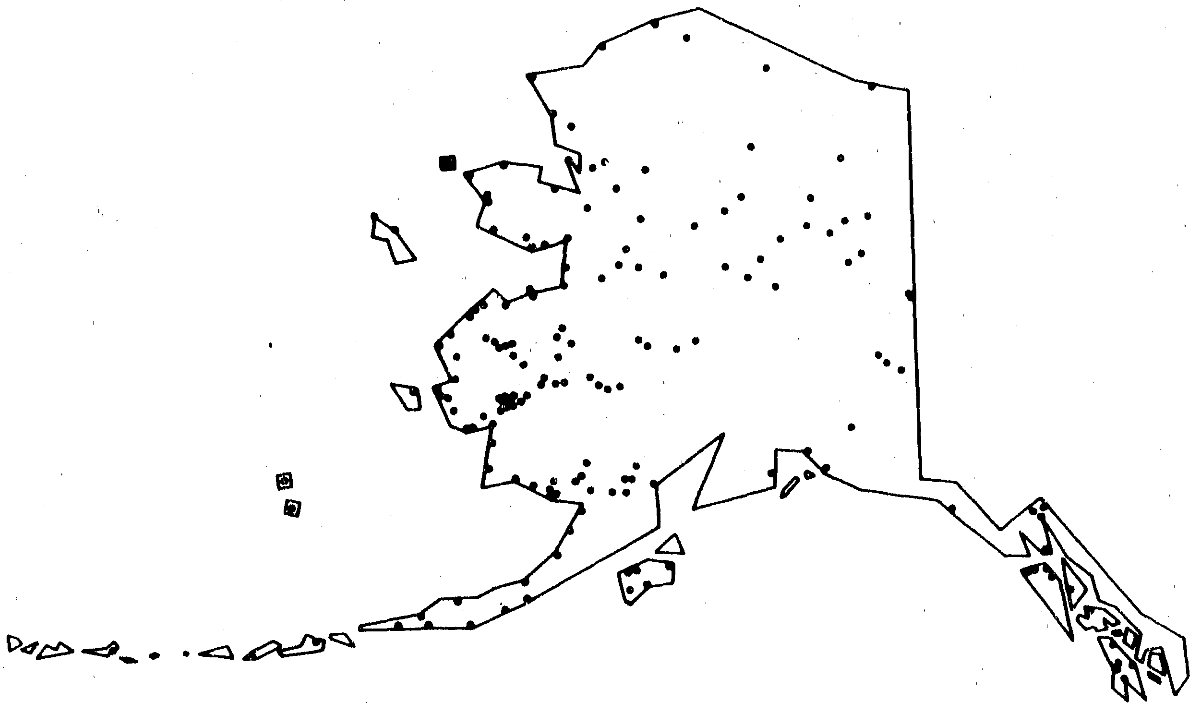
Average annual wind speeds in Alaska range from Class 1 to Class 7. Most areas of high winds (Class 5 or above) are found along the coast and on islands. Additional high wind resources are found in interior mountain ranges and some mountain passes. Seasonal curves for these areas show peaks in the winter at most locations. Diurnal curves are quite flat; winds are relatively constant and high on an hour-by-hour basis. Southwestern Alaska shows a slight midday peak.[2-1]

4.1.2 Market Opportunity: Village Electrification

Opportunity Description: The largest market in Alaska, near and long term, consists of village electrification applications (package and retrofit wind/diesel systems) for the utilities that participate in the Alaska Energy Authority's (AEA) Power Cost Equalization (PCE) Program. Since eligibility for this subsidy program is contingent upon a local utility producing at least 75% of its electric power by means of diesel generators, all 170 affected communities (Figure 4.1.1) are potential candidates for wind/diesel installations or retrofits.[2-2] About 100 of these communities are situated in areas having winds of Class 5 to Class 7. Figures from the Energy Information Administration (EIA) show the total installed diesel generating capacity for Alaska to be about 259 MW.[2-3] A significant portion of this capacity is likely to be found in these approximately 100 communities, which represents a significant market for retrofit of wind turbines within the existing system.

An increase in electrical energy consumption of about 10% occurred between 1987 and 1988 for all the PCE utilities. The growth in consumption may lead to demand for new generating capacity, which could be satisfied by package wind/diesel systems. Economics for wind/diesel look promising, with high winds and 1988 fuel costs ranging from $0.62/gallon to $2.48/gallon (weighted average of $0.97/gallon). Average (not weighted) cost of electricity was roughly $0.22/kWh.[2-2]

Project Funding and Contacts: Fossil energy subsidies are most often considered detrimental to the economic viability of a renewable energy project. In this instance, they work in favor of wind/diesel funding because the subsidizing agency, rather than a multitude of small utilities, is the proposed key player for wind/diesel project initiation and financing. The incentive to the AEA would be the future reduction of fossil power subsidies, which amounted to about $17 million in FY 1988. In fact, the AEA has already demonstrated interest in hybrid systems, having sought vendors in 1987 for the installation of a wind/diesel system to provide power for the island community of St. Paul, in the Pribiloff Islands. Having received no response from the wind industry, the program was canceled. Interest in hybrids remains, and there are plans for installation of smaller wind/photovoltaic/diesel systems with battery backup at remote fly-in sites. The AEA is actively seeking ways to help the local utilities to reduce their power costs, including waste heat recovery and a few micro-hydro projects.[2-4]



ALASKA

Power Cost Equalization Program (170 Communities)

Figure 4.1.1

Source: Alaska Energy Authority

Existing Power Environment: Although the PCE program requires only 75% of the utilities' generation to be produced by diesel units, the amount of diesel as a percentage of installed capacity for all the utilities is much closer to 100%. Diesel units vary greatly in size, manufacturer, and operating efficiencies. They include U.S., Japanese, Chinese, and popular German air-cooled generators. Table 4.1.1 details the size ranges found, indicating that a large number of machines are rated at 151-300 kW and greater than 1 MW. The largest plant noted was 6.5 MW. Several market characteristics derive from the sale of a variety of makes of diesel generators. First, the likelihood of being able to arrange sales and maintenance of wind/diesel systems through some existing diesel manufacturers or distributor networks is high, because there are so many different companies selling in the area. However, growth of the wind/diesel market may require contacts with several diesel manufacturers, since no diesel manufacturer has a monopoly on the market. Finally, retrofit applications may have to be tailored to the specific micro-grid in a number of instances to assure that the generation systems are optimized for a specific make and size of diesel. Package wind/diesel systems would be less subject to this constraint.

Table 4.1.1
Utility-Operated Diesel Generators
in Alaska by Capacity in 1988

Nameplate Rating Range, kW	# Installed Units
71 - 150	49
151 - 300	114
301 - 500	28
501 - 1000	39
> 1000	84

Source: Energy Information Administration

Operating conditions vary tremendously. All plants are owned and operated by the local electric utilities. While the larger facilities in the more populated areas have full-time maintenance staff, the smaller typical sites will employ only a part-time operations person, perhaps two hours per day. The common utility procedure of contracting out major maintenance and repair to firms located in the larger urban areas results in extraordinary O&M costs because of the transportation and labor involved. In some villages, not only maintenance personnel but also fuel is delivered by air. The lack of on-site skilled personnel has other less immediately felt, but serious effects. Power quality tends to be very poor, costing the State of Alaska about $5 million per year in repair to state-owned equipment.[2-2] Dramatic excursions in voltage cause problems such as damage to airport runway lighting, a serious hazard in a community dependent on air transport for all supplies. Reliable wind/diesel installations that improve power quality would win strong praise.

Although the norm is to find one diesel generating system supplying power to the village, it is not unheard of to see two sets operating independently. The town of Allakaket in the northern interior of Alaska, for instance, has a dedicated generator for the school, which is owned and operated separately from the unit serving the remainder of the village. Typical loads might be, in a smaller village, peaks of 60 kW with a generator set rating of 85 kW. This might represent about 250 kWh per month per household. Load curve data logged at 15-minute intervals is currently being collected for interior Alaskan villages by the AEA and Sandia National Laboratories for CORECT. They anticipate gathering data from 14 villages. In smaller villages, the load curves may be dominated by one or two loads, such as a 20 kW electric range in the school building. Possible controls of loads of this nature are being considered under a $350 thousand AEA load management program.[2-4] The availability of good quality load curve data and the possible preexistence of load control should be a boon to wind/diesel system installers.

Potential Wind/Diesel System Description and Operating Strategy: The nature of the electrical energy use in the Alaskan villages and the efforts in load management being exerted by the AEA immediately suggest a wind/diesel strategy that includes direct control of key loads. Relevant loads may be easily identified by use of the load curve data that will have been gathered. Given the relatively flat diurnal wind speed curves in some locations, it might be possible, with short-term (5-10 minutes) flywheel, hydraulic, or battery storage, to keep a diesel generator (in a multiple diesel system) off-line for significant periods of time if major loads were assigned priorities and coordinated appropriately. Dump loads for fixed pitch wind turbines, such as space or water heating, should not be difficult to locate.

The likelihood of success in preventing frequent use of the diesel generator would be heightened by consideration of a system similar to that used in the United Kingdom on Fair Isle. There, consumers are given an indication of the source and cost of the energy they are using and can make decisions on appliance use on the basis of that information. Additionally, they have a set number of hours of guaranteed power per day, which can insure diesel generator shutdown for a number of hours daily, in good winds. In Alaska, if the existing diesel system is undersized for the loads, the wind turbine may be considered to have some significant value in added capacity because the winds appear relatively constant on an hourly basis. Wind/diesel systems will be viewed even more highly if they can demonstrate added benefit in the area of grid stability, an area of particularly great concern in Alaska.

Maintenance and repair issues in Alaska, as in other remote villages around the world, could be addressed by smart performance monitoring systems and modular design of system electronics and other components. The system can then, with semiskilled maintenance personnel and telephone calls to the system supplier, help keep availability high without the field visits that could easily negate the economic benefits of a wind turbine.

4.1.3 Market Opportunity: Military Installation Power

Opportunity Description: Some military facilities in Alaska, independent from grids as a result of their location, constitute an attractive market for (1) retrofit of wind turbines to existing diesel systems and (2) installation of high reliability micro-hybrids at the smaller remote facilities. Good examples of the former are the Coast Guard bases on Kodiak Island and Adak Island in the Aleutian Islands.[2-5] These markets have several distinct advantages: short-term opportunities, reliable funding, and availability of skilled personnel for O&M and data collection.

Project Funding and Contacts: If capital costs of wind/diesel projects for larger base power supply can be justified on a lifecycle cost basis, funds should not be a major problem. The funding for smaller, high reliability installations should be even less of a problem, given their critical nature.

Initial funding and project leadership for demonstration programs may be found in such groups as the Naval Civil Engineering Laboratory, the Air Force Engineering Services Center, or the U.S. Army's Construction Engineering Research Laboratory (CERL). CERL is currently involved in small load photovoltaic/wind hybrid research, and personnel there indicate an interest in seeing wind hybrid systems operating on bases, but they are more oriented and immediately interested in systems designed for high reliability remote communications applications.[2-6] The initiative for installation of a larger system on a military base might better come about through a joint effort of the military research laboratory and the base energy engineer, with project financing (in the $100 thousand range) provided through standard base operating funding.

4.1.4 Corollary Opportunities

Excellent opportunities in the remote community power market in Alaska and an established market in remote telecommunications imply similar possibilities in northern Canada. This is indeed the case, with an even more recently open market in Canada because of the Free Trade Agreement and similar populations, infrastructures, and climates. Assuming established technology and package wind/diesel systems for community power, other potential markets for similar systems, design/consulting agreements, or joint ventures include the Antarctic and the Soviet Union.

4.2 CANADA

CANADA WIND/DIESEL MARKET SUMMARY

Opportunities:

- Village electrification: Estimates of as much as 500 MW of installed capacity in 300 communities.
- Private industry power: Mines, fish hatcheries, and logging operations use remote power to tap Canada's three top resources.
- Remote, high reliability power: Market for small load hybrid facilities for military use.

Advantages:

- Strong government interest: Wind/diesel 35% of wind research budget for FY 1987/88.
- Excellent trade conditions between United States and Canada.
- Class 4 to Class 7 winds over most of country, with high average winds along all coastlines.
- Many remote areas with high fuel costs.

Disadvantages:

- Competition from Canadian wind industry, with growing expertise in wind/diesel systems.

4.2.1 Wind Resource Characterization

Average annual wind speeds along both the Atlantic and Pacific coasts are uniformly high: Class 4 to Class 7. Class 4/5 winds are commonly found in the western half of the country on ridge crests in the Great Plains north of the U.S. border. Class 5/7 winds are indicated for the Hudson Bay area and much of the far north.[7-2] Although not necessarily representative of diurnal wind speed variations around the country, wind speeds in northern

Ontario (represented by data logged at the Fort Severn wind/diesel system) appear to vary significantly on a diurnal basis.

4.2.2 Energy Market Characterization

Canada has substantial coal, petroleum, and natural gas resources. Hydropower contributes a significant portion to the total electricity capacity of 100,737 MW.[1-2] The breakdown of installed diesel units by size given in Table 4.2.1 indicates the range of 1984 installed diesel capacity for prime power applications would be from about 100 - 200 MW.[9-3] The same source predicted that installed diesel capacity would increase by about 30% by 1990. Another source stated in 1987 that 800 remote diesel generator units with a total installed capacity of about 350 MW supplied electricity to 290 villages.[3-6]

Figure 4.2.1

Canada's interest in renewable energy is substantial. Hydropower is the most prominent of the renewable energy resources. The James Bay C$7.5 billion hydroelectric project is one of a series of hydro projects in Canada's ongoing expansion. Funding for wind/diesel research is expected to be about one-third of the FY 1990 wind budget, showing the commitment to the technology. Ontario Hydro is continuing to collect data from its demonstration wind/diesel facility at Fort Severn, with the participation of the Canadian Department of Energy, Mines and Resources (EMR), the Ontario Ministry of Energy, and the Canadian Electrical Association. The Northwest Territories (NWT) Power Corporation is scheduled to soon take over operation of the Cambridge Bay installation (whose funding was assisted by EMR), consisting of four 25-kW turbines on the local diesel grid. Two wind/diesel test beds are being funded, one at the Atlantic Wind Test Site by EMR and the Institute of Man and Resources and one by EMR and Hydro Quebec at the latter's Varennes site.[3-4]

Table 4.2.1
Diesel Generating Sets in Canada
by Size and Capacity, 1984

Application	Rated Power (kW)	Inst. Units
Prime Power	to 5	26
	5.1 - 30	1333
	31 - 70	317
	71 - 150	269
	151 - 300	167
	301 - 500	39
	501 - 1000	17
Compact Portable	to 5	107
	5.1 - 30	445
	31 - 70	0
	71 - 150	0
	151 - 300	0
	301 - 500	0
	501 - 1000	0

Source: Power Systems Research

4.2.3 Business Conditions

Canada is the United States' largest trade partner, with imports from the States of over $60 billion in 1987. The United States provides 70% of their imports and purchases 78% of their exports. With the implementation on January 1, 1989, of the U.S./Canada Free Trade Agreement, relief from all tariffs to both goods and services is guaranteed in the future as existing tariffs are reduced each year for select goods until all tariffs are removed by 1998. The agreement also streamlines border-crossing procedures for professionals and other visitors on business.[3-2] Canada has consistently, in the last half dozen years, had one of the strongest economies among the OECD (Organization for Economic Cooperation and Development) countries. It grew at a rate of 4.5% in 1988. The outlook for U.S. exports to Canada is expected to remain good.[3-3] Canadian import of diesel generator sets was predicted in 1985 to increase by more than 80% by 1990 to over 7000 units, the majority between 5 and 30 kW.[9-3] The Foreign Credit Insurance Association (FCIA) and the Export-Import Bank are imposing no special conditions on export credit insurance for Canada.[1-3]

Representatives from the wind industry have characterized the market for hybrid systems in Canada as very promising, second only to Alaska, because of the opportunities both in private industry and in village electrification and because of the few trade, geographical, and cultural barriers U.S. firms would need to overcome.

4.2.4 Market Opportunity: Village Electrification

Opportunity Description: Canada is the second largest nation (in area) in the world, and over 80% of its population is concentrated within about 100 miles of the U.S. border. Many regions will be remote enough to justify exclusion from the national grid on a long-term basis.[1-2] The potential market for village electrification may be several hundred megawatts. The Northwest Territories (NWT) are a good example of a potential (although relatively small) wind/diesel market: it is remote from the national grid, with a population of only about 52,000 and one-half of its land in very good wind regimes. Average costs throughout northern Canada are about C$0.36/kWh, with some community costs exceeding C$1.00/kWh. Hydro-Quebec estimates that for the average wind speed expected in northern Quebec Province, 54% of the fuel used to produce electricity could be displaced by wind energy in an optimum wind penetration case.[3-6]

The Cambridge Bay Wind Energy Conversion System, a joint effort of the Northern Canada Power Commission and the Remote Community Demonstration Program of Canada EMR, is an illustration of the appropriateness and viability of such a system in the far north, although it may be argued that it does not qualify as a true wind/diesel hybrid system because the wind turbines supply only up to 10% of the community load. In that community, electricity costs were about C$0.40/kWh, with winds of Class 7. The utility, now the NWT Power Corporation, has the perspective that "wind power in the north holds no great challenges" and that "the only hurdle that remains to more widespread implementation is one of economics."[3-5] They explain the latter statement to mean that standardized commercial systems with the lower costs associated with increased experience and production will make wind/diesel hybrid systems economical. It is significant to note that the turbine manufacturer for this system was a U.S. firm (Carter Wind Systems, Inc.).

Project Funding and Contacts: Government subsidies to remote utilities represent a barrier to direct sales of wind/diesel systems to the utilities. As in Alaska, because of the subsidies, the incentive for implementation for a renewable energy program is transferred to a central entity, the federal government. Because the utilities and they have maintained interest in wind/diesel, EMR Canada and the various utilities would appear to be a promising contact for an expanded program of installations, if the economics could be demonstrated.

Existing Power Environment: The entire Canadian far north, including all of the NWT and many northern parts of the southern provinces, is removed from the national power grid. The Fort Severn wind/diesel installation, for instance, is located 500 miles from Ontario Hydro's nearest transmission lines. Remote diesel plants vary from 100 kW to 50 MW. Electricity costs are high, averaging C$0.36/kWh. The capacity factor averages just over 17%. The distribution of sizes can be seen in Table 4.2.1. A load curve example for Fort

Severn for April is shown in Figure 4.2.2. Average load for this community of 300 is about 80 kW, with peaks of about 110 kW occurring just before local noon.

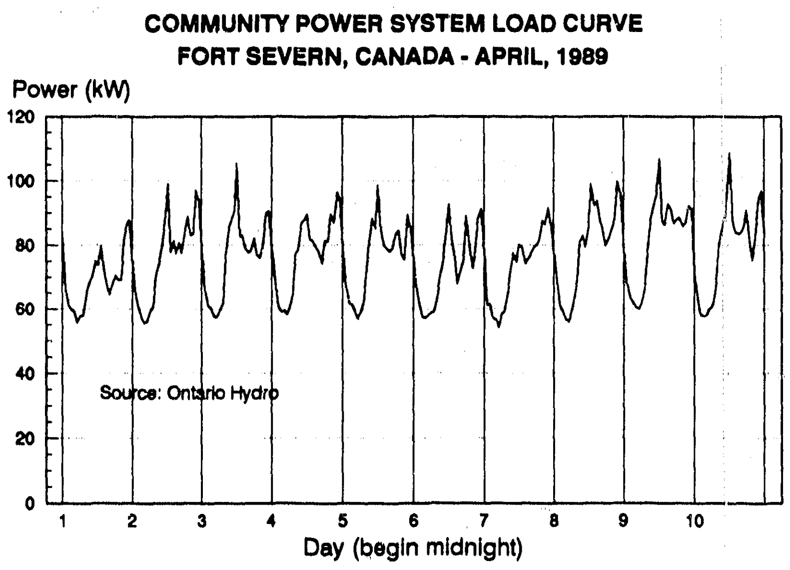


Figure 4.2.2

Potential Wind/Diesel System Description and Operating Strategy: Desirable system size is reported to be 100 kW and under,[9-7] a useful limitation in that it may lead naturally to a standard package system size. Systems will have essentially the same parameters as those operating in Alaska, with specifics varying according to local wind conditions. Generators could be oversized for high wind power (denser air or higher wind speeds than in more southern latitudes). Maintenance and repair issues in Canada, as in Alaska, could be addressed by smart performance monitoring systems and modular design of system electronics. The system could then, with semiskilled maintenance personnel and telephone calls to the system supplier, maintain high availability without field visits. As in the wind/diesel demonstration program at Cambridge Bay, the logical choice for maintenance (as well as initial installation) personnel would be local electricians, mechanics, and other technicians.

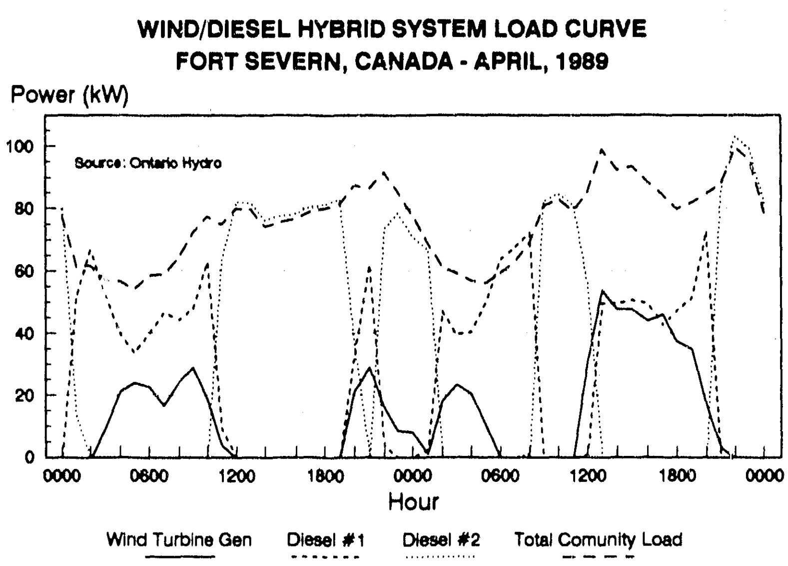


Figure 4.2.3

In regard to operating strategy and expected savings from the wind turbine in Fort Severn, Figure 4.2.3 shows that although significant amounts of diesel fuel were diverted, the turbine did not reduce the peak load experienced during the two days depicted which were typical for that month. That is, from a utility perspective, plant capacity requirements were not reduced. The vagaries of the wind, the nature of the community load (high base load), and the wind/diesel system design (relatively small turbine and practical, simple controls) also prevented all diesels from being brought off-line simultaneously, even though the system is considered to have a high wind power penetration.[3-7] For retrofit installations such as this, there are no simple ways to change this operating mode. However, for communities whose increasing demand requires additional diesel units, there exists the possibility of sizing the new units so that the wind turbine input brings one of the diesels off-line a majority of the time while the remaining unit operates near peak efficiency. In summary, although the system at Fort Severn proved quite effective in reducing fuel consumption, the most economical systems in the future could have even higher penetrations and be placed where local wind and electric demand peaks come closer to coincidence.

4.2.5 Market Opportunity: Private Industry Power

Opportunity Description: Mining operations that are under expansion or rehabilitation and are remote from electric grids may constitute a substantial market. Canadians mine or drill large quantities of zinc, copper, lead, molybdenum, gold, iron, nickel, potash, coal, oil, and natural gas. These mining operations have played a critical role in Canada's development. Over one-quarter of the work force is employed in the industrial sector. An example of a potential opportunity is Inco Ltd's C$100-million plans for expansion of nickel mining operations in northern Manitoba.[3-3] If sites are near the Hudson Bay area, the Class 4 and 5 winds may make wind systems look attractive. Economic expansion in British Columbia is expected to continue, with increases in mining capacity providing a significant portion of the growth.

In the near term, some other industries do not look as promising as mining. Wood exports have fallen significantly from 1987 levels, meaning that in the near term less capital may be available in the lumber industry for investment in projects such as wind turbine retrofits. In the fishing industry, reductions in allowable catches combined with lower prices will result in reduced revenues for the Atlantic coast provinces in the short term. However, because refrigeration is so appropriate a load to wind turbines, hybrid systems serving the fishing industry along the coasts, where winds are excellent, should prosper in the long term.

4.2.6 Corollary Opportunities

Alaska has been previously discussed as having nearly identical conditions to Canada in many ways. Similar climates, communities, and industries will be found in the Soviet Union and mainland China. Even if the direct sale of equipment to these countries is limited, the opportunity to sell system designs and provide services is enormous.

A joint diesel generator operation study between the University of Alaska and Brazil has demonstrated great similarities between small community power systems in the two countries. This suggests that the basic design and operational experience gained in the installation of wind/diesel systems in Canada and Alaska will be readily transferred to village power applications in many other areas of the world.

4.3 REPUBLIC OF CHILE

CHILE WIND/DIESEL MARKET SUMMARY

Opportunities:

- Remote utility power plants: Utility diesel generating capacity over 100 MW, with excellent winds in the southern areas that are not served by an electric grid.

- Private industry power: Total diesel capacity of perhaps hundreds of megawatts; copper industry alone accounts for 50% of export revenues.

- Water pumping: Both inexpensive and large volume pumping systems in demand; agriculture is a growing mainstay of the economy.

Advantages:

- Wind resource: Most areas of southern Chile have winds of Class 5 and greater.

- Economic status: Growing and healthy economy, with stabilizing political situation.

Disadvantages:

- Hydroelectric power: Still much undeveloped hydroelectric capacity, and possibility of competition from mini-hydro in remote areas.

4.3.1 Wind Resource Characterization

Wind regimes of Classes 5 to 7 are found along most of the southern coast of Chile, with areas in the far south of the country having winds of up to Class 10.[7-2]

4.3.2 Energy Market Characterization

Chile's energy resources consist of small oil reserves, moderate quantities of natural gas, and very large coal reserves. In addition, the country has great hydroelectric potential. In 1986, hydroelectric represented over two-thirds of the country's total generating capacity. Still, there are significant hydro resources that remain untapped. Three-quarters of the electricity in Chile was generated by public utilities in 1983, with the remainder produced by industrial and mining operations.[4-2] Total utility capacity in 1988 was 3987 MW.[1-2] The transmission and distribution systems consist of two main grids, the primary Central Interconnected System and the Norte Grande in the far north. These two cover the majority of the country, except the southern third. Isolated capacity in this region is about 45 MW.[1-1]

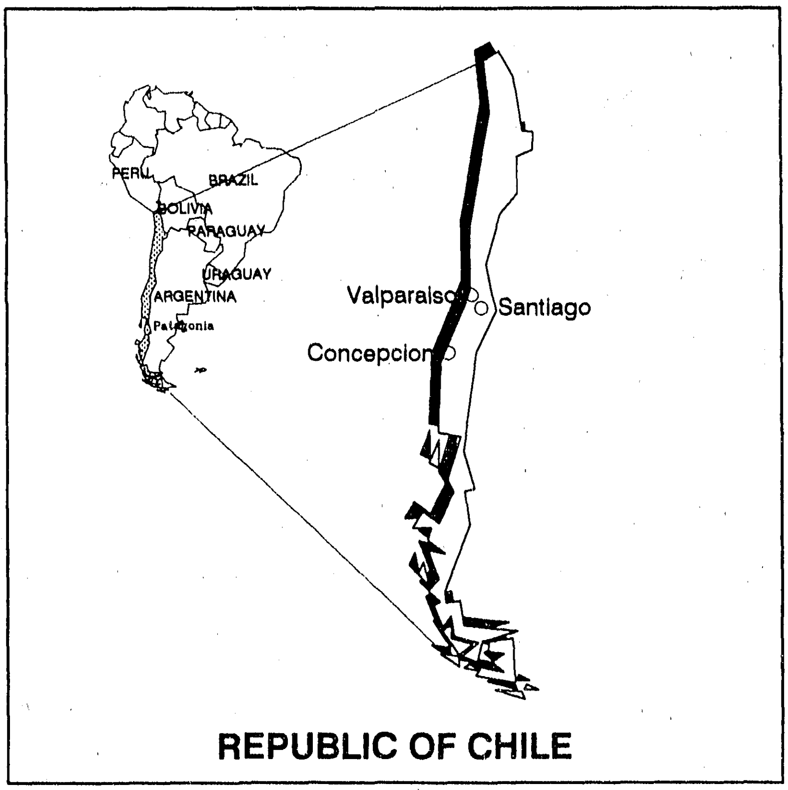


Figure 4.3.1

Utility-owned diesel generating capacity is over 100 MW. A significant quantity of privately produced electricity from thermal sources is probably from diesel generators, with likely capacities of hundreds of megawatts. Some of this is isolated from the grid, while many times there is grid interconnection, with private industries buying from, and at certain times of the year selling to, the utilities. This means that the opportunities for diesel-connected wind turbines are varied. The turbines could be either connected to a grid and owned by a utility or an industry or isolated and owned by a utility or industrial firm. Wind energy will face its strongest competition from hydroelectric facilities. The most promising areas for wind/diesel may be where diesels are in use, but demand is not great enough to justify the installation of a hydro facility and mini-hydro is not feasible. Alternatively, wind/hydro hybrid plants are another opportunity for wind energy application.

Wind energy is not unknown in the country; entrepreneurs in rural Chile are leasing small wind generators for battery charging. The renters of the equipment are among the 10% of the population that have no other source of electricity.[4-3] There are also more technically advanced efforts. The Universidad Tecnica Federico Santa Maria in Valparaiso has designed and constructed a Darrieus and a 25 kW horizontal axis machine. Energia Andina has constructed prototype wind turbines from designs of the Universidad de Concepcion and is ready for manufacture of 3 kW to 30 kW units. Other groups are working on wind turbines of up to 50 kW.[4-1] Chile was represented at the 1989 Wind Energy Applications and Training Symposium by a professor in the Electrical Engineering Department at the Universidad de Chile in Santiago.

4.3.3 Business Conditions

The recent history of Chile has been one of political instability. However, most recent trends have been toward a more stable government and officials at the USDOC confirm that trade relations and general conditions look promising. The country's economic growth has been good: 6.8% in 1988. Unemployment and inflation have decreased in the last eight years.[1-2]

The FCIA and the Export-Import Bank are imposing no special conditions on export credit insurance for Chile.[1-3] Chile is not included in the programs of OPIC.

4.3.4 Market Opportunity: Remote Utility Power

Opportunity Description: Chile's two largest utility companies are in the process of selling a number of their small companies that use diesel generators.[1-1] In spite of subsidization of fossil fuels, some U.S. wind industry representatives believe that these smaller companies will realize the positive economics associated with wind turbines as opposed to remote thermal generation and distribution. Wind regimes are excellent in the same southern areas that have only isolated power facilities. This makes prospects for wind/diesel excellent, depending on the competition from mini-hydro facilities. This also assumes that turbine designs can remain relatively trouble free in the high wind (high turbulence) regimes.

An attractive non-wind/diesel opportunity is the potential for wind farm development for connection to the Central Interconnected System, to replace thermal generation, with excellent winds along the coast served by the grid. Of course, the problem of utility subsidies has to be dealt with in evaluating economics.

4.3.5 Market Opportunity: Private Industry Power

Opportunity Description: The application of wind turbines to the private sector's generating facilities is similar to that for the utilities, the primary differences being that diesel generating capacity for mines and industries appears to be substantially larger than that of the utilities and the ability for the industries to finance wind/diesel projects may exceed that of the utilities. Even during recent slumps in the mining industry, copper accounted for over 50% of the export revenues.[1-2] Between 10% and 15% of the electricity generated in Chile by either utilities or industry is produced by the Corporacion Nacional del Cobre-Chile (CODELCO). Other major energy producers are the cement and saltpeter industries. This sector is being supported by a World Bank project providing $75 million in long-term financing to industry.[1-4] Of course, not all self-producers are necessarily removed from the grid. Many are grid connected and may sell electricity back to the government.

4.3.6 Corollary Opportunities

Argentina stands out as perhaps even more promising than Chile, in some respects, for wind/diesel applications. U.S. wind industry contacts have been very positive about the possibilities, citing the excellent wind regime and U.S. business activity in the region. One estimate is that 90% of Patagonia contains at least Class 5 winds. Populations in these good wind areas are higher than those in Chile, as well. Problems with power reliability in the country could be a major incentive for the development of wind energy. There are a number of wind energy projects under way in Argentina. The State of Chebut, in particular, is promoting the use of wind turbines. This state operates 62 diesel-electric facilities totaling 8.4 MW, with sizes varying from 20 kW to 1.3 MW.[4-1] Estimated electricity costs are as high as $0.50/kWh. A major drawback to the marketing of wind/diesel systems in Argentina, however, is the extreme economic situation. Economic growth has slowed, inflation in recent years has reached into three figures, and external debt has doubled since 1978.

4.4 PEOPLE'S REPUBLIC OF CHINA

PEOPLE'S REPUBLIC OF CHINA
WIND/DIESEL MARKET SUMMARY

Opportunities:

- Telecommunications: A national priority, covering investment in long-distance telecommunications, defense communications, television broadcast networks, and navigational aids.

- Industrial power: Need for dispersed power systems, potentially owned by industry, that increase electricity supply and improve reliability.

- Village power: Western China currently has no access to the electricity grid and does have good wind resources.

- Water pumping: Shortages of diesel fuel, coupled with current use of Chinese wind turbines, indicates that there may not be large usage of diesel-electric pumps.

Advantages:

- Chinese have a long history of familiarity with wind energy systems, especially for remote water pumping. They have experience in developing, manufacturing, and installing wind turbines.

- China needs electric generation technology that can be rapidly deployed to reduce electricity shortages. China also needs generation technology that will improve system reliability. China's installed capacity is growing -- about 103 GW in 1987 (World Bank) to 110 GW in 1988.[1-2] In 1988, per capita electricity consumption was 480 kWh.[1-2]

Disadvantages:

- Potential exporters of U. S. technology may face Chinese reluctance to spend hard currency. This hurdle can be overcome by using several strategies: advantageous financing, barter agreements, technology transfer agreements, joint ventures.

- Bringing business deals to closure requires time and patience.

- Patent protection laws are weak.

4.4.1 Wind Resource Characterization

Provinces with annual average wind speeds of 5 to 8 m/s at 10 meters hub height (Classes 3 to 7) include Zhejiang, Shandong, Fujian, Liaoning, Inner Mongolia, and Jiangsu.[5-5, 5-11] These areas encompass terrains including

- Seacoast (southeastern China: Fujian, Zhejiang, Jiangsu, Shandong, and Liaoning). The strongest winds are in the fall and winter for Fujian and Zhejiang and the winter and spring for Shandong and Liaoning.
- Prairies (Inner Mongolia and Gansu province). Strongest winds in spring, with winter being next best. Annual mean wind speeds are reported to be between 4 and 5 m/s for Mongolia, with 5 to 7 m/s in the best areas.
- Songhuajiang river valley ridges (Heilongjiang province). Strongest winds in winter.
- Ridges and mountain passes of interior China (Anhui, Hubei, Hunan, Guizhou provinces). The Xinjiang Autonomous Region (western China) has good wind in mountain passes because of a combination of desert basins and mountain ranges.

Table 4.4.1
Energy Consumption in China
(Percent of Total)

Coal	56
Biofuels*	25
Oil	14
Hydroelectric	4
Natural Gas	1
Shale Oil/Geothermal	Negl.

* Firewood, charcoal, crop residues, and animal wastes.

Source: World Bank, 1989

4.4.2 Energy Market Characterization

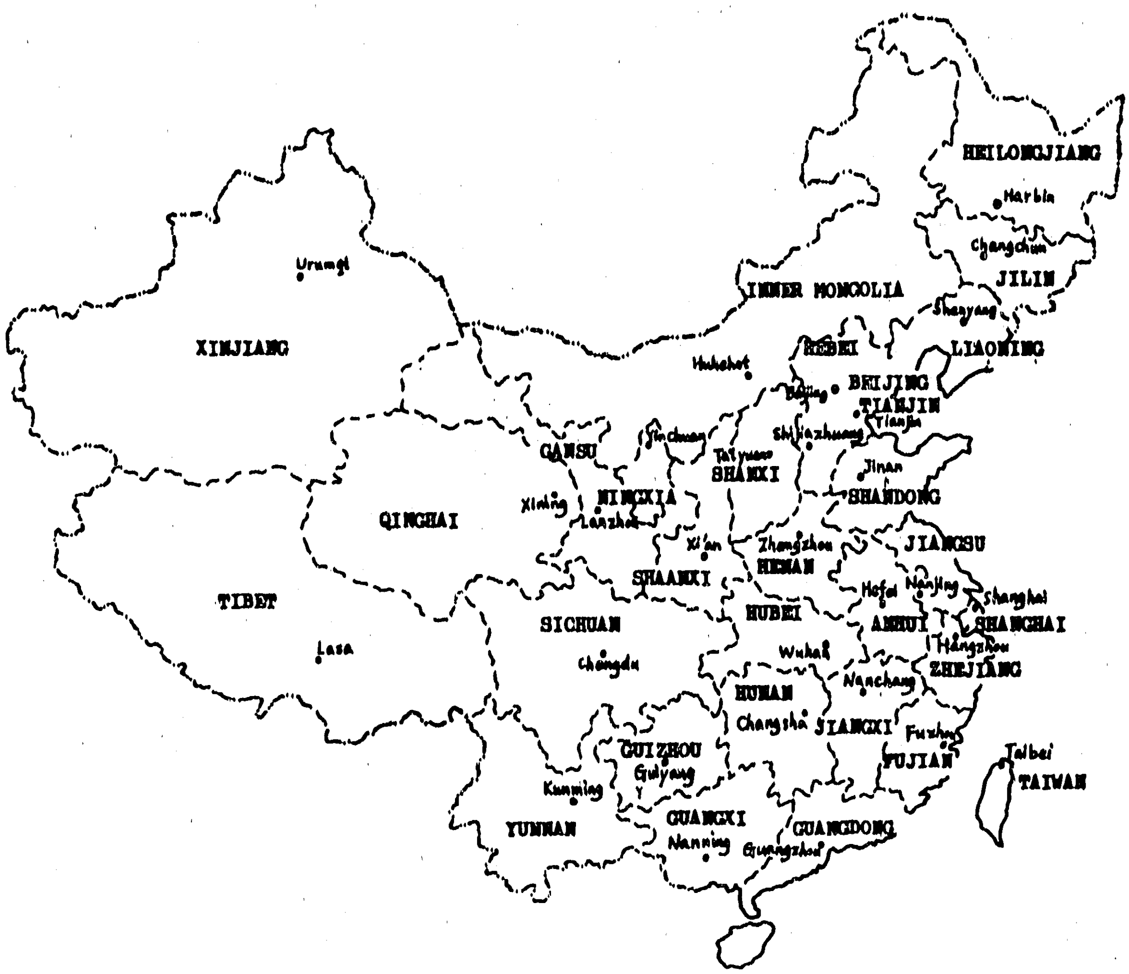
As indicated in Table 4.4.1, China is a significant fossil energy consumer. China meets its energy demand with its own fossil resources. For instance, China is the second largest producer of coal in the world, after the United States. To meet economic growth goals, China will need to increase its rate of energy resource development. The need is particularly acute for increased supply of coal and electricity. Diesel fuel is scarce, making operation of diesel gen sets difficult. Diesel fuel is supplied to farmers and fishermen by the government for use in tractors and boats, in return for produce and fish.[5-7]

Table 4.4.2
Energy Resources of China
Recoverable Reserves

Coal/Lignite	770 billion tons
Oil	9 to 25 billion tons
Gas	4.8 trillion cubic feet
Resource Potential	
Hydropower	1,900 trillion watt-hours/year
Uranium	15,000 MW equivalent plant for 30 years

Source: World Bank, 1989

Table 4.4.2 indicates that China has the natural resources to support increased



PROVINCES OF THE PEOPLE'S REPUBLIC OF CHINA

Figure 4.4.1

Source: [5-5]

energy and fuel production; however, resource development does require significant investment capital and infrastructure development. For instance, only 100 TWh/year (5%) of hydroelectric power have been developed because most of the potential lies far from industrial centers. Increased production of coal will require expanded railroad capacity. China's incentive for developing its energy resources is partly that export of such resources provides a source of hard currency. Currently, oil exports account for 22% of export earnings.

Electric Power Generation System: China has become the fifth largest producer of electricity in the world, with an installed capacity of 102,897 MW in 1987. About 71% this capacity was thermal based; about 29% was hydro based. Table 4.4.3 indicates the size and number of power plants in the system. Additional capacity is expected to grow to meet industrial and growing commercial and residential requirements. For instance, the Central China Power Grid (Hubei, Hunan, Henan, and Jiangxi provinces) projects growth of peak demand from 9 GW in 1987 to 23 GW in 1996. The Henan Power Grid projects peak demand growth from 3 GW to 7 GW between 1987 and 1996.

Table 4.4.3
Electric Power Generation Capacity of China
1988

Plant Type	Plant Capacity (MW)	No. Plants
Thermal	> 250	77
Thermal	>1000	3
Hydro	> 250	19
Hydro	25-250	63
Hydro	< 25	78,000

Source: [1-1]

Table 4.4.4 shows that currently most electricity is consumed by industrial users. Demand for electricity outpaced capacity enough from 1978 to 1988 to produce industrial power shortages, resulting in a 15% demand shortfall. Power shortages due to high demand growth have resulted in a quota system for electricity distribution, potentially increasing industrial demand for self-generation systems.

Table 4.4.4
Electricity Consumption of China - 1987
(Percent of Total)

Industrial	73
Agricultural	16
Transportation	1
Residential/ Municipal	10

Source: World Bank

Only 65% of the population has access to electricity. In 1979, per capita residential and commercial electricity use was less than 12 kWh/year, on a par with domestic use in India and Indonesia.[5-9] Residential demand for electricity for lighting and home appliances is expected to grow at 11-13% per year as household incomes grow.[5-10]

Electric Power Grid System: Development of the electricity transmission and distribution system has lagged behind development of the generation system. The transmission and distribution system is composed of six regional grids (50% of China's capacity) -- Southwest, Northwest, East, Central, North, and Northeast. There are also six provincial grids, two autonomous regions, and many small remote installations. China is planning a major grid expansion program, especially to bring electricity from the resource-rich western provinces to the industrial east coast. Electricity supply planning is conducted by the Ministry of Electric Power.

4.4.3 Business Conditions

Wind Turbine Technology Familiarity: Users of energy conversion technology in developing countries usually have a strong preference for staying with technologies they are currently using. In many developing countries the major dispersed power generation technology in use is the diesel engine gen set. China, however, has a history of small wind turbine use, and 30,000 turbines are reported to be in use.[5-7] National wind technology activity is managed by the Chinese Wind Energy Development Centre. Turbines developed by the Wind Energy Research Institute (in the town of Xilinhaute in Inner Mongolia) are manufactured by four factories in Mongolia, Shanxi, and Heilongjiang. The turbines come in 50 W, 100 W, and 150 W sizes. About 15,000 of these turbines have been installed to provide electricity for lighting, television, and electric appliances owned by families of herdsmen. Sales potential is estimated at 100,000 turbines for the Autonomous Region of Mongolia. The turbines are sold as a system with a rectifier, a storage battery, and an inverter. The 100 W system is capable of producing 100 to 120 kWh of electricity annually (assuming 3-hour daily use). A 500 W turbine design is being considered to meet potential growth in electricity demand.[5-7]

Equipment Maintenance Infrastructure: Most counties in China have an agricultural machinery service company that supplies spare parts and repairs and maintains machinery, including diesel engines and water pumps.[5-5]

Economic Hurdles: China is interested in importing technology, but is often not willing to spend hard currencies. It helps to be able to offer advantageous financing and to barter. Other strategies to overcome this hurdle include joint ventures or technology transfer agreements.

Per capita GNP in China is very low, at U.S. $320 (1988).

Trade Hurdles: Japan, because of proximity, low prices, and liberal credit terms, is a dominant supplier of technology to China. The Europeans have also been able to arrange very attractive low-interest financing.

Potential wind/diesel technology exporters should be aware that patent protection laws are weak.

Credit Availability: FCIA (6/1/89) -- Short-Term Political & Comprehensive: Coverage requires guarantee or irrevocable letter of credit from the Bank of China. Other Chinese financial institutions will be considered. Medium Term Coverage: Coverage requires guarantee or irrevocable letter of credit from the Bank of China. Other Chinese financial institutions will be considered.

Export-Import Bank (6/1/89) -- Bank of China must be obligor or guarantor. Other Chinese institutions will be considered.

4.4.4 Market Opportunity: Water Pumping

An estimated 40,000 waterwells on the Mongolian grasslands depend on human or animal power.[5-7]

Low-lift, high-volume water pumps are used for farmland irrigation, aquatic products breeding , and salt refining. Electric pumps and diesel pumps are now used for these applications; wind/diesel technology would alleviate problems with diesel fuel supply.[5-5] Major crops include rice, wheat, corn, other grains, oilseed, cotton. Agriculture is mainly at a subsistence level.

4.4.5 Market Opportunity: Village Power

The agricultural sector was responsible for 26% of real GNP in 1987. China's many villages without electric grid access currently depend on electricity generation sources including wind, microhydro, and diesel generation to pump drinking water, provide lighting, and run a growing number of appliances. Introduction of wind/diesel package systems and retrofit of wind turbine to existing diesel generators would accomplish two goals: (1) reliability of electricity supply could be increased above that possible using either wind or diesel generation technology alone, and (2) scarce diesel fuel supplies could be extended. These villages cover a range of climates, from the cold winter conditions of Inner Mongolian plains where herdsmen require power to more moderate climates along the coast.

China has a number of dispersed wind pump manufacturing facilities (e.g., Inner Mongolia, Shanxi, Heilongjiang, Jiangsu, and Shandong provinces). These factories also install wind pumps and provide qualified system maintenance personnel.[5-5. 5-7] Such facilities are available to support a large wind/diesel village power market.

4.4.6 Market Opportunity: Industrial Power

China's major industries include iron, steel, coal, petroleum, machine and armaments building, and textiles. Production grew about 15% in 1987; however, planned annual growth is 7.5%. Industry had a 43% share of real GNP in 1987.

Industry faces power shortages because growth of electricity demand has outpaced capacity growth. Shortages are concentrated in the northeastern, northern, and eastern regions. Industrial facilities own about 6% of China's capacity.[1-1] This self-generation capacity reduces the impact of the electricity distribution quota system on their operations. Self-generation capacity might benefit from wind/diesel technology as a fuel saver.

4.4.7 Market Opportunity: Telecommunications

China is interested in developing its long-distance telecommunications network, its defense communications, and its television broadcast network. Currently, China has 7,500,000 telephones, 274 AM radio stations (215 million radios receivers), and 407 television stations (16.8 million television sets).[1-2]

As part of its plan, China is developing a satellite system for telecommunications. As of June 1987, there were 5 earth stations, with a 5-year plan to add 10 more. Also, the ministries of petroleum and coal intend to build 23 (contracting SPAR of Canada to build) and 5 stations, respectively.

China wants to produce as much of its telecommunications technology as possible. Revenues for U. S. exports of telecommunications equipment and systems to China grew at 44% per year from 1982 through 1986, including a 38% rate for navigation and traffic control applications. Competitors to the United States in this market include Japan, France, Belgium, Sweden, West Germany, and Canada.

The Ministry of Posts and Telecommunications is the primary buyer and sets technical specifications for China. The USDOC (June 1987), however, advises manufacturers to work with the end users to develop specifications and to introduce the technology. The final sales transaction is managed by a Foreign Trade Corporation (FTC). The FTC determines contract awards based on price, quality, delivery, service, and credit, listed in order of importance. Tariff rates range from 12.5-30%.

4.4.8 Corollary Opportunities

The end-user market demand for electricity in China is characterized by a potentially large number of users in the industrial, commercial, agricultural, and residential sectors. The Chinese have the technical expertise to manufacture and maintain wind/diesel hybrid systems. Other countries with this same combination of market need, developing infrastructure, and growing technical expertise include India, Mexico, the Philippines, and South Africa.

4.5 DOMINICAN REPUBLIC

DOMINICAN REPUBLIC WIND/DIESEL MARKET SUMMARY

Opportunities:

- CDE (Corporacion Dominicana de Electricidad) and large industrial consumers: Includes Corporacion Estatal de Azucar (CEA), Gulf and Western's Central Romana, Grupo Vicini, Falconbridge, Rosario Dominicana, Alcoa Corporation.
- Residential customers: Energy consumption dominated by location and income. Rural use is largely fuels, not electric.
- Tourist hotels: A potentially large market. The Dominican Republic has 16,100 hotel rooms, more than any other Caribbean destination. Hotels are often not close to the electric grid. Grid electricity is not reliable. Hotels use diesel gen sets, potentially in the 1 to 3 MW range.

Advantages:

- Reduced oil imports: All petroleum, which is the dominant energy source, is imported. Oil imports are a major use of valuable hard currency (e.g., US dollars), since they account for 30% of total import expenditures (ECRE, 1985).
- Subsidies were removed from energy prices in late 1985 for all users except the state-operated utility (CDE), which is one of largest potential consumers. CDE continues to purchase fuel at subsidized rates, estimated to be 50% below the real cost.
- Favorable private investment incentives and Industrial Free Zones to attract foreign investment in tourism and industry, respectively.

Disadvantages:

- No national energy policy; no government agency responsible for renewable energy development.
- High tariffs on imported technology.
- High technology cost relative to consumer purchasing power. High inflation. Need for external financing.

4.5.1 Wind Resource Characterization

The Dominican Republic has several coastal and mountain locations with wind resources at annual average levels from Class 5 to Class 7. These sites, identified by analyses by PNL, are indicated in Figure 4.5.1. Minimum wind speeds occur from September to November. Maximum wind speeds occur from December to March and from June to July. However, useful power levels are achieved most of the year.

4.5.2 Energy Market Characterization

The Dominican Republic imports all petroleum. In 1985, prices for petroleum products were decontrolled, resulting in a 160% increase in one year. From 1975 to 1985, diesel fuel prices increased at an annual rate of 23% (0.48 RD$/gallon in 1975 to 3.95 RD$/gallon in 1985). Price fluctuations within the country produce fuel prices that may be 15-25% above average inland and along rural coastal areas.

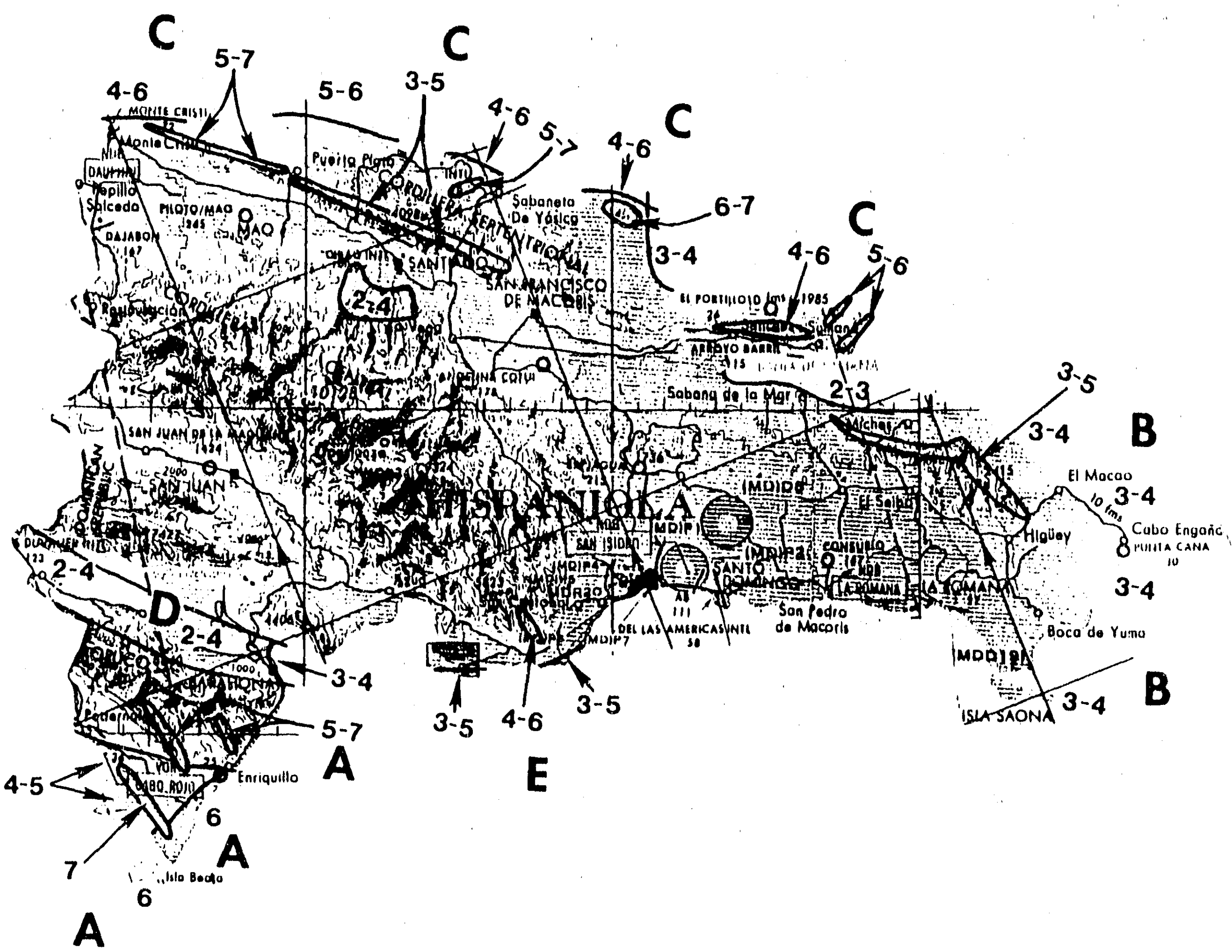
4.5.3 Business Conditions

Dominican Republic Government Private Investment Incentives: Laws limit or exclude foreign participation in electric utility sector and telecommunications; however, new laws are being considered to promote private power. Tax incentives exist, under the Industrial Incentive Law (Law No. 229), to encourage manufacture of products exclusively for export and for import substitution industries. Also, the Tourist Incentive Law (Law No. 409) promotes investment in new and established facilities in designated tourism development zones.

Credit Availability: The FCIA (6/1/89) places limitations on short-term comprehensive and short-term political coverage. There are no conditions on bank letter of credit. Medium-term cover is not available. The Export-Import Bank (6/1/89) does not offer coverage. OPIC has a program offering insurance against expropriation and war risk, which covers industries including tourism and mining.

Market Development Programs: OPIC funds feasibility studies.

Exchange Rates: Assumed 3 RD$/US$ to convert prices in ECRE report [6-2] to 1985 US dollars, based on published conversion rates.[1-2]



WIND RESOURCES IN THE DOMINICAN REPUBLIC

Figure 4.5.1

Key: Numbers indicate wind classes.

Area	Annual Average Power Class	Useful Power
A	5-7	All year
B	3-4	November-August
C	4-7	All year
D	2-4	December-September
E	3-6	All year

Source: D. L. Elliott et al., International Wind Energy Resource Assessment Update, Pacific Northwest Laboratories, December 1986.

Market Hurdles: The size of the market is limited by consumer purchasing power and technology cost, especially the residential market. There is a lack of market infrastructure to support alternative technologies. Sales and installation are done by vendors because labor skilled enough to perform renewable system installations is not available. There is a high import duty, and no bilateral investment treaties as of January 1988.[6-5] However, Dominican Republic laws encourage foreign investment by providing favorable tax and import duty treatment and by providing Industrial Free Zones where companies can import materials duty free.[6-5]

4.5.4 Market Opportunity: CDE and Large Industrial and Commercial Customers

The CDE is an autonomous, financially independent, state-operated utility that is responsible for providing electricity in the Dominican Republic on a long-term basis. The CDE had 17.2 MW of diesel capacity in 1985. The real cost of electricity produced by CDE is understated because it purchases petroleum at subsidized rates. Recognizing the high cost of operating diesel capacity, the CDE expects future capacity expansion to incorporate steam coal, hydro, and nonconventional power generation systems. CDE support for renewable energy power generation systems, including wind, is compromised by financial and organizational problems.

The economic development of the Dominican Republic is dependent on improving the reliability of the power generation system. The CDE has old, poorly maintained generation and transmission facilities that cause frequent power supply interruptions. Indeed, power blackouts of 1 to 4 hours each day are common. Demand on capacity is aggravated by intense daily peaks.

Poor CDE power system reliability has encouraged development of private power in the Dominican Republic. Electricity consumers have found that many local banks will not approve project financing without diesel stand-by power generation units. Therefore, to encourage economic expansion, the government of the Dominican Republic has private power legislation under consideration. The CDE has a tradition of purchasing private power. Industries producing electricity for internal use have been able to get buy-back agreements. However, the CDE has not been willing to negotiate firm price and purchase agreements acceptable to private sector producers.

Financial institutions that could provide CDE with the loans necessary to improve its power generation system are requiring that the CDE improve both its financial condition and its operating performance. The CDE has at least two options to attain these objectives: encourage private power and reduce operating costs. For instance, to raise its share of funding for a World Bank and Inter-American Development Bank project to rehabilitate and expand the electric generation and distribution infrastructure, the Dominican Republic is approaching the private sector. The CDE faces several conditions that increase operating costs, including high system losses, theft of electricity, and fuel cost subsidies. Multi- and bilateral assistance agencies are making funding of CDE capacity expansion contingent on improved operating performance and reduced fuel cost subsidies.

The Dominican Republic has a system of Industrial Free Zones to promote foreign investment. About 175 companies operate in these zones; 75% are owned by U. S. parent companies, including Westinghouse, GTE, Hanes, Baxter Travenol, Warner Lambert, and American Airlines. The large industrial users with operations in these zones need access to reliable electric power. In 1985, installed capacity in these areas included 198 MW at Falconbridge (ferronickel mining), 80 MW in the Industrial Free Zones, and 62 MW at CEA (the state sugar corporation).[6-2]

4.5.5 Market Opportunity: Residential Customers

Some level of residential electrification is available in roughly 60% of Dominican Republic homes (Table 4.5.1). However, 95% of the electricity is consumed in wealthier urban areas, including 55% consumed by the two highest income classes. Rural areas use only 15% of the electricity produced. Further electrification of rural markets will require development of financing options.

Enersol Associates, Inc. (Somerville, Massachusetts), a U.S. firm operating in the Dominican Republic, offers a creative approach to financing investments in residential and village power.[6-12] Since 1984, Enersol has been selling photovoltaic electric systems to rural families and businesses in the Dominican Republic with increasing success. Initial financing from USAID has enabled the formation of community credit associations. These associations make loans for the purchase of a $200-$500 photovoltaic system. Loans are repaid over 3 to 5 years, and the replenished load fund is used to make additional loans.

Enersol systems purchased under this financing arrangement have provided reliable electricity to homes, country stores, dairy farms, clinics, schools, churches, and community centers for lighting and other appliances. These photovoltaic lighting systems replace kerosene lamp and diesel generator lighting systems, which create smoke and

Table 4.5.1
Energy Use in the Residential Sector of the Dominican Republic, 1985

Energy Source	Whole Country	Rural
	(Percent of Homes)	
Electricity	60	15
Commercial Fuel	<36	<8
Annual Per Capita Energy Consumption Below Mean Annual Income (~$US 85)	< 30 Gallons Oil Equivalent	
Electricity Consumption	>95% consumed in urban areas; >55% consumed in two highest income classes	

Source: ECRE

noise, respectively. They also replace battery-operated lighting systems. Batteries must be hauled many miles to gasoline stations for recharging. Enersol estimates that daily residential electricity requirements would initially be for 1-3 hours of lighting (60-180 Wh daily).

Additionally, Enersol sponsors training workshops to give villagers the capability to assemble, sell, install, and repair the photovoltaic systems. Such activity adds needed jobs to the local economy.

4.5.6 Market Opportunity: Tourist Hotels

The Dominican Republic has 16,100 hotel rooms, more than any other Caribbean destination. Major resort development areas include Santo Domingo, Costa Caribe (Boca Chica, Juan Dolio, and Guayacanes), Puerto Plata, Playa Dorada, Playa Grande, Peravia, Barahona, La Romana, Macao-Punta Grande, Higuey, and Miches. The current number of rooms is up from about 12,000 in 1987, and continued growth is expected. An example major hotel consumed approximately 348 MWh in 1984 and 359 MWh in 1985. High energy prices are forcing users to consider alternative energy sources.

As an example, the Punta Cana Yacht Club (520 condominium units) has been interested in a wind turbine retrofit to a hotel power generation system currently supplied with on-site diesel-electric power. Waste heat from the system is used to run the hotel laundry facility. The site is remote; the nearest utility line is 54 kilometers away. Furthermore, connection to the grid may not be the optimal choice because the CDE power supply is unreliable. The Punta Cana project includes two 500 kW, 1800 rpm diesels in phase 1. Three more units would be added later, for a total 2.5 MW. Wind turbines would be considered as fuel-saving devices, because diesel fuel must be trucked in and stored in a 20,000-gallon tank. Wind speed is estimated at 5-6 m/s at 10 meters (Classes 3 to 5). Under hurricane conditions, wind speeds can peak at 40 m/s (above Class 7). Installation considerations include salt corrosion and absence of construction cranes in the area. There is potential for mini-grid expansion to a nearby Club Med facility (350 rooms, three 500 kW diesels).[6-4]

4.5.7 Corollary Opportunities

The Dominican Republic provides an example of an island market with poor infrastructure, potential fuel supply problems because of dependence on imported fuels, and unreliable electricity supply. Yet, if reliable power can be developed, the island economy has growth prospects in tourism, mining, and industry. Corollary opportunities lie in other islands that have similar potential markets but also face fuel supply or electricity reliability problems. Other Caribbean islands (e.g., Jamaica, Aruba, Antigua, Barbados, Haiti, Turks and Caicos Islands) and South Pacific islands fall into this category. Also, resort owners, such as Club Med, could be potentially interested parties.[6-4]

4.6 ARAB REPUBLIC OF EGYPT

EGYPT WIND/DIESEL MARKET SUMMARY

Opportunities:

- Red Sea development: Substantial expansion of hotels and industries along the Red Sea coast is planned; wind/diesel is already in use in this area.

- Village power: Thousands of villages likely to never be connected to grid.

- Diesel-supplied grids: Grid-installed diesel capacity estimated at 218 MW, with additions of 22.3 MW scheduled for construction completion by the government by 1991.

- Water pumping: Estimate of 280 MW installed diesel capacity for private irrigation. Government plans for southwest desert aquifer pumping could involve hundreds of additional megawatts.

- Military facilities: Many remote bases require independent power.

Advantages:

- Strong Egyptian government interest and USAID involvement in wind energy, project funding available.

- Class 7 winds along Red Sea coast, good winds in a few other areas.

- Rising energy needs: 10% growth in demand currently, expected to be at least 7% through the end of the century.

Disadvantages:

- Government subsidies for fossil fuels are resulting in #2 diesel oil price of about $0.12/gallon. Wind energy cannot compete privately until prices reflect economics, expected by 1995.

4.6.1 Wind Resource Characterization

A wind energy resource assessment for Egypt was recently carried out by PNL and the Egyptian Electricity Authority (EEA), sponsored by the government of Egypt and USAID.[7-1] The study indicated excellent wind resource potential (Class 6 or greater) along coastal areas of the Gulf of Suez and good wind resource potential (Class 4) along much of the coastal area of the Red Sea (north of 24° N latitude) and the Gulf of Aqaba, along Mediterranean coastal regions (west of Alexandria), in areas of southwestern Egypt, in the highlands of eastern Egypt (east of the Nile River), and in the southern Sinai (see Figure 4.6.1). The region surrounding the city of Ras Ghareb on the Gulf of Suez was cited as having excellent winds. Regarding seasonal variations in this area, the best winds averaged nearly 10 m/s and 660 W/m^2 from June to October. Even the lowest resource months of December, January, and February had winds above 6 m/s and 250 W/m^2. In general, the highest winds occur shortly after sunrise, with a secondary maximum around midnight. The diurnal variations in wind speed, however, are small; and all times of day have mean hourly wind speeds above 7 m/s.

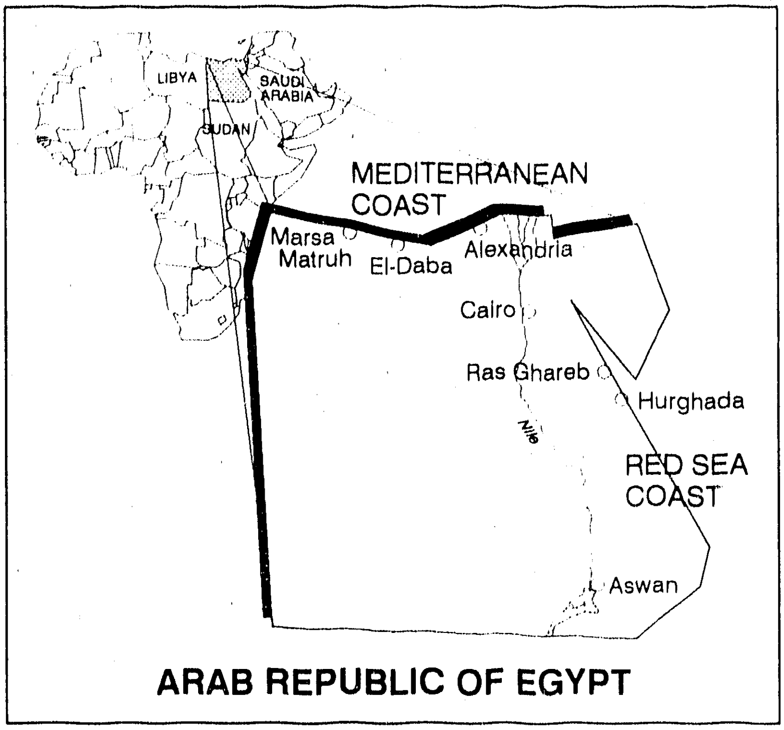


Figure 4.6.1

4.6.2 Energy Market Characterization

Egypt's main energy resources are oil, coal, natural gas, wind and solar resources, and hydropower. Most of the last resource has been harnessed. Hydropower facilities at the Aswan Dam produced nearly one-quarter of the nation's electricity in 1988.[7-4] The government is putting emphasis on the increased domestic use of natural gas and coal to displace oil, and on energy conservation and demand management. USAID funding for development in the power sector exceeds $915 million.[7-3]

Egypt's total installed electric capacity in 1988 was 9673 MW.[1-2] Diesel capacity is estimated at 218 MW, with additions of 22.3 MW scheduled for construction completion by the government by 1991. Recent growth in electricity demand has been dramatic, rising from 1000 MW in 1969 to 6000 MW in 1988. The pace of growth is expected to slow from the current 10% to about 7% by the end of the century. Electricity consumption in relation to total energy consumption in Egypt is high in comparison with other nations, both developing and industrialized.[7-3]

Almost all energy sales in Egypt are subsidized, some heavily. In early 1989, weighted average prices of petroleum products were running at about 36% of long-run marginal cost (LRMC). Electricity tariffs were at 24% of LRMC. Selected fuel prices that affect the economic viability of wind/diesel systems competing in the private sector were even more heavily subsidized. The price of gas oil (small diesel engines) was just over $0.12/gallon, and fuel oil was between $0.05 and $0.06/gallon. Although Egypt is a net oil exporter, the pricing of fossil fuels is devastating the economy, encouraging diversion of potential exports. The government realizes the damage this policy is causing to the balance of trade, and agreed with The World Bank in 1987, as part of a medium-term economic reform program, to raise domestic energy prices to economic levels by FY 1994-95 at the latest. Egypt backed up this commitment in March of 1989 by raising petroleum product prices as much as 40%. Gas oil prices were raised an average of 31%. With further radical changes in the prices of petroleum products anticipated, the forecasts for growth in electrical demand may be significantly affected.

Renewable Energy: Egypt's effort to reduce domestic fossil fuel consumption is stimulating efforts in renewable energy development. The government has allocated about $4 million for its wind energy program over the next five years.[7-5] Wind programs have historically been funded by outside sources: USAID ($27 million in this decade), the EEC, and the UN. USAID is currently conducting a windfarm feasibility study that preliminarily shows potential for 200 MW of turbine capacity. Egyptian interest in wind power has been emphasized by the presence of six representatives of the New and Renewable Energy Authority (NREA) at the Windpower '89 conference. A wind energy trade mission sponsored by CORECT was conducted in May 1990. Other countries also are taking an interest in the future of wind energy in Egypt. Egypt recently received $6 million in tied aid from the Danish.

4.6.3 Business Conditions

The United States is Egypt's largest trade partner. Exports to Egypt, having declined from 1984 levels, were over $2.2 billion in FY 1986-87.[7-7] This represents about one-quarter of Egypt's total imports. Although the country's shortage of foreign exchange limits severely the levels of trade with the public sector, government trade levels, often tied to aid, are high. U.S. equipment is considered to be of high quality, but transportation costs often make it less desirable than that of Europe. The Egyptians remain receptive to joint venture and investment opportunities.[7-7] The FCIA lists several restrictions on export credit insurance for Egypt. The Export-Import Bank notes that its coverage is not available for public buyers and government-owned banks.[1-3] OPIC provides investment insurance to U.S. firms working in Egypt, as well as loans to small businesses. They offer special programs to U.S. firms working in solar or other energy projects.

Regulations restricting private sector production of electricity have recently been relaxed, resulting in a significant market for goods in the power sector. The USDOC reports that "A critical factor in buying decisions for electrical equipment in Egypt is the availability of attractive financing." Imports of gen sets between 5 and 270 kW are prohibited because of local production of sets in that range.[7-3] However, diesel gen sets manufactured locally are recognized to be of low quality, providing an incentive for the government to avoid application of the restriction to package wind/diesel sets.

4.6.4 Market Opportunity: Red Sea Coast Development

Opportunity Description: Because of winds up to Class 7 in this area, the Red Sea and Gulf of Suez coasts (east and west) are the primary areas of interest for several different applications of wind energy. One such application is resort hotels. The Egyptian government believes tourism to be of major importance, citing its development as a prime component of the country's economic reform program. Diving and other water sports are becoming increasingly popular in the area. Absence of grid power to this area and current use of a wind/diesel system at an ice-making facility suggest that a proven package system for hotel or industry use should be very popular. Aside from the positive economics of wind turbine installation, operators are beginning to realize the aesthetic benefits: tourists are given occasional relief from the exhaust and noise that accompany the diesel generators. Military facilities on the coast also rely on diesel generators and are good potential buyers.

Project Funding and Contacts: Pilot projects, such as the ice-making facility at Abu Ghossoun, would be coordinated through the NREA and potentially funded by donor agencies. Major hotels will tend to be joint ventures, with the foreign partner being the most likely project initiator. Examples would be the Hurghada Sheraton or the Magawish Club Med in Hurghada. Local agents to handle distribution of a system can be found through the USDOC's Agent/Distributor Service.

Existing Power Environment: The existing resort facilities of significant size are reported to have a diesel-generating capacity totaling 1-1.5 MW.[7-10] No grid-supplied power exists. However, the possible installation of a wind farm along the coast that would be interconnected with the Cairo grid is compatible with wind/diesel development. Planning power supply for hotels, including the estimation of a likely load curve, is made simpler by the fact that usage will follow that of resorts elsewhere in the world, where consumption patterns are long established. Private industries and military facilities have much more varied consumption patterns.

Potential Wind/Diesel System Description and Operating Strategy: Projects for the Red Sea area will be both retrofit for existing facilities and potentially large package units for planned hotels and industries. Consequently, the system description will vary greatly with the application. One common suggested element in the design of all the systems is that they have the potential for uncomplicated grid connection. That is, the stand-alone system characteristics should be acceptable to the EEA since there are considerations of wind farm installation in the area with transmission lines to the national grid.

Because of the coastal location and the scarcity of potable water, reverse osmosis would be an excellent application for wind energy for both hotels and industries, with potential as a dump load. Another potential dump load is ice making.

4.6.5 Market Opportunity: Village Power Systems

Opportunity Description: Egypt, as of 1980, had about 30,000 villages with an average population of 1500. There are probably several thousand small villages of 500 or fewer people not connected to the national electric grid. Of these, several hundred villages might be found along the coastal areas of high wind resource. If it were deemed uneconomical to connect these villages to the national grid, even if a wind farm and transmission and distribution lines were installed in the area, then wind/diesel stand-alone systems would be a likely alternative source of electricity.

Project Funding and Contacts: USAID would be a likely vehicle for support of this type of project, working with the EEA, the Rural Electricity Authority, or the NREA.

Existing Power Environment: The Rural Electricity Authority had as its goal in 1980 the grid interconnection of all villages with a population of 500 or more.[7-8] It was reported in 1989 that 96% of villages in the country had been electrified. Assuming that this means that 96% of the larger villages had been electrified, there are about a thousand villages of more than 500 people and thousands of villages of lower population still without electricity.

Potential Wind/Diesel System Description and Operating Strategy: As in similar environments in other countries, systems should be simple in operation and overall design concept, rugged and easily maintained, and possess features such as easily changed-out control electronics boards. (Microprocessor-based control systems that are tolerant of the climate should be considered mandatory.) Battery banks require shelter from the heat. Transportation and erection considerations must be taken into account. Since it may be difficult or impossible to move cranes to the villages, turbine towers must be small enough to erect using other available vehicles. This will probably limit turbine sizes to 50 kW and smaller. Depending on the project goals, diesel units may be sized to support only critical loads: communications, essential refrigeration, and minimum drinking water and lighting needs.

4.6.6 Market Opportunity: Diesel-Supplied Electric Grids

Opportunity Description: Diesel installations of significant size either exist or are planned in the more remote small cities. Several of those scheduled for construction completion by 1990/91 are in areas of Class 3 or 4 winds on the Mediterranean coast west of Alexandria. In the coastal towns of El-Daba and Marsa Matruh, 10.1 MW of additional installed diesel capacity are planned for 1990/91. Class 4 winds in these areas make them prime candidates for wind turbine connection.

Project Funding and Contacts: Initial contact would be made through the NREA or through the funding organization. Project financing might be obtained through the World Bank as a component of a major power project or as part of a World Bank/UNDP ESMAP project.

Potential Wind/Diesel System Description and Operating Strategy: Depending on the number of wind turbines to be added to the particular plant, wind capacity may not be a large enough percentage of the total system capacity to require special controls or operating strategies. However, this does not obviate the necessity of designing the turbines for low maintenance requirements. Aside from geographical considerations, Egypt suffers from a shortage of engineers and technicians and an oversupply of semiskilled labor.

4.6.7 Market Opportunity: Water Pumping

Markets exist for both proposed and existing water pumping facilities. Egypt's 1991-92 plan calls for the reclamation (irrigation and other preparation) of over 800,000 acres of desert land.[7-11] This is both a public and private sector effort. The estimate in 1980 of existing private diesel pump capacity for irrigation was 280 MW, of which 255 MW was composed of some 40,000 small, privately owned units. Actual market size will depend on the amount of existing and planned pumping capacity that is diesel-electric. The government is already beginning to recognize the potential for wind pumping; a wind turbine-powered water pumping system has been installed in southwestern Egypt, where the average annual wind speeds are moderate to high.

4.6.8 Corollary Opportunities

With the exception of water pumping, the major applications of wind energy in Egypt will be implemented along the coast. Parallel opportunities for powering coastal areas remote from a major grid and developing in industry/tourism might include Greece, Caribbean nations and dependencies, some islands of the South Pacific, Turkey, and Sri Lanka.

4.7 HELLENIC REPUBLIC (GREECE)

GREECE WIND/DIESEL MARKET SUMMARY

Opportunities:

- Diesel-supplied small grids: Some 2000 islands, many with Class 5-7 winds. Potential market of hundreds of megawatts.
- Tourist resorts and other commercial island applications: New construction in luxury-class hotels, with government incentives both inside and outside the energy sector.

Advantages:

- Government interest: Strong Greek government interest and USAID involvement in wind energy, with ongoing projects.
- Wind resource: Class 5 winds in many areas along Mediterranean.
- Government incentives: Tax credits and grants for both producers and end users of wind and other renewable systems.
- Local industry status: Greece has a good industrial infrastructure and a growing wind industry to support turbines in remote sites.

Disadvantages:

- Market monopoly: Hellenic Aerospace Industry plans to manufacture turbines locally for the Public Power Corporation (PPC), with the assistance of a foreign firm.

4.7.1 Wind Resource Characterization

Wind resource estimates issued by the National Technical University of Athens show hundreds of Greek islands having winds of Classes 5, 6, and 7.[8-3] The highest annual winds are found in the Dodecanese islands, all of which are associated with winds of Classes 6 and 7. Andros shows an annual average wind speed of about 6.6 m/s at one site (Stavropeda). Variations in mean monthly wind speed there show a low of 4 m/s and a high of 10 m/s. Winds vary considerably from month to month in the two years depicted, but do not appear to have a marked correlation with the seasons.[8-7]

4.7.2 Energy Market Characterization

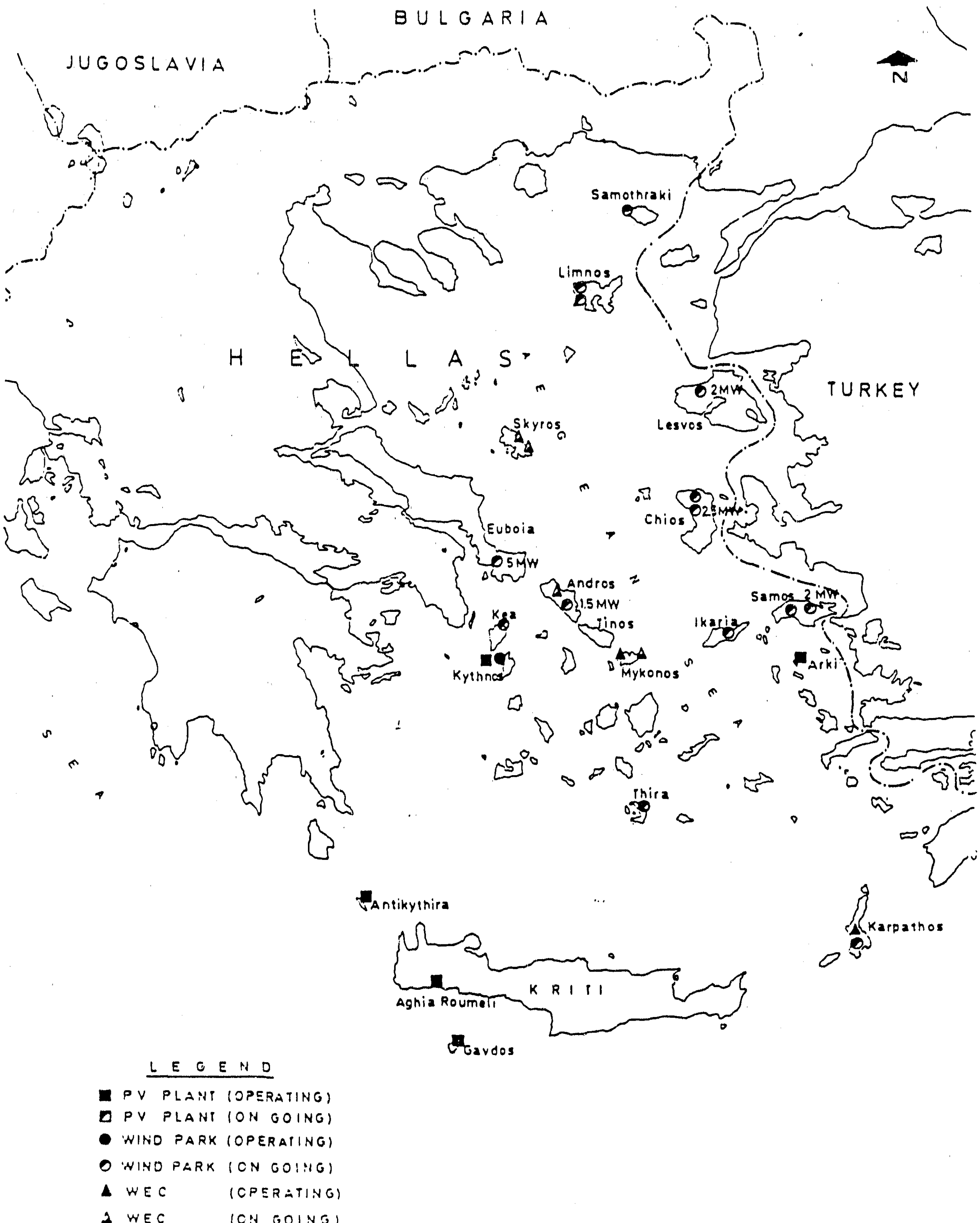
Although Greece numbers oil among its natural resources, it remains a net oil importer and buys coal, natural gas, and liquified natural gas as well.[1-2] It has recently been making a serious effort to reduce petroleum consumption.[8-1] A recently signed agreement with the Soviet Union, along with pipeline construction, will bring 1-2 billion cubic feet of natural gas per year into the country. The total installed electric capacity of Greece was 10,531 MW in 1988, provided primarily by hydroelectric facilities and coal-fired plants.[1-2] Diesel generators represent a substantial portion of capacity, many hundreds of megawatts, dominating electricity production in the islands. The PPC of Greece provides electricity to 99.7% of the population. Average cost of electricity in the islands was $0.064/kWh in 1984.

Greece is showing significant interest in renewable energy other than hydroelectric, which it continues to develop. Renewable energy development is being encouraged by the institution of grants and tax credits for producers and end users of renewable energy systems. The country has substantial geothermal potential, perhaps 750 MW. A 2 MW demonstration geothermal facility is operating on Milos. Relatively small solar photovoltaic plants exist.

There has been much recent emphasis on wind energy as the government began to realize the extent of the resource. The PPC has set a target of 20 MW of installed wind capacity by 1992.[8-4] As shown in Figure 4.7.1, projects among the islands, operating or ongoing, include wind parks or single turbines on Kythnos, Kea, Chios, Euboia, Thira, Mykonos, Karpathos, Samos, Ikaria, Lesvos, Limnos, Samothraki, Skyros, and Andros.[8-2] Installation of wind parks on a dozen other islands is anticipated through 1992. A goal of 10% of energy to come from wind has been set for the next 10 years.[8-8]

4.7.3 Business Conditions

Although Greece continues to have ambitious development plans and instituted a comprehensive two-year economic stabilization program in 1985, the Greek economy has shown only modest improvement, suffering an inflation rate of 16.4% in 1987. Trade is primarily with EEC countries; the United States accounted for only 3.2% of Greece's imports in 1987. However, U.S. exports to Greece rose by 62% in 1988.[8-6] More recent figures showed continuing growth in exports for 1989. Greece will become part of the single European market in 1992. Although the United States is forced to pay import taxes not imposed on the EEC countries, no such tax is imposed on wind turbines imported by the government or municipalities.



GREECE

Figure 4.7.1

Source: Public Power Corporation of Greece

Greece is included in the programs of the OPIC. The FCIA and the Export-Import Bank are imposing no special conditions on export credit insurance for Greece.[1-3]

4.7.4 Market Opportunity: Small Grids

Opportunity Description: Estimates are that the wind farm market potential in Greece lies between 70 and 400 MW.[8-3] Realistically, diesel-connected systems, particularly on the islands, will represent the most economically attractive portion of this total. Fuel cost in these remote locations in some cases represents 70% of the total cost of generation. Although some islands close to the mainland are connected to the grid by submarine cable, the great majority are not. Strong competition can be expected from the Europeans in this market, but U.S. production of a particularly attractive system qualified for European standards and ultimately for manufacture locally could be popular with the PPC and the municipalities. One industry source indicates that competition with the EEC may be effectively sidestepped through establishment of a partnership with an appropriate military-related manufacturer, since the public utility is controlled by the military.[9-7] That joint venture might need to be with the Hellenic Aerospace Industry (HAI), since official plans are for HAI to manufacture wind turbines locally in league with a foreign producer, with all subsequent PPC purchases for three years to be from that union.[8-3]

Project Funding and Contacts: Cultivation of contacts with contractors for the military, who ultimately influence utility purchasing, is said to be the key for U.S. establishment of a niche in the wind/diesel market. Both OPIC and the Export-Import Bank support U.S. business ventures in Greece. OPIC offers special loan and insurance programs to U.S. firms working in solar or other energy projects.

Potential Wind/Diesel System Description and Operating Strategy: Diesel grids on the islands vary considerably in size, from the 270 kW grid on Agios Efstratios to the several megawatt systems. This has resulted, and will continue to result, in a variety of system configurations. Wind industry representatives believe, however, that package wind/diesel systems from 10 kW to 50 kW, manufactured in Greece, will be appropriate and popular. [9-7]

4.7.5 Market Opportunity: Remote Resorts and Other Commercial Applications

Opportunity Description: Greece has recently altered its tourism policy, looking to attract higher income tourists. One result of this change will be an increase in the construction of luxury-class hotels as the policy is given strength by the implementation of grants and tax credits for investment in these facilities. Many of these facilities will probably be in areas with favorable winds and without grid-supplied electricity. One study indicates that the potential commercial wind market size is between 2 MW and 20 MW. In the event of grid connection of a commercial facility, the PPC will buy back surplus electricity at the same price at which it is sold. So far, private industry in Greece has been somewhat wary of wind turbines. A break in the market may require that packages for specific applications be developed.[8-6]

4.7.6 Corollary Opportunities

Parallel opportunities for small diesel-powered grids can be found on thousands of islands. Examples are the Hawaiian Islands and numerous others in the higher wind regions of the South Pacific, the Azores, Cape Verde Islands, numerous islands of the United Kingdom, Canary Islands, Falklands, Turks and Caicos Islands, Barbados, and parts of the Bahamas.

4.8 REPUBLIC OF INDIA

INDIA WIND/DIESEL MARKET SUMMARY

Opportunities:

- Village electrification: Wind/diesel package system market of about 145,000 villages that are without electricity as well as 250,000 nominally electrified, 60,000 to 80,000 of which may never be grid connected.

- Village electrification: Market for wind turbine retrofits to existing diesel generator sets supplying communities not connected to major grids.

- Water pumping: Many of the approximately 9 million diesel mechanical and electrical pumpsets in India may be diesel-electric sets and therefore appropriate for wind turbine retrofit.

- Private industrial and agricultural power: Numerous small industries and farms, many times removed from regional electric grids, have excellent wind/diesel potential for applications such as ice making and crop drying.

Advantages:

- Renewable energy experience: High profile in the wind energy community because of ambitious goals for wind farm installation.

- Trade environment: Wind turbine import on the open general license, with no duties. United States is India's largest trading partner ($4.5 billion in 1987).

- Power environment: Severe power shortages are motivating the government to use all available sources of energy, with the short lead time in wind energy particularly attractive. High fuel costs in remote villages that have electricity. High estimated installed diesel generating capacity.

Disadvantages:

- Trade environment: Through the use of tied aid, the Danish have captured a large portion of the wind market.

- Wind resources: Although many areas of Class 4 winds, none of Class 5 on annual average.

4.8.1 Wind Resource Characterization

Average annual wind speeds reach Class 5 only along the Kutch coast in Gujarat. Class 4 winds are found on the Saurashtra (Gujarat), south Tamil Nadu, Konkan (Goa), and northeastern coastlines, as well as in several mountain passes and peninsular locations (see Figure 4.8.1). The predominant winds are highly seasonal, changing in intensity and reversing direction twice yearly. Winds are strong across most of India from March to August as the summer monsoon approaches with primarily southwesterly winds, which reach Class 7 in many areas. From October to March, the winter monsoon causes weaker predominant winds to be from the northeast. Tamil Nadu provides an exception to this, having higher wind speeds during the winter monsoon. The diurnal wind speed variations tend to be small during the monsoon seasons.[9-1]

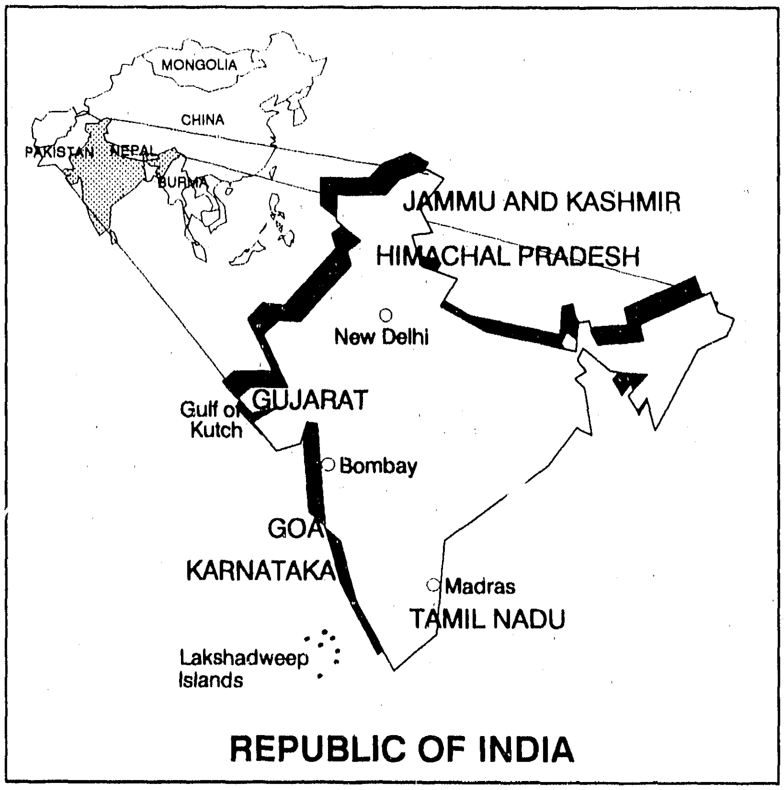


Figure 4.8.1

4.8.2 Energy Market Characterization

The State Electricity Boards (SEB), who operate about 80% of the country's generating capacity, have, in practice, all major policy decisions prescribed by the state governments and all of their operations coordinated by the Central Electrical Authority. Conservative estimates have put the production losses in the industrial and agricultural sectors in India through the past decade, caused primarily by insufficient electric power, at over $20 billion per year.[9-2] Nevertheless, India is the seventh largest producer of electricity in the world, generating 205 billion kWh with an installed capacity of 55 GW in 1988.[1-2] This capacity includes installed diesel capacity for prime power applications conservatively estimated at more than 1 GW.[9-3] One source gave an estimate of over 2700 MW of diesel capacity for 1980.[9-17] A breakdown of installed diesel generating capacity by size is found in Table 4.8.1. Annual growth in generation has been a steady 10% over the last five years.[1-2,9-10]

Goals in power development in India are ambitious and multifaceted. Establishment of a national power grid is one of these and will most likely be fulfilled in the next few years.

Major coal, oil, gas, and hydroelectric resources are available, as are uranium resources to support a modest nuclear program. These resources provide the foundation for an expansion program supported to a large extent by financing from The World Bank. Part of an $850- million Bank-supported power project now under evaluation will address, if approved, the improvement of legislation encouraging private sector participation in power sector development. The major emphasis in power planning is on fossil fuel-based generation and improvement of transmission and distribution (T&D) systems. However, the county's vast needs and serious interest in renewable energy suggest that wind energy can contribute, particularly with adequate incentives to the private sector.

Table 4.8.1
Diesel Generating Sets in India
by Size and Capacity, 1984

Application	Rated Power (kW)	Inst. Units
Prime Power	to 5	69
	5.1 - 30	9634
	31 - 70	7514
	71 - 150	854
	151 - 300	654
	301 - 500	405
	501 -1000	84
Compact Portable	to 5	235
	5.1 - 30	2078
	31 - 70	130
	71 - 150	0
	151 - 300	0
	301 - 500	0
	501 -1000	0

Source: Power Systems Research

Renewable Energy Experience: The government of India has set ambitious goals for the use of renewable energy to assist in the relief of continuing power shortages, looking toward 15,000 MW of renewable capacity by the year 1990.[9-18] A significant target of 1200 MW of wind energy has been set for 1995.[9-19] Although these plans do not specifically include wind/diesel hybrids, they illustrate the sober intent of the Department of Non-Conventional Energy Sources (DNES) to make renewable energy an indispensable part of the solution to India's long-term energy needs. India is installing wind farms in Gujarat and Tamil Nadu with major assistance from DANIDA. Wind resource assessment and water pumping studies have been carried out by the DNES and supported through joint efforts of The World Bank and UNDP.

Several small wind turbines have been installed in remote areas to feed into larger diesel grids. Three 10 kW Bergey turbines were installed in Jammu and Kashmir to feed a 1 MW diesel grid. Similar installations are in progress in the Lakshadweep Islands. DANIDA and the government of India are discussing the possible installation of three pilot 100 kW wind/diesel systems on the Lakshadweep Islands, Karnataka, and Himachal Pradesh.[9-4,9-20]

4.8.3 Business Conditions

The United States is India's largest trading partner: trade amounted to about $4.5 billion in 1987.[9-5] Under the new export-import policy announced by the government of India in April 1988, the import of wind turbines was placed on the Open General License, meaning that there is no requirement for obtaining government permission prior to their importation. This policy is valid through March 1991. At present, no import tariffs or duties are levied on wind turbines, and this is expected to continue in the short term.[9-6] The DNES has supported duty free imports so far, and is likely to oppose any lobby for their imposition. The FCIA and the Export-Import Bank are imposing no special conditions on export credit insurance for India.[1-3] This trade status, coupled with the fact that the country is significantly short of power, means that the timing for wind generators is good. OPIC provides investment insurance to U.S. firms working in India, as well as loans to small businesses. They offer special programs to U.S. firms working in solar or other energy projects.

The negative side of the state of trade is that the reintroduction of tariffs, perhaps of 250%, is likely not far away. A second, hidden drawback to trade is the presence of electricity tariffs lower than cost. Tariffs for electricity for agricultural and irrigation use are particularly low; thus, private initiative wind energy projects for rural areas that are supplied by major grids will not be economically viable until energy pricing reforms are undertaken. Third, the Danish have made use of tied aid to India and rapidly claimed a lion's share of the wind energy market. However, in their focused effort to capture the wind farm market, they have abandoned the market for turbines under 100 kW, a key size range for wind/diesel village power applications.[9-7]

4.8.4 Market Opportunity: Village Electrification, Package Systems

<u>Opportunity Description</u>: Work in village electrification will be available through various Indian state and national agencies. Rural electrification is a major Indian goal, and recent claims were that 50% of rural India had been electrified. For marketing and other practical purposes, however, the percentage may be considered significantly smaller, since a village provided with a 40 W photovoltaic panel and a single light bulb might be considered "electrified." There are about 400,000 villages in India that are either without electricity or nominally electrified, and about 60,000 to 80,000 of these are likely to never be connected to the proposed national grid.[9-8] The number of inhabitants to never have grid-connected power may therefore be about 115 million.[9-9] A long-term solution to the problem of electricity supply to these villages will almost certainly include some form of renewable energy technology because fossil fuel costs to these areas will continue to be high for the same reasons that make grid connection impractical.

Currently, photovoltaic panels are almost synonymous with renewable energy in government-initiated village electrification projects. Emphasis on photovoltaic technology is more a result of precedent than of economics. Over 3000 villages have been provided with power from photovoltaic panels.[9-16] If small, reliable, wind/diesel package systems can be proven for this service where the wind regimes are adequate, there is no reason why they should not prosper.

The nature of the opportunity available to U.S. firms will depend on the exact character of the technology being marketed, the import restrictions in place at the time, and the source of the project funding. Package systems that can be demonstrated to have significant advantages over hybrids constructed piecemeal will have a better chance of success because the government-owned Bharat Heavy Electricals Ltd. (BHEL), which presently produces wind pumps and turbines for local use and conducts R&D, would be tempted to manufacture wind/diesel systems once their use in rural electrification was well established. Eventually, the systems would probably be required to be manufactured by an Indian firm such as BHEL. It may be expected that diesel generators manufactured locally would be required for all hybrid systems (perhaps excepting those projects funded through tied aid) because they are more economic and in common use. One Indian renewable energy developer believes that it is possible to view the installation of a stand-alone system as infrastructure already in place for the time that grid extension becomes affordable. If this becomes a government perception, diesel hybrid systems could be a significant part of long-term power planning, in theory, never becoming obsolete.

Project Funding and Contacts: The Rural Electrification Corporation's (REC) Decentralized Generation and Supply Division is responsible for electricity supply to areas for which grid connection is not feasible. Projects involving renewable energy in village electrification are generally coordinated with the DNES, as well as the SEBs and State Renewable Energy Agencies, where they exist.

Funding for wind/diesel projects may be obtained through several sources. USAID has an active office in India. The most favorable opportunities for U.S. firms may be obtained if funding is made available through USAID with the provision of aid contingent on purchase of U.S. equipment. A recently passed export aid bill has provided USAID with $15 million to be used to combat global warming through the use of renewable energy and reforestation programs.[9-11] To date no wind energy projects have been funded through The World Bank, appraisals are underway regarding the support of wind farm projects. Sources in the Bank indicate that although they have a history of financing larger scale projects, such as the construction of major thermal and hydroelectric power facilities, the possibility exists for the support of wind/diesel projects through ESMAP, a joint effort of The World Bank and UNDP.[9-12] ESMAP has a windfarm development preinvestment study under way in India. The World Bank approved $885 million in loans to the country in the power sector in 1989.[1-4] India also commonly obtains power sector financing from the Asian Development Bank.[9-13]

Existing Power Environment: The REC's objective of rural electrification (for villages previously without electricity) is that electricity should be available on demand in quantities required for agricultural loads, small-scale industrial loads, domestic and commercial lighting, community lighting, and drinking water loads.[9-10] One estimate of the needs of small rural communities, composed of between 100 and 1000 families, is about 2 kWh per family per day.[9-9]

Potential Wind/Diesel System Description and Operating Strategy: Systems with the greatest chance for success will likely be those that are fairly simple in operation and overall design concept, rugged and easily maintained, with features such as easily changed-out control electronics boards. (Microprocessor-based control systems that are tolerant of the climate should be considered mandatory.) These same features that enhance the maintenance and control aspects of the systems may also be their critical selling points. Transportation and erection considerations must be taken into account. Since it may be difficult or impossible to move cranes to the villages, turbine towers must be small enough to erect using other available vehicles. This will probably limit turbine sizes to 50 kW and below. Depending on the project goals, diesel units may be sized only to support critical loads: communications, essential refrigeration, and minimum drinking water and lighting, perhaps only a few kilowatts capacity.

4.8.5 Market Opportunity: Village Electrification, Retrofit Turbines

Opportunity Description: A number of remote areas in India are supplied by diesel generators on small grids and by smaller diesel gen sets. Wind turbines have already been installed successfully on small grids in several areas. Since electricity subsidies from the Government of India for rural areas were $0.04-$0.06/kWh in 1987, private purchase of wind turbines for this application are unlikely. Indian government agencies would be the purchasers. The incentives for them to purchase are the desire to reduce the subsidies that they provide for fossil-based electric generation and the desire to increase total national electric capacity in any economical manner. One estimate of rural diesel fuel cost was $1.60/gallon in 1985 [9-21], and the cost is probably much more in remote regions. Just as important an incentive to the government is the fact that the value of India energy imports is more than 50% of export earnings (1984). Preparation is under way for a $225 million project financed by The World Bank that specifically addresses the need to substitute fossil fuels with other forms of energy in the industrial sector.

Project Funding and Contacts: The same sources for funding and project leadership would be available for this opportunity as were available for the new village electrification option: various Indian government organizations supported by groups such as USAID, UNDP, and The World Bank. The Tata Energy Research Institute (TERI) installed its wind turbines under a project to study decentralized options in rural electricity supply. Its projects are sponsored by various Indian government ministries and by international organizations such as UNESCO, UNDP, and EEC.

Potential Wind/Diesel System Description and Operating Strategy: The system, as before, will be rugged, modular, and easily maintained. The variety of village sizes will yield loads that vary from tens of kilowatts to several megawatts. TERI installed 10 kW Bergey turbines in remote regions of Jammu and Kashmir, connected to grids of several megawatts.[9-4]

4.8.6 Market Opportunity: Water Pumping

Opportunity Description: In 1983-84, there were over 5.3 million electric pumpsets and 3.5 million diesel pumpsets in India.[9-1] One source evaluates traditional pumping costs by saying that if electric water pumping is considered as contributing to peak demand, the cost of supply of electricity for that use to a rural area (through the installation of 1 kW of thermal power with associated T&D costs) comes to about $2600.[9-1] On this basis, wind turbines may certainly compete favorably. The advantage of wind turbines connected to diesel generators is overwhelming, however, when it is considered that the diesel units may be shut down for long periods of time, depending on the sizing of the system. Additionally, wind turbines are particularly attractive when it is considered that many diesel sets are oversized and only a portion of the diesel gen set rating may actually be required from a turbine.[9-1]

The drawback to this opportunity is that the tendency may be for the Indian government and private enterprises to use locally manufactured wind pumps because of economics, except in the case of USAID projects (which use U.S. equipment).

Project Funding and Contacts: Since the value of energy imports in India has been over 50% of export earnings, there is significant incentive for the government to take steps to reduce the use of fossil fuel for diesel pumpsets. The use of electric pumpsets is being encouraged. However, in the many rural areas where electric grid T&D costs become quite high, the use of wind turbines with diesel gen sets is now an important option. The DNES has shown significant interest in the potential of wind turbines in water pumping. Almost 2500 windpumps have been installed.[9-14] It has been indicated that there is significant government funding available.[9-1] The World Bank and UNDP have supported the preparation of a study on India under the Global Windpump Evaluation Programme.

Existing Power Environment: The average pumpset capacity in 1983-84 was about 3.8 kW, and average yearly consumption was about 3500 kWh/ year. These performance data result in a load factor for irrigation pumping that is quite low: under 11%. Estimates are that by the year 2004-05, there will be about 12 million electric pumpsets in India, with a total of 44-48 GW of connected load.[9-1]

Potential Wind/Diesel System Description and Operating Strategy: The application of wind/diesel systems to water pumping may be a simpler technical challenge than that of village power for the simple reason that high availability at a certain demand is not as critical. It may be that changeovers from wind to diesel power may be needed only several times per season, following the seasonal winds and rains.

4.8.7 Market Opportunity: Private Industrial and Agricultural Power

Opportunity Description: By necessity, many private enterprises are removed from the regional electric grid. Invariably, their power costs are quite high. Grid-connected industries suffer huge power cuts in an undersupplied country. Ice making is one application that stands out as particularly suited to wind energy integration because of the substantial power requirements that could be met whenever adequate wind is available. Chemical plants of several megawatt demand have been cited as a significant private power opportunity. Wind industry sources indicate that these opportunities are numerous.[9-7]

Project Funding and Contacts: Aside from the numerous options for financing through the private sector, the Indian government is involved in a $225-million, World Bank-financed industrial energy conservation project. One objective mentioned specifically is to "improve the efficiency of processes [in selected industries], including substitution of petroleum-based fuels by other sources of energy."[9-15] The project is currently in the preparation phase.

Potential Wind/Diesel System Description and Operating Strategy: Since load curves and other power characteristics for different industries will vary so greatly, wind/diesel systems will tend to be one-off designs until wind industry practice and government research delineate standard approaches/hardware for their integration into specific industries.

4.8.8 Corollary Opportunities

In any country where the government is committed to supplying electricity to remote rural communities that are (and will be for some time) removed from a major electric grid, great potential exists for the installation of wind/diesel systems. This holds true even in areas where wind speeds are only moderate. Leaders of LDCs recognize that the costs to the country of not electrifying these areas are greater than costs of electrification at a premium; lack of electricity drives rural poor to city slums, while its provision helps local industry develop, reduces population growth, makes raising health standards easier, and unites the country through the electronic media. India's installation of photovoltaic systems in rural communities is clear evidence of these working principles. Perceptive leaders and governments that are receiving financial guidance from The World Bank realize the additional necessity of using renewable sources of energy to displace imported fossil fuels that are so detrimental to their balance of trade. The decision-making process for evaluating electrification options in this environment will strongly favor wind energy if the technology is demonstrated to be reliable for remote applications.

Much of northern and central Africa (e.g., Egypt, Ethiopia, Tanzania), the Near and Middle East (Pakistan, Saudi Arabia, Syria, for example), coastal and mountain areas in South America (such as Argentina and Chile), and predominantly island nations with moderate wind resources (e.g., Sri Lanka, Greece, Fiji, Madagascar) are all good opportunities, providing the governments are committed. A caveat would be that the opportunities are not necessarily equally open to all countries; some developing nations with a history of strong European presence might be less likely to use the services of the U.S. wind industry.

4.9 REPUBLIC OF KOREA

SOUTH KOREA WIND/DIESEL MARKET SUMMARY

Opportunities:

- Utility grid power: State-owned Korea Electric Power Corporation operates 1158 MW of diesel generating facilities, many of which are located in probable high wind areas.
- Military installation power: Many military facilities with diesel generators. U.S. military installations present opportunity to introduce technology to the country.

Advantages:

- Trade environment: Korea in excellent condition economically; USDOC notes it as one of top four targeted countries for exports.
- Energy environment: Government stressing reduction of (imported) petroleum use, with high price placed on diesel fuel and efforts in energy conservation.
- Country infrastructure: Rapid improvements being made in road systems, power systems, and technical education provide a foundation for introduction of wind turbines.

Disadvantages:

- Industrial environment: The advanced state of Korean industry suggests that wind turbines will be manufactured locally soon after they achieve popularity.

4.9.1 Wind Resource Characterization

Estimates by PNL, which are probably conservative, show Class 4 winds along the east coast of the country and in northern mountain regions. Exposed ridge crests and coastal areas may have winds of Class 5 or greater.[7-2]

4.9.2 Energy Market Characterization

South Korea's economy is energy intensive compared to those of nations with similar per capita incomes. This results in large part from the Korean focus on the development of industry. To support this emphasis, the country has in the past relied heavily on imports of petroleum, coal, and uranium. Its own non-renewable energy resources consist solely of anthracite coal. A new energy policy in 1980, however, was aimed at reducing oil and other imported energy dependence.

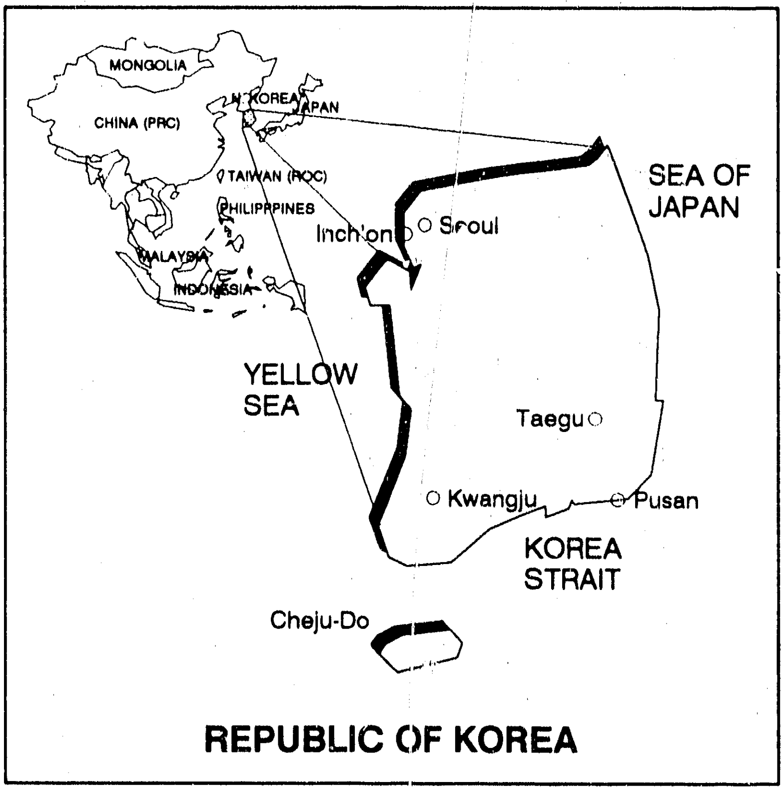


Figure 4.9.1

The impact of the new policy on the power sector was dramatic. In 1982, the Korea Electric Power Corporation generated 80% of its electricity using oil. By 1985, with shifts to coal and nuclear power, only 34% of generation was oil fired.[10-2] Plans for the use of domestic coal were set back, however, by mining difficulties and trouble with the hard-firing anthracite. To avoid importation of nuclear fuel, the Korea Nuclear Fuel Company was set up to manufacture needed fuel. It was scheduled to begin production in 1988. Hydropower is also being developed. Thirteen projects, to total 989 MW, are either under construction or planned.[1-1] Strong efforts in conservation have been made in both the residential and the commercial/industrial sectors. Energy pricing policies appear to be well conceived and effective. These well-planned efforts in the power sector have led to an astounding increase in total generating capacity from 367 MW in 1961 to 19,100 MW in 1988.[1-2] Diesel generating facilities are said to represent 1158 MW of that total.[1-1] Electricity consumption was expected to increase by about 29% between 1987 and 1991. Transmission lines span the country, with electricity reaching 99.6% of the total population in 1985.[10-2] Only isolated homes, small islands, and a few deep valleys remain to be electrified. The 345 kV transmission lines will eventually be extended to form three loop lines connecting the entire nation.[1-1] This energy situation has both positive and negative implications for wind/diesel generation.

4.9.3 Business Conditions

Ambitious planning of an export-oriented economy has resulted in a GNP increase of nearly 13% in both 1986 and 1987 and just over 12% in 1988, with accompanying modest inflation rates of 3% in 1986/87 and 7% in 1988. South Korea's industrial production growth rate in 1987 was 16.8%.[10-3] Growth in the economy is expected to continue at a reduced pace. The United States is South Korea's largest export market, and Korean imports from the States are second only to their imports from Japan. Exports to the United States in 1988 were valued at $21.2 billion, while merchandise imports from this country amounted to $12.8 billion, a 46% increase over the previous year's levels.[1-2] Significant appreciation in the Korean Won against the U.S. dollar and the easing of currency restrictions have contributed to this increase, as has the South Korean government's encouragement of private firms to buy U.S. merchandise whenever possible.

Tariff cuts, aimed at stimulating capital outflows and damping inflation, will reduce average tariffs from 18.1% in 1988 to 8.0% by 1993. Tariffs on industrial electronics and components are currently 5%-10%.[10-3]

OPIC provides investment insurance to U.S. firms working in South Korea, as well as loans to small businesses. They offer special programs to U.S. firms working in solar or other energy projects. The FCIA and the Export-Import Bank are imposing no special conditions on export credit insurance for South Korea.[1-3]

4.9.4 Market Opportunity: Utility Grid Power

Opportunity Description: With a clear picture of the power situation in South Korea, it becomes fairly easy to delineate the role that wind/diesel systems might play in the utility generation of electricity. With a number of diesel generating facilities still isolated from the national grid, coastal and mountain power plants would be able to reduce the use of diesel fuel (at $1.50/gallon in 1985) substantially by installing wind turbines. Generating facilities, varying in capacity, will have differing percentages of wind penetration, and therefore require more or less sophisticated control equipment.[10-4] With 1158 MW of installed diesel capacity, however, wind turbine capacity at most plants will probably be a relatively small percentage of the total plant capacity, and system controls and storage may be quite simple. (Connection is obviously not limited to diesel plants, if the economics are favorable.)

With extension of the transmission lines and continued large power plant construction planned, the isolated generating facilities will in time be connected to the national grid; and the capacity supplied by diesel generators will eventually be absorbed by other facilities. Grid expansion need not work to the detriment of wind systems, however. Wind electric generation is a long-term solution to power shortage with a short lead time. Connection of wind turbines to the existing diesel grid may be very attractive to South Korea regardless of future plans for diesel generation if wind systems installations are made with national grid connection in mind. Repair and maintenance of any wind systems installed will be made easier by the improving roads and relatively high level of technical training available in the country. The World Bank is helping to support a $513 million road improvement project and a $30 million technological education improvement project.[1-4]

An example of a site with excellent potential for retrofit installation of wind turbines is the southern island of Cheju Do. The island's total generating capacity of about 100 MW includes one 23.1 MW and one 25.0 MW diesel unit, with another diesel generator planned.[10-5] Winds on this island are estimated at Class 4.[7-2]

Project Funding and Contacts: The state-owned Korea Electric Power Corporation would be the purchaser of wind hybrid systems for grid connection. The recent increasing activity and cooperation, through CORECT, among DOE, USDOC, the Export-Import Bank, ECRE, the U.S. Department of the Treasury, and OPIC offer a logical path for technology development.[10-6] The USDOC, under the Trade Development Program, regularly sponsors trade fairs in and missions to various nations and provides financing for project feasibility studies.[10-7] Loans and export insurance are available through the Export-Import Bank and OPIC.

4.9.5 Corollary Opportunities

U.S. firms are currently banned from trading with North Korea; however, North Korea is now rapidly and inconspicuously making efforts to import Western technology. The head of the Ministry of Foreign Trade recently stated that they "favour expanded trade with Western countries irrespective of their own economic systems."[10-1] A number of North Korean firms are now actively trading with western European countries, Canada, Japan, and Hong Kong. With an increasing trade deficit, caused in part to major imports of petroleum from the U.S.S.R. and China, and with wind regimes of Class 4 to 6, a market potential exists.[7-2] The UNDP has been one avenue for trade in recent years and has the potential for being the means of introducing wind/diesel hybrid systems.

4.10 REPUBLIC OF THE SUDAN

SUDAN WIND/DIESEL MARKET SUMMARY

Opportunities:

- Village electrification: 92% of the population has no access to electricity, with grid extension unlikely for many villages. Private diesel generation estimated at 100 MW.
- Utility-owned diesel plants: Many remote diesel installations will not likely be connected to a large grid in the near future. Utility diesel capacity, remote and otherwise, totals 141 MW.
- Water pumping: Estimated capacity of 125 MW of diesel-driven pumps in the north; 85% of the labor in Sudan is agricultural. Great continuing needs for inexpensive water pumping. Black market diesel prices make irrigation unfeasible.

Advantages:

- Development project funding/renewable energy interest: Continuing World Bank assistance under the International Development Association's lenient loan terms supports development projects, including those in the power sector. Government shows some interest in renewable energy, looking for funds for wind/hybrid feasibility study.
- Wind resource: Class 4 and 5 winds in a substantial portion of northern and central Sudan, subject to verification by site measurements.
- Diesel fuel shortages: Supplies unreliable, with process of obtaining rations complex. Black market fuel price outside Khartoum three times that of official price.

Disadvantages:

- Stalemated political situation: Ongoing civil war makes any work, even supply of critical aid, extremely difficult in all three southern regions of the country; no market opportunities will be immediate.
- Economic status: Poverty of the Sudanese people limits export opportunities to development projects with outside financing.

4.10.1 Wind Resource Characterization

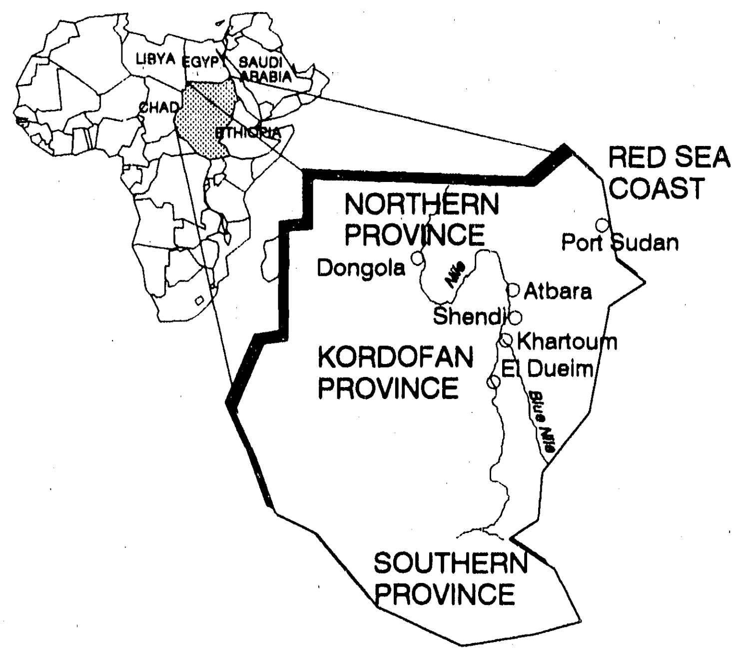


Figure 4.10.1

Estimates of wind resource by PNL show the most favorable areas (Classes 4 and 5) as being in the northern and central portions of Sudan, in the Northern and Kordofan provinces.[7-1, 7-2] Another assessment, based on meteorological data, shows only small areas of perhaps Class 3 winds at a 15-m height. [11-5] A third estimate, prepared by the Sudan National Energy Administration and apparently based on the same meteorological data, shows the highest winds to be near Dongola, in the Northern Province, at about 400 W/m^2 at a 15-m height. This estimate translates to about 6.6 m/s at 10 meters (using a standard power law), or Class 6 winds. Class 4 to 6 winds are specified for a large portion of the same north central area, including Khartoum.[11-1] In light of the conflicting reports, it appears that more complete resource assessments are required, with reliable equipment and proper siting.

4.10.2 Energy Market Characterization

Sudan has some reserves of petroleum and natural gas, as well as some unharnessed hydroelectric potential. However, quantities are not vast; other resources need to be developed, particularly as the population becomes more dependent on commercial sources of energy. The noncommercial fuels of wood, charcoal, and biomass supplied 82% of the country's energy needs in 1982.[11-1] This relatively low level of commercial use is due in part to limited access to electricity and frequent shortages of petroleum products, particularly fuels for transportation. Supplies of gasoline and diesel fuel are unreliable, and the process of obtaining rations is involved and timeconsuming. Black market fuel prices outside Khartoum are three times the official rate.[11-10] It has been common in the past for trucks to wait in line in Khartoum for diesel fuel for days at a time.

In the power sector, total installed capacity in 1988 was 606 MW.[1-2] Hydroelectricity represented 240 MW of this total. The remainder of capacity was petroleum based. Diesel capacity made up about 141 MW in 1986, with an estimated 100 MW of additional private diesel capacity.[11-9,11-2] Because of long construction lead times for hydroelectric facilities and the need for rapid expansion in generating capacity, new installations have included, and will likely continue to include, diesel plants. In the past, The World Bank considered thermal installations to be the sole option when rapid increases in generation were required, discounting wind energy potential.[11-1] In spite of their stated view, which has changed since their 1983 report, that renewable energy contributions to the country's energy supply could be marginal at best, they recommended the development of windmills for water pumping and the use of solar and biomass resources. Other sources indicate that the government is looking for funds for feasibility studies for wind/hybrid systems.[11-9]

Increases in electric consumption were expected to be almost 9% through 1991. The potential for demand increase is enormous, after political conflicts are resolved and even more basic human needs than electricity are provided. Average per capita consumption in 1988 was 50 kWh. In 1986, only 8% of the population had access to electricity. Most of them were served by the primary electric grid, the Blue Nile Grid, which produced 96% of total electric generation. There have been substantial improvements in power supply since 1985. Before that time, many long blackouts and power cuts were common. Despite problems of political unrest, drought, and shortage of foreign exchange, electric capacity has been raised; and salaries and working conditions for employees have been improved. USAID has been working with the Sudanese for a number of years to provide training and planning assistance, helping them to implement healthier energy pricing schemes. Many problems still exist, however, including power factor problems and electricity theft. In 1986, technical losses and unbilled consumption represented about 22% of total generation.[11-9] Since 15% is probably the most that can be attributed to technical losses, theft is significant. There are difficulties with high rates of staff absenteeism, low productivity, and overstaffing. All these factors make the prospect of working with the National Electricity Corporation (NEC) somewhat daunting.

Aside from hydroelectric generation, there are a number of renewable energy projects sponsored by various aid organizations, though small in terms of overall impact, and with no coordination among them. The United Kingdom, Germany, and Australia are sponsoring three wind energy projects.

4.10.3 Business Conditions

The economy of the Sudan continues to deteriorate, with average inflation through 1988 running at 55% and inflation at the end of the year galloping at 80%. Over 80% of the population are engaged in agriculture, the mainstay of the economy. GNP real growth rate from 1987 to 1988 was about 6%. Since 1979, the International Monetary Fund

(IMF) has been working with the country on its economic policies, forcing reforms in an effort to reduce high foreign debt. New assistance to Sudan from the United States has been suspended several times because of failure to repay loans for military equipment. U.S. law now requires that aid be limited to humanitarian relief and commodity sales. Under an amendment to the Foreign Assistance Act, USAID is required to develop a wind-up program for its mission in Sudan. A significant gray market economy exists in the country, aided by the transfer and exchange of income earned by Sudanese workers in the Arabian Gulf through channels other than commercial banks.[11-7]

Imports from the United States, primarily wheat and agricultural machinery, were $60 million in FY 1987/88, about four times the value of exports to the United States. Export credit insurance is not available for Sudan through the FCIA and the Export-Import Bank.[1-3] However, programs are available through OPIC.

The USDOS has issued a Travel Advisory for southern Sudan, western Sudan, and Khartoum. Although the most dangerous areas are the southern and southwestern areas of conflict, there have been terrorist incidents in Khartoum.

4.10.4 Market Opportunity: Village Electrification

Opportunity Description: Knowing that only 8% of the population has electricity, electrification of remote communities should be a priority if political and economic difficulties in the country can be resolved. Most likely, stand-alone systems will be prevail, since 70% of the population of 24 million live in rural areas and since extension of the small existing electric grid in a country the size of the United States west of the Rockies would be impractical. Wind/diesel systems are a particularly appropriate source of generation because more than 80% of the population is engaged in agriculture and wind pumping is already being promoted in the country. Besides the millions of Sudanese without electricity, some areas with privately owned diesel generators may have potential for connection to wind turbines.

Project Funding and Contacts: Village electrification could take two economic paths. The obvious path is that of development through foreign assistance, with opportunities for installation of U.S. wind/diesel systems coming through such agencies as The World Bank, the African Development Bank, or USAID. However, the near-term future of the USAID mission in Sudan in question. Additionally, DANIDA has ongoing projects in rural electrification in Sudan. Alternatively, if wind/diesel or other isolated power systems are demonstrated to be economical, purchase of the systems may come through the establishment of cooperatives, such as those found in northern Yemen. Remittances to Sudanese workers in the Gulf may be used to buy generating facilities on the gray market for their home villages. In this case, however, systems would not come directly from the United States.

Potential Wind/Diesel System Description and Operating Strategy: Wind/diesel systems for isolated villages will have requirements similar to those designed for the same application in India, (climate-tolerant, microprocessor-based control systems; installation using only four-wheel-drive vehicles). The need for a high reliability system will be even greater because skilled maintenance for the system will be impossible to obtain. Sudan shares with other developing nations in the region (such as Yemen) the problem that most skilled technicians and engineers have taken jobs in the oil-rich Gulf nations offering four times or more the salary of their home country. Wind resources and political considerations may dictate that wind hybrid systems be installed primarily in the north of the country, perhaps only in the Northern, Kordofan, and Khartoum regions. Wind turbines located too near the areas of conflict in the south may become easy targets for terrorists. Sand erosion of the turbine towers at various saltation levels and the effects of sand and dust on turbines at hub height will need to be investigated.

4.10.5 Market Opportunity: Isolated and Grid-Connected Utility Diesel Units

Opportunity Description: Generating facilities owned by the NEC and regional governments include about 140 MW of diesel plants (rated capacity). Of these, about 31 MW of isolated diesel facilities appear to be located in areas of Class 4 or greater wind speeds. Diesel plants connected to the Blue Nile Grid in areas of similar wind speed total about 76 MW. (However, since some discrepancies exist between the reports of wind resources; the figures for the Blue Nile Grid especially should not be taken as definitive.) Additionally, a number of the units were, as of 1986, undergoing rehabilitation, leaving the actual capacity for isolated locations at about 12 MW and the actual Blue Nile Grid capacity at 50 MW. Actual cost for heavy diesel fuel for nonremote locations in 1984 was about $0.60/gallon, with prices to the public about 20% lower. These prices are not representative of real current costs in more remote locations. Unreliable fuel supply will be a strong incentive, along with fuel cost, to connect wind turbines to the diesel generators. A final incentive is environmental. Pollution is widespread in the Sudan as a result of refuse burning, dust, and sewage; and the government is indicating that it wants to avoid additional pollution from the power sector.

Project Funding and Contacts: The World Bank has, in the past, helped to fund development in the power sector in Sudan and will likely continue to do so. DANIDA is currently undertaking missions to the country and is specifically financing diesel installation. The African Development Bank also has a history of financial support of Sudanese projects.

Existing Power Environment: One-half of the public utility rated diesel capacity is located in Burri, near Khartoum. This capacity is composed of 12 units, ranging from 1.5 to 2.5 MW each. There are about 50 isolated units in areas of good potential wind resource, owned by regional governments. These units appear to be between 200 kW and 500 kW, some larger, with as many as 10 units at one location. Only about one-half of these units appeared to be in service in 1986. The isolated stations include units at Atbara, Dongola, Shendi, El Gourashi, El Dueim, and the region of Kordofan. New diesel generators have recently been installed at Port Sudan. Maintenance standards are poor, and machines are often in disrepair because of lack of spare parts.

Potential Wind/Diesel System Description and Operating Strategy: Connection of wind turbines to the utility diesels should not pose the same problems as small village systems since high wind penetration will probably not be the norm. A strategy should be developed for wind turbine operation during extended no-diesel periods, which may be occasioned by lack of fuel or other problems. The most critical requirements are that turbines require very infrequent skilled maintenance and repair and that project planning be comprehensive, including provision of spare parts and training for low-level technicians.

4.10.6 Market Opportunity: Water Pumping

Opportunity Description: All three wind energy projects under way in the Sudan involve water pumping. About 12,500 diesel-driven pumps are in use in the northern part of the country, representing an installed capacity of some 125 MW. Unreliable supplies of diesel fuel and gray market prices for diesel fuel between 3 and 10 times the official price result in fields being abandoned because of the inability to provide irrigation at crucial points in the crop cycle. Final fuel prices may be many dollars per gallon. Agriculture is the primary sector in the economy, with over 80% of the population involved. Groundwater resources in Sudan are enormous, and it has been said that the country has the potential of being the breadbasket of the African continent. As with other opportunities, however, severe economic and political problems are making this a poor time for the initiation of projects. Competition in this application from western Europe and Australia will also be a significant impediment to the efforts of the U.S. wind industry and government.

Project Funding and Contacts: Considering the extremely high price of diesel fuel in the Sudan, a commercial market for wind systems will be possible when there is some significant improvement in the economy. Potential interest by private traders in the wind pump could be pursued through the USDOC's Agent/Distributor Service.

The other, more obvious market, will be through the work of such organizations as The World Bank and USAID. A USAID opportunity will hinge on the country's economic situation as well, since restrictions have been imposed on the organization because of Sudan's arrearage problems on military assistance loans. Even after that difficulty is resolved, the USAID mission in Sudan will need to decide what role it should play in helping develop wind pumping. The aid organizations of several countries have already outrun the United States in the initiation of wind pumping projects. Although 250 U.S.

wind pumps were installed in the early 1950s in Sudan, the design proved inadequate; and repair costs were high. The wind pumps were replaced with diesel and electric-driven pumps. In the past decade, Great Britain, Australia, and West Germany have been involved in wind energy programs involving water pumping. Most recently, the Dutch are installing 12 wind pumps in the area around Khartoum. No projects have made mention of potential wind/diesel interconnection.

In 1988, The World Bank approved a $20 million South Kassala agricultural project. Although this does not appear to be an area of particularly good annual winds, it is likely that other more promising areas of the country will be the focus of development work, with possibilities existing for wind pumping systems to be involved.

4.10.7 Corollary Opportunities

Sudan is an extreme case of a country in great need of reliable, less expensive sources of electricity for community and agricultural use. A number of African nations with similar needs and good wind resources have somewhat more promising economic situations. These include Somalia, Madagascar, Mauritania, Morocco, Algeria, Mali, Ethiopia, and Niger.

APPENDICES

WIND/DIESEL DATABASE

Classes of wind power density at 10 m and 50 m[a].

Wind Power Class	10 m (33 ft) Wind Power Density (W/m²)	10 m (33 ft) Speed[b] m/s (mph)	50 m (164 ft) Wind Power Density (W/m²)	50 m (164 ft) Speed[b] m/s (mph)
	0	0	0	0
1				
	100	4.4 (9.8)	200	5.6 (12.5)
2				
	150	5.1 (11.5)	300	6.4 (14.3)
3				
	200	5.6 (12.5)	400	7.0 (15.7)
4				
	250	6.0 (13.4)	500	7.5 (16.8)
5				
	300	6.4 (14.3)	600	8.0 (17.9)
6				
	400	7.0 (15.7)	800	8.8 (19.7)
7				
	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) of elevation.

Source: Pacific Northwest Laboratory

WIND/DIESEL DATA SPREADSHEET

Country	Wind Class	InstDiesl Gen Cap (MW)	Diesel FuelCost (US$/gal)	Diesel Market Gwth(%yr)	Wind Z	Gen Z	Fuel Z	Market Z	Total Z	Village Electrif Mkt (MW)
Albania	5				-1.13				-1.13	
Algeria	6	66.0	0.37	-1.1	-0.12	-0.49	-1.32	-0.86	-2.78	217
Andora	6				-0.12				-0.12	
Antarctica	7	8.0			0.89	-0.62			0.26	
Antigua	5	29.0			-1.13	-0.57			-1.70	
Argentina	9	7[illegible]0.0	0.43	0.1	2.90	1.17	-1.16	-0.55	2.35	142
Aruba	7	310.0			0.89	0.09			0.97	
Australia	7				0.89				0.89	
Austria	6	0.1	1.27		-0.12	-0.64	0.99		0.22	
Azore Isl	7	80.0			0.89	-0.45			0.43	
Bahamas	5	41.6			-1.13	-0.54			-1.67	
Barbados	6	74.0			-0.12	-0.47			-0.59	2
Brazil	5	807.0	0.51		-1.13	1.26	-0.96		-0.83	1135
Bulgaria	5				-1.13				-1.13	
Canada	7		0.68		0.89		-0.52		0.36	
Canary Isl	7				0.89				0.89	
Cape Verde Isl	5	10.3			-1.13	-0.62			-1.75	
Chile	10	741.0	0.55		3.91	1.10	-0.86		4.15	39
China	6				-0.12				-0.12	3824
Colombia	6	300.0			-0.12	0.06			-0.06	178
Costa Rica	6	140.0			-0.12	-0.31			-0.43	11
Crete	5	170.0			-1.13	-0.24			-1.37	
Cyprus	5	5.0			-1.13	-0.63			-1.76	0
Czechoslovakia	6				-0.12				-0.12	
Denmark	6	144.0	0.83		-0.12	-0.30	-0.14		-0.56	
Djibouti	7	80.0	0.76		0.89	-0.45	-0.32		0.11	
Dominica	5	4.8			-1.13	-0.63			-1.76	
Dominican Republic	7	200.0			0.89	-0.17			0.71	64
Egypt	7	218.0	0.05	10.2	0.89	-0.13	-2.14	2.02	0.64	505
Ethiopia	5	75.0	1.11		-1.13	-0.46	0.58		-1.02	801
Falkland Isl	8	9.2			1.89	-0.62			1.27	
Finland	6		0.75		-0.12		-0.34		-0.47	
France	6		1.19		-0.12		0.78		0.66	
Germany, East	5				-1.13				-1.13	
Germany, West	5		0.62		-1.13		-0.68		-1.81	
Great Britain	7		0.78		0.89		-0.27		0.62	
Greece	7		0.87		0.89		-0.04		0.85	
Greenland	7				0.89				0.89	
Haiti	5	137.0			-1.13	-0.32			-1.45	106
Iceland	8				1.89				1.89	
India	6	2000.0	1.15		-0.12	4.06	0.68		4.62	14492
Ireland	7		1.02		0.89		0.35		1.23	
Israel	6				-0.12				-0.12	
Italy	5		1.58		-1.13		1.78		0.65	
Jamaica	5	40.0	1.18		-1.13	-0.55	0.76		-0.92	25
Japan	6		1.17		-0.12		0.73		0.61	
Jordan	7	126.5	0.79		0.89	-0.34	-0.24		0.30	34
Kenya	5	68.0	1.27		-1.13	-0.48	0.99		-0.62	397
Korea, South	5	1158.0			-1.13	2.08			0.95	52
Kuwait	5				-1.13				-1.13	
Lebanon	6		0.79		-0.12		-0.24		-0.36	
Liechtenstein	6				-0.12				-0.12	
Madagascar	5	99.0	0.90	3.0	-1.13	-0.41	0.04	0.19	-1.31	193
Mauritania	6	44.0			-0.12	-0.54			-0.66	32
Mauritius	6	148.5	1.17	0.1	-0.12	-0.29	0.73	-0.55	-0.24	83
Mexico	7	1890.0	0.23		0.89	3.80	-1.68		3.01	394
Morocco	6	26.5	0.87	-4.0	-0.12	-0.58	-0.04	-1.59	-2.33	342
Namibia	7	24.0			0.89	-0.58			0.7[illegible]	
Netherlands Antill	7	125.0			0.89	-0.35			0.54	
New Zealand	8		1.00		1.89		0.30		2.19	
Norway	7		1.05		0.89		0.42		1.31	
Oman	5				-1.13				-1.13	
Peru	6	809.0	0.49		-0.12	1.26	-1.01		0.13	155
Philippines	7	600.0	0.52		0.89	0.77	-0.93		0.72	848
Poland	6				-0.12				-0.12	
Portugal	6	210.0	2.01		-0.12	-0.15	2.88		2.61	14
Romania	6	280.0			-0.12	0.02			-0.10	
St Lucia	6	21.7	1.49	5.9	-0.12	-0.59	1.55	[illegible]2	1.76	
Saudi Arabia	5	1090.0	0.91		-1.13	1.92	0.06		0.86	
Senegal	6	71.0			-0.12	-0.47			-0.60	115
Somalia	6	52.9		2.5	-0.12	-0.52		0.06	-0.58	80
South Africa	7				0.89				0.89	
South Pacific Isl	7				0.89				0.89	
Spain	7		1.13		0.89		0.63		1.51	
Sri Lanka	5	36.0	1.14		-1.13	-0.56	0.65		-1.03	318

WIND/DIESEL DATA SPREADSHEET

Country	Wind Class	InstDiesl Gen Cap (MW)	Diesel FuelCost (US$/gal)	Diesel Market Gwth(%yr)	Wind Z	Gen Z	Fuel Z	Market Z	Total Z	Village Electrif Mkt (MW)
Sudan	5	241.0	0.48	5.9	-1.13	-0.07	-1.04	0.92	-1.32	412
Sweden	6		1.11		-0.12		0.58		0.46	
Switzerland	6		0.60		-0.12		-0.73		-0.85	
Syria	6	280.0	1.18	0.1	-0.12	0.02	0.76	-0.55	0.10	108
Tanzania	5	167.0			-1.13	-0.25			-1.38	478
Tunisia	6	52.0	0.85		-0.12	-0.52	-0.09		-0.73	64
Turkey	5	585.0	1.01		-1.13	0.73	0.32		-0.07	400
Turks & Caicos Isl	6	9.1			-0.12	-0.62			-0.74	
USSR	7				0.89				0.89	
United States	7		0.62		0.89		-0.68		0.21	
Uruguay	5	12.0	0.83		-1.13	-0.61	-0.14		-1.88	5
Venezuela	6		0.07		-0.12		-2.09		-2.21	
Yemen (northern)	7	116.0	0.57		0.89	-0.37	-0.81		-0.29	186
Yemen (southern)	7	67.6			0.89	-0.48			0.40	36
Yugoslavia	5		1.63		-1.13		1.91		0.78	62
Zambia	5	130.0			-1.13	-0.34			-1.46	60
Means	6.1	272.7	0.88	2.3						
Std Devs	1.0	425.6	0.39	3.9						
Z Weighting					1.00	1.00	1.00	1.00		
Total		15000								26409

WIND/DIESEL DATA SPREADSHEET

Country	Wind InfoDate	Gen Cap InfoDate	Diesel FuelCost InfoDate	Market Growth InfoDate	Comments
Albania	1981				All wind data 89 gen fm Elliott,al!'81 fm wind map;vill mkt '80 WB % elect@.03kW/cap
Algeria	1981	1986	1987	1986	Cap from World Bank; all mkt data '82 to latest data;lt fuel oil,no trans,no subsidy
Andora	1981				
Antarctic	1989	1989			Cap estimated & assumed diesel
Antigua	1986	1986			
Argentina	1981	1988	1988	1988	Cap from WB rpt;light fuel oil,EIA;exp growth inst cap shown both + and - to 1993
Aruba	1986	1988			Cap assumed diesel,CIA;wind Carib assessment
Australia	1981				
Austria	1981	1989	1988		Residential light fuel oil costs,EIA
Azore Isl	1981	1989			Cap estimated from Portugal self-prod nos
Bahamas	1981	1988			Cap from World Bank
Barbados	1986	1988			Cap from World Bank
Brazil	1981	1980	1988		Self-prod thermal assumed diesel;light fuel oil,EIA
Bulgaria	1981				
Canada	1981		1988		Light fuel oil cost not for remote locs, EIA
Canary Is	1981				
Cape Verd	1984	1986	1984		Wind at 6.6 m/s from WB;gasoil for power gen from WB
Chile	1981	1980	1988		Self-prod thermal assumed diesel; fuel oil
China	1981				
Colombia	1981	1980			Self-prod thermal assumed diesel
Costa Ric	1989	1984			Wind est based on WindP Monthly 8/89 narrative
Crete	1981	1986			Cap est; much thermal assumed diesel
Cyprus	1981	1980			Self-prod thermal assumed diesel
Czechoslo	1981				
Denmark	1981	1985	1988		Half of diesel/gas cap assumed diesel;light fuel oil (indus),EIA
Djibouti	1981	1986	1988		Fuel oil cost for public elect
Dominica	1981	1987			Cap from World Bank
Dominican	1986	1980			Cap est; much self-prod thermal assumed diesel
Egypt	1989	1980	1989	1991	Self-prod therm assum diesel + WB rpt-data old;mkt data from proj to '91;fuel oil-WB
Ethiopia	1981	1986	1988		Cap estimated from IDEU;light fuel oil,EIA
Falkland	1981	1988			Cap assumed diesel
Finland	1981		1988		Light fuel oil,EIA
France	1981		1988		Light fuel oil,EIA
Germany,	1981				
Germany,	1981		1988		Light fuel oil,EIA
Great Bri	1981		1988		Light fuel oil residential, EIA
Greece	1981		1988		Light fuel oil not for remote isl,EIA
Greenland	1981				
Haiti	1981	1984			
Iceland	1981				
India	1989	1980	1988		Cap estimated; much self-prod thermal assumed diesel;lt fuel oil not remote cost,EIA
Ireland	1981		1988		Light fuel oil not for remote isl,EIA
Israel	1981				
Italy	1981		1988		Light fuel oil not for remote isl,EIA
Jamaica	1986	1986	1988		Cap from World Bank;light fuel oil,EIA
Japan	1981		1988		Light fuel oil, EIA
Jordan	1981	1986	1987		Self-prod thermal cap assumed diesel;diesel fuel costs fo electric gen in Marka
Kenya	1981	1984	1982		Self-prod thermal cap assumed diesel;industrial diesel oil,# from WB
Korea, So	1981	1986			
Kuwait	1989				
Lebanon	1981		1988		Light fuel oil,EIA
Liechtens	1981				
Madagasca	1981	1986	1987	1987	Cap from World Bank; diesel#2 cost approx; market # is demand growth avg 1981-85
Mauritani	1981	1984			
Mauritius	1981	1987	1987	1987	Cap from World Bank;diesel oil cost
Mexico	1986	1980	1988		Self-prod thermal cap assumed diesl;resident lt fueloil cost not for remote locs,EIA
Morocco	1981	1986	1988	1986	Cap from World Bank;light fuel oil,EIA
Namibia	1981	1986			
Netherlan	1986	1988			Cap assumed diesel,CIA;wind Carib assessment
New Zeala	1981		1988		Light fuel oil,EIA
Norway	1981		1988		Light fuel oil,EIA
Oman	1981				
Peru	1981	1980	1988		Self-prod thermal cap assumed diesel; fuel oil w/ subs, # from IEA
Philippin	1981	1980	1988		Self-prod thermal cap assumed diesel;lt fuel oil residential, not remote areas,EIA
Poland	1981				
Portugal	1981	1980	1988		Cap is 290 MW less est cap for Azores;light fuel oil not remote areas,EIA
Romania	1981	1980			Cap est as one-third of total self-prod
St Lucia	1986	1987	1984	1987	Cap from World Bank;diesel fuel
Saudi Ara	1989	1986	1988		Light fuel oil,EIA
Senegal	1981	1986			Cap is projected; date is approx
Somalia	1981	1987		1988	Cap from World Bank
South Afr	1981				
South Pac	1981				
Spain	1989		1988		Wind est based on WindP Monthly 9/89 narrative; light fuel oil,EIA
Sri Lanka	1981	1980	1988		Self-prod thermal cap assumed diesel;light fuel oil,EIA

WIND/DIESEL DATA SPREADSHEET

Country	Wind InfoDate	Gen Cap InfoDate	Diesel FuelCost InfoDate	Market Growth InfoDate	Comments
Sudan	1981	1986	1986	1986	Cap incl 100 MW est private;all WB nos;heavy diesl w/ subsidy
Sweden	1981		1988		Light fuel oil,EIA
Switzerla	1981		1988		Light fuel oil,EIA
Syria	1981	1984	1985	1985	No mkt data but 0% suspected;gasoil price at parallel mkt rate of exchange
Tanzania	1981	1986			
Tunisia	1981	1987	1988		Self-prod thermal cap assumed diesel,added to STEG 2MW;lt fuel oil residential,EIA
Turkey	1981	1980	1988		Self-prod thermal cap assumed diesel;light fuel oil,EIA
Turks & C	1986	1989			Cap assumed diesel (CIA)
USSR	1981				
United St	1981		1988		Light fuel oil cost not for remote locs, EIA
Uruguay	1981	1984	1988		Light fuel oil, EIA
Venezuela	1981		1988		Light fuel oil, EIA
Yemen (no	1981	1988	1984		Cap data is projected, WB; gasoil/fueloil costs
Yemen (so	1981	1980			Cap data old; total cap >doubled since 1980
Yugoslavi	1981		1988		Light fuel oil, EIA
Zambia	1981	1982			

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LIST OF ACRONYMS

AEA	Alaskan Energy Authority
BHEL	Bharat Heavy Electricals Ltd., India
CDE	Corporacion Dominicana de Electricidad, main Dominican Republic utility
CEA	Corporacion Estatal de Azucar, Dominican Republic
CERL	Construction Engineering Research Laboratory, U.S. Army
CODELCO	Corporacion Nacional del Cobre-Chile, Chilean electricity generator
CORECT	Committee on Renewable Energy Commerce and Trade
DANIDA	Danish international aid organization
DNES	Department of Non-Conventional Energy Sources, India
DOE	U.S. Department of Energy
ECRE	U.S. Export Council for Renewable Energy
EEA	Egyptian Electricity Authority
EEC	European Economic Community
EIA	Energy Information Administration, U.S. Department of Energy
EMR	Department of Energy, Mines, and Resources, Canadian government
ESMAP	Energy Sector Management Assistance Program
Export-Import Bank	Export-Import Bank of the United States
FCIA	Foreign Credit Insurance Association, United States
Gen set	generator set
GNP	Gross National Product
HAI	Hellenic Aerospace Industry, Greece
IMF	International Monetary Fund
LDC	less developed country
LRMC	long-run marginal cost
m/s	meters per second
NEC	National Electricity Corporation, Sudan
NREA	New and Renewable Energy Authority, Egypt
NWT	Northwest Territorities, Canada
OECD	Organization for Economic Cooperation and Development
OPIC	Overseas Private Investment Corporation, United States
PCE	Power Cost Equalization Program, Alaska Energy Authority
PNL	Battelle Pacific Northwest Laboratories
PPC	Public Power Corporation, Greece
REC	Rural Electrification Corporation, India
SEB	State Electricity Boards, India
T&D	transmission and distribution
TERI	Tata Energy Research Institute, India
TWh	trillion watt-hours
UN	United Nations
UNDP	United Nations Development Program
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USAID	U.S. Agency for International Development
USDOC	U.S. Department of Commerce
USDOS	U.S. Department of State

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16. Abstract (Limit: 200 words)

Wind/diesel generation systems combine wind turbine technology with diesel generator sets. Such systems could be an attractive energy-producing technology option in many areas of the world that currently depend on diesel generator sets for electricity. Advantages of these hybrid systems over conventional diesel generator sets include the systems' ability to: reduce consumption of expensive diesel fuel in remote locations ("fuel-saver" capacity); extend the diesel fuel supply in locations where fuel delivery is infrequent; and provide electricity at a cost that is lower than diesel generator set electricity.

The world market potential for wind/diesel hybrid technology is a function of the need for electric power, the availability of sufficient wind resource to support wind/diesel power, and the existence of buyers with the financial means to invest in the technology. This study includes data related to each of these three factors. This study does not address market penetration, which would require analysis of application-specific wind/diesel economics. Buyer purchase criteria, which are vital to assessing market penetration, are discussed only generally.

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