APPENDIX III

PRE-FEASIBILITY STUDY ON WIND POWER PROJECTS

CHAPTER 1 INTRODUCTION

1.1 Objectives of the Study

The objective of the whole study is to formulate a rural electrification implementation plan by Renewable Energy in La Paz and Oruro. The study on wind power focused on the following objectives:

1) To identify appropriate sites for wind monitoring and install ten wind monitoring systems; 5 in La Paz and 5 in Oruro.
2) To identify priority sites for wind power development and evaluate cost competitiveness.
3) To select high priority projects for pre-feasibility study; one in La Paz and two in Oruro and conduct the pre-feasibility study.

1.2 Survey and Study Conducted:

The field survey commenced on August 7, 1999 and continued up to September 7, 2001 intermittently with the following survey stages:

1)	First field survey:	August	7, 1999	-	September	20, 1999
2)	Second field survey:	January	5, 2000	-	February	12, 2000
3)	Third field survey:	May	15, 2000	-	July	14, 2000
4)	Forth field survey:	January	5, 2001	-	February	15, 2001
5)	Fifth field survey:	May	10, 2001	-	June	8, 2001
6)	Sixth field survey:	August	27, 2001	-	September	7, 2001

Survey and study conducted during the above period are as follows:

- Collection of the existing wind data and information.
- Site selection of the wind monitoring system.
- Procurement of equipment and contractor, and supervision of construction

- Monitoring of the wind monitoring system / collection of data and analysis of the wind data.
- Project formulation for wind power development.
- Selection of high priority and economic/financial analysis of the projects.

CHAPTER 2 DATA COLLECTION

Related data and information were collected from following organizations:

(1) VMEH

"ELECTRIFICATION RURAL Base de Datos"
Contents: population, source of energy

" Reporte de Mediciones Estacion #3" CRE"
Contents: wind data in Santa Cruz

(2) SENAMHI

Wind Speed and Direction（1 to 10 years ）
The following wind data were collected and are presented in Table 1.1 and 1.2.

La Paz	・EL ALTO	・CHARAÑA	・AYOAYO
	・PATACAMAYA	・PUERTO ACOSTA	
	・TIWANACU	・COLLANA	
	・HICHUCOTA	・HUARINA	・ACHIRI
Oruro	・ORURO	・CARACOLLO	・CORQUE
	・HUACHACALLA		・COIPASA
	・SALINAS DE GARCI MENDOSA		

Wind Map: Wind Map of Bolivia

The available wind data and information on wind are quite limited and no reliable wind data exist in La Paz and Oruro. As the picture shows climate observation unit of SENAMHI, the monitoring height is low and the wind speed is recorded manually.

Climate Observation Unit of SENAMHI

CHAPTER 3 SITE SELECTION AND INSTALLATION OF WIND MONITORING SYSTEM

3.1 Site Selection of Wind Monitoring System

For the installation of the wind monitoring systems, 5 in La Paz and 5 in Oruro, site selection of the wind monitoring system was conducted on the basis of following criteria.

3.1.1 Selection Criteria

For the selection of the candidate sites for the wind monitoring, the following aspects were taken into account and compared.

(1) Sites where meteorological observation record was available by SENAMHI

If the accuracy of the SENAMHI data was confirmed by the results of JICA survey, the data will be used for the rural electrification plan. However, the result of the comparison indicates that the data of SENAMHI was not accurate.

(2) Sites where other alternative energy sources (except grid extension) are available.

Wind is not a stable energy source for isolated power plant. In general, wind generation is combined with diesel, micro-hydro power or photovoltaic power to produce stable power in electrification plan for isolated communities. Besides, the villages using other energy sources have ample experience in operation and maintenance of isolated power plants.

(3) Size of population

Available VMEH data were used to assess population of Cantons in La Paz and Oruro. As appropriate sizes of population, Cantons with population over 300 in La Paz and over 200 in Oruro were selected considering the magnitude of beneficiaries of the project. Canton population in Oruro is smaller than that of La Paz in general.

(4) Sites which will not be covered by grid extension within 5 – 10 years

Isolated system is planned for the power generation by renewable energy in this study on the rural electrification. The sites to be selected are non-electrified sites by grid within a foreseeable future.

(5) Geographical distribution and accessibility for data collection

Geographical distribution was taken into account for selecting the sites to cover the non-electrified area. At the same time, access condition to candidate sites was also considered because data collection on the candidate sites will be carried out for a year.

3.1.2 Selected Sites

Using the criteria mentioned above, appropriate sites for installing the wind monitoring system were selected; 5 sites in La Paz and 5 sites in Oruro. The characteristics of the selected sites are summarized as follows and their locations are indicated in Figure 3.1 and Figure 3.2.

(1) La Paz

1) Achiri, Municipality : Caquiaviri
Population : 1609
Household : 977
Existing alternative energy source: Diesel (20kW), PV for hospital and public well

2) Charaña, Municipality : Charaña
Population : 1016
Household : 331
Existing alternative energy source: Diesel (135kW), PV

3) Ramon Gonzales Municipality : G.J.J.Perez
Population : 545
Household : 202
Existing alternative energy source: Hydro Power Station from Chayazani 60kW

4) Isla Taquiri Municipality: Manco Kapac
Population : 300
Household : 100

Existing alternative energy source: None

5) Santiago de Llallagua Municipality: Colquencha
Population : 1537
Household : 498
Existing alternative energy source: None

(2) Oruro

1) The boundary between Comujo and Coipasa Municipality : Coipasa

Comujo
Population : 150
Household : 25
Existing alternative energy source: Connected with Hydro Power Station from Todos Santos 150kW

Coipasa
Population : 371
Household : 187
Existing alternative energy source: Connected with Hydro Power Station from Todos Santos 150kW

The candidate site of wind monitoring system is located between Comujo and Coipasa

2) Caripe Municipality: C.de Carangas
Population : 206
Household : 93
Existing alternative energy source: None

3) ChachacomaniMunicipality : Turco
Population : 470
Household : 232
Existing alternative energy source: None

4) Salinas de Garci Mendoza Municipality :S.Garci Mendoza
Population : 1564
Household : 1038
Existing alternative energy source: None

5) Sevaruyo Municipality: S.de.Quillacas
Population : 694
Household : 504
Existing alternative energy source: Diesel (60kW)

3.2 Installation and Monitoring

3.2.1 Installation Work

(1) Scope of Work for Installation

Wind monitoring systems were installed at the selected sites. Scope of work for the installation consists of the following items.

1) Transport equipment of the wind monitoring system
2) Construction of the tower foundation.
3) Installation of wind monitoring system.
4) Installation of fence.
5) Grounding Work.
6) Final inspection.

(2) Contract and Supervision of Construction Work

a) Process of the Contract

Process of the contract award to the local construction company, EDESER Co.,Ltd., were explained below.

1) Request for cost estimate to three local construction companies was issued on 2 September 1999. The JICA Study Team sent the specifications for the installation work to the following companies after checking the contents of their duties and experience.

   1. EDESER.Co.,Ltd., (EDESER)
   2. CADE Bolivia S.A. (CADE)
   3. CODIMEC S.R.L. (COIMEC)

Cost estimate of EDESER Co.,Ltd., was the lowest among the three companies, which was finally selected as the contractor for installation.

b) Outline of the Construction Company

The EDESER Co., was founded in January 1997and presently has two hundred fifty employees, one hundred twenty five in La Paz office, thirty five in Oruro office and ninety in Santa Cruz office.

(3) Installation of Wind Monitoring Systems

The installation works of the wind monitoring systems begin on 6 January and finished on 4 February 2000. The installation works started later than originally scheduled due to the customs clearance. The installation process of the wind monitoring systems is shown in following photos.

(a)Anemometer and wind vane

(b) Grounding work

(c) Monitoring tower election

(d) Sensor set-up

(e) Data logger set-up

(f) Data logger

(g) Monitoring tower at Caripe

(h) Monitoring tower at Comjo

(4) Problems and Countermeasure during Installation Work

Supervising work for the construction was conducted by the JICA expert, in which the following problems were encountered.

Problems	Countermeasure
Only one set of gin pole with a winch was available for tower erection works of ten sites.	Rearrange the tower installation schedule. Foundation work commenced before the tower erection works.
More than 4 days were required for concrete curing because of the rain.	Concrete foundation was built in the beginning of installation work.
Short of labors for fence work, grounding work and tower erection work.	The contracted company hired labors in the villages at the site.
Area for wind monitoring system installation was too small.	Reduce the diameter of anchors.
Transportation problems due to bad road condition in rain season.	Avoid travel at night and with one vehicle.
Ground was too soft to install anchors.	Instead of screwing the anchors into the ground, fixed by cement.
Software for receiving raw data from Data Card could not be installed into PC computer of La Paz prefecture.	Install the software to the computer in the office of VMEH.
The absolute pressure was too low to collect data by using a BP-20 pressure sensor and a DL9300 data logger.	It was necessary to change the SIM card in the data logger.

(5) Considerations for Wind Turbine Installation in Future

Following aspects are to be taken into consideration for installation in future.

- In the rainy season, it is difficult to construct the foundation and transport the heavy equipment especially in the southern part of Oruro. The foundation work shall be constructed during the dry season.
- Electricity is not available at most of the sites. Engine driven generators shall be used for construction work.
- Tower of the wind turbine shall be erected by a winch due to limited space for crane or using other heavy construction machine. For easy maintenance, installation of the hand driven type winch is recommended for wind turbine foundation.

- Communication equipment such as portable telephones or satellite phones are necessary for work.

3.2.2 Monitoring

After installation of the system, the JICA Study Team commenced monitoring and data collection for the planning of wind power development projects.

(1) Monitoring System

The wind monitoring system consists of three components: the NRG 9300 stand-alone logger, the Term Reader, hand held terminal reader and the Base Station (data collection and management software). The wind data sampling will be made in the following process.

- Wind data is collected from multiple sites by NRG 9300 data logger.
- Collected data in data card is transmitted to Base Station by using Term Reader.
- Base Station produces ASCII data files.

Stand Alone Data Logger

The stand-alone logger collects samples from meteorological sensors that measure wind speed, wind direction, temperature, humidity, absolute pressure and solar radiation. The logger has 12 input channels, removable SIM cards for customization of sensor inputs, a programmable real-time clock, and removable 256-kilobyte non-volatile Flash Data Card for data storage. According to the specification, 8 input channels are used for data collection, two counter inputs for anemometers and six analog inputs for the other sensors.

The data logger collects samples from all input channels once every seconds, then, calculate the average for each channel at the end of 10 minutes. In addition to calculating averages, the microprocessor calculates standard deviation of one-second samples in the intervals, updates minimum and maximum values. The ranges of the raw sensor output and data logger output are shown below. The data card has a storage capacity covering 53 days by 10 minutes average interval with 8 channels. The data logger records voltage of internal batteries and temperature. The data cards are collected during periodic visits to the measurement site and then, downloaded to the base computer's serial port using the Term Reader. Structure of the wind monitoring system is also presented in the following figure.

Term Reader

Term reader is used to configure and monitor the stand-alone logger in the field. When attached to a computer running Base Station software, the Term Reader downloads data stored on data card to the Base Station.

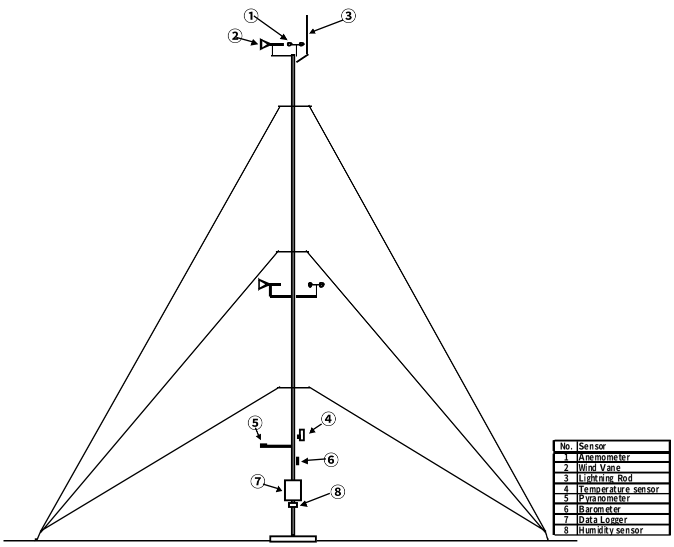
Base Station

Base Station software manages the collection and organization of raw data from the logger. The Base Station reads raw data from data card, applies slopes and offsets the installation sensors and maintains site information and historical data. The Base Station also exports data as ASCII files with spreadsheets or other programs.

Parameters of Sensors

No.	Channel No.	Input	Sensor	Raw Sensor Output	Data Logger Output Range
1	1	Counter	Anemometer(20m)	0 to 120 Hz	0 to 91.3 m/s
2	4	Counter	Anemometer(10m)	0 to 120 Hz	0 to 91.3 m/s
3	1	Analog	Wind Vane(20m)	0 to 2.5 V	0 to 359 degrees
4	2	Analog	Wind Vane(10m)	0 to 2.5 V	0 to 359 degrees
5	3	Analog	Pyranometer	80 to 100 μA/1000W/m	0 to 3000 W/m2
6	4	Analog	Temperature Sensor	0 to 2.5 V	-40 to 52.5 ℃
7	5	Analog	Barometer	0 to 5 V	78.5 to 108.6 kPa
8	6	Analog	Relative Humudity Sensor	0 to 5 V	0 to 100 %

(Source: JICA Study Team)



(Source: JICA Study Team)

Wind Monitoring System

(2) Data Sampling

The collected data for the wind analysis are from February 2000 to January 2001. The table below summarized percentage of collected data throughout one-year wind monitoring period. The data collection was successfully conducted. However, the barometric pressure was not recorded for 4 months because of SIM card problems and some data errors on solar radiation data caused by sensor problems.

Collected Data

ID No.	Site	Collected data / annual hours
1	Achiri	99.1%
2	Charaña	99.1%
3	Gonzales	97.2%
4	Is. Taquiri	97.3%
5	Llallagua	90.6%
6	Comjo	100.0%
7	Caripe	99.6%
8	Chachacomani	99.6%
9	Salinas	90.5%
10	Sevaruyo	91.8%

Source: JICA Study Team

The collected data from the wind monitoring are presented in Table 3.1.

3.3 Analysis of the Collected Data

Analysis of the collection data was made for formulating the priority projects for wind power development. The data analysis on annual wind speed and diurnal wind speed are most important for selecting sites for wind power development.

3.3.1 Monthly Average Wind Speed

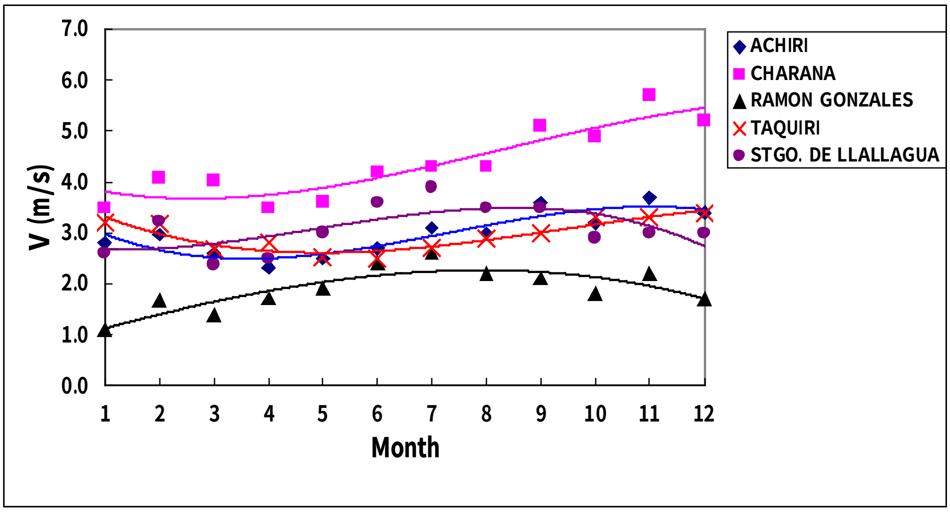
The wind speed is a very important factor for the energy to be generated by a wind turbine. The energy of the wind power varies with the cube of the average wind speed. If the wind speed is two times it produces eight times of energy. The sites with average annual wind speed higher than 4.5m/s at 10 meters above ground level is recommended for planning wind power.

Wind speed at 20 meters and 10 meters above ground level was monitored for a year. The following figure shows monthly average wind speed at 20 meters height at the monitoring sites in La Paz. The monthly average wind speed at Charaña is the highest throughout a year. The wind speed is the lowest at Ramon Gonzales during the monitoring period. The average wind speeds at the other sites, Achiri, Taquiri and Santiago de Llallagua are at almost same level. Charaña recorded the highest monthly average wind speed in La Paz.

Monthly Average Wind Speed in La Paz

ID No.	Site Name	1	2	3	4	5	6	7	8	9	10	11	12
1	ACHIRI	2.8	3.0	2.6	2.3	2.5	2.7	3.1	3.0	3.6	3.2	3.7	3.4
2	CHARANA	3.5	4.1	4.0	3.5	3.6	4.2	4.3	4.3	5.1	4.9	5.7	5.2
3	RAMON GONZALES	1.1	1.7	1.4	1.7	1.9	2.4	2.6	2.2	2.1	1.8	2.2	1.7
4	TAQUIRI	3.2	3.2	2.7	2.8	2.5	2.5	2.7	2.9	3.0	3.3	3.3	3.4
5	STGO. DE LLALLAGUA	2.6	3.2	2.4	2.5	3.0	3.6	3.9	3.5	3.5	2.9	3.0	3.0

Source: JICA Study Team



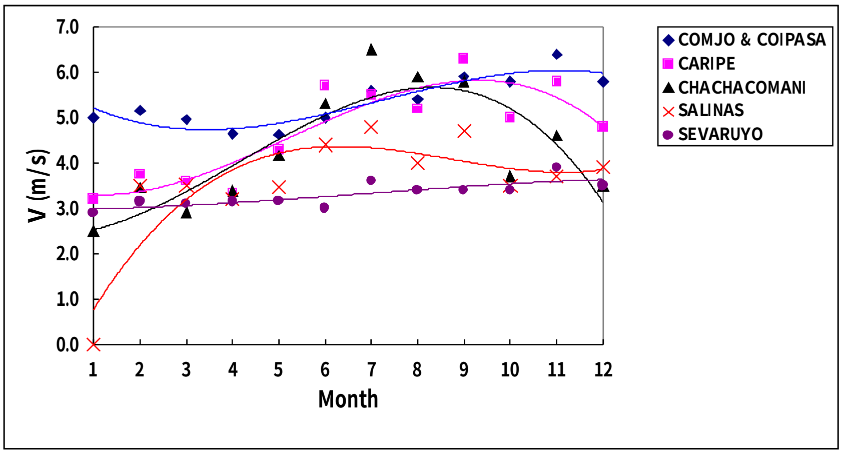
Source: JICA Study Team

In Oruro, the average wind speed Comjo / Coipasa recorded the highest wind speed throughout one year wind monitoring. The average wind speed recorded at Caripe and Chachacomani is also high. All of the three sites are located west side of Oruro department, adjacent to high mountains. As indicated below, strong wind was recorded at the west side of Oruro department.

Monthly Average Wind Speed in La Paz Prefecture

ID No.	Site Name	1	2	3	4	5	6	7	8	9	10	11	12
6	COMJO & COIPASA	5.0	5.2	5.0	4.6	4.6	5.0	5.6	5.4	5.9	5.8	6.4	5.8
7	CARIPE	3.2	3.8	3.6	3.3	4.3	5.7	5.5	5.2	6.3	5.0	5.8	4.8
8	CHACHACOMANI	2.5	3.5	2.9	3.4	4.2	5.3	6.5	5.9	5.8	3.7	4.6	3.5
9	SALINAS	-	3.5	3.5	3.2	3.5	4.4	4.8	4.0	4.7	3.5	3.7	3.9
10	SEVARUYO	2.9	3.1	3.1	3.1	3.2	3.0	3.6	3.4	3.4	3.4	3.9	3.5

Source: JICA Study Team

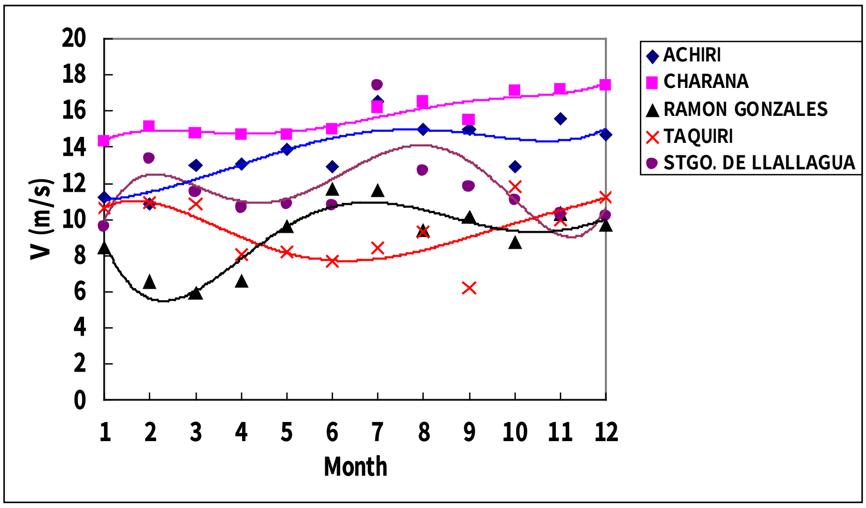


Source: JICA Study Team

3.3.2 Maximum Wind Speed

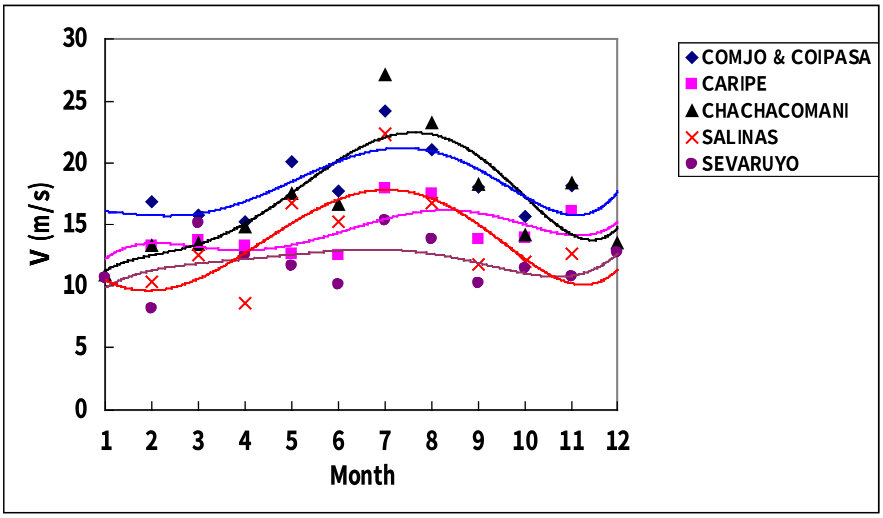
Maximum instantaneous wind speed at 20 meters height should be under 60 m/s for wind power generation.

The following figure shows monthly maximum wind speed (10 minutes average) at 20 meters above ground level in La Paz. The maximum wind speed is high at Charaña and Achiri throughout a year and low in Taquiri and Ramon Gonzales. In Charaña, the maximum wind maintains high level continuously. The highest maximum wind speed of 17.4 m/s was recorded at Santiago de Llallagua in July.



Monthly Maximum Wind Speed in La Paz

In Oruro, the maximum wind speed is high in Chachacomani and between Comjo and Coipasa and low in Sevaruyo. The highest maximum wind speed of 27m/s was recorded at Chachacomani in July.

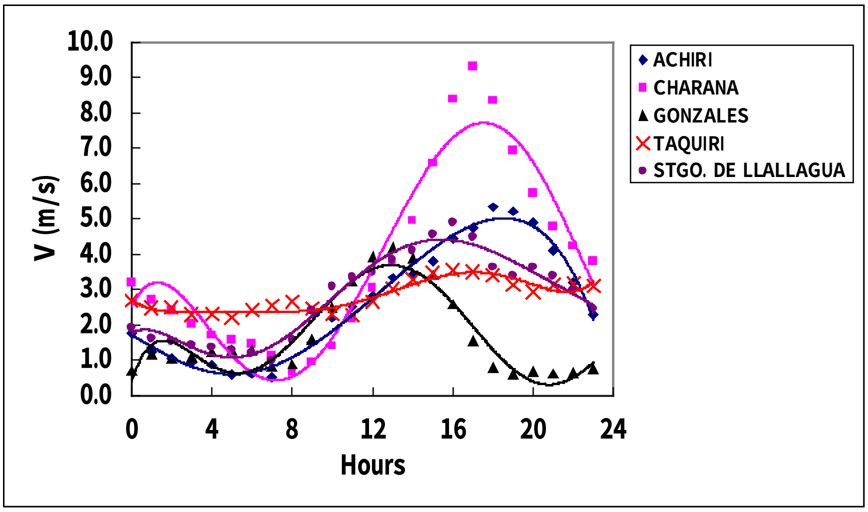


Monthly Maximum Wind Speed in Oruro

3.3.3 Diurnal Wind Speed

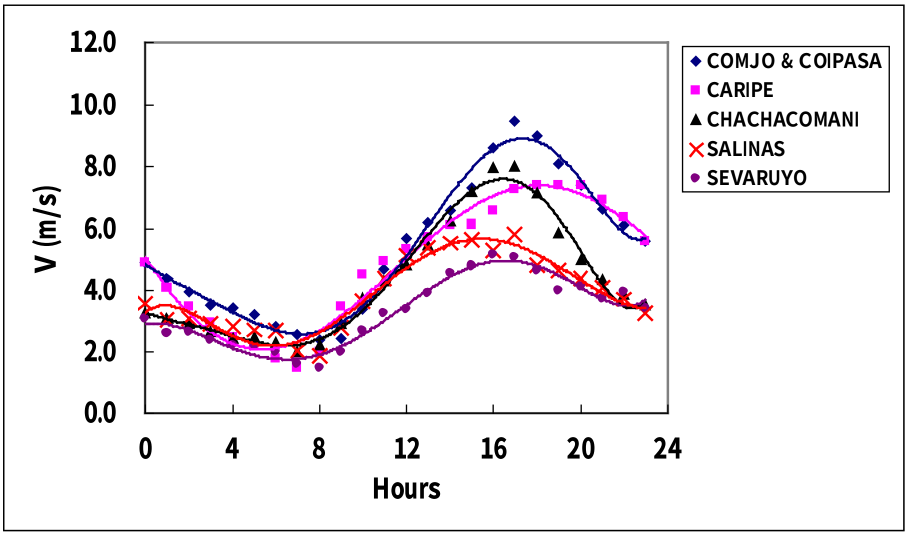
The diurnal wind speed is an important factor for the estimate of the balance between power output from wind turbine and the demand at sites. The produced energy of the wind power differs from time to time in a day. If the wind speed is high and steady at peak demand time, large capacity of battery is not required for the system.

The next figure shows diurnal wind speed at monitoring sites in La Paz department. The diurnal wind speed presented in the figure indicates the average during February 2000 to January 2001. The data of Charaña show unique diurnal wind speed pattern. The average wind speed in a year is 4.4 m/s, however, the average wind speed from 13:00 to 23:00 is high at 7.0 m/s. Since the peak power demand at Charaña is between 19:00 to 21:30, the diurnal wind speed pattern corresponds to the demand. At Achiri and Santiago de Llallagua, the wind speeds become stronger in the afternoon till evening. At Ramon Gonzales, the average diurnal wind speed is the highest at noon. At Taquiri Islands, the diurnal wind speed is relatively stable and low.



Diurnal Wind Speed in La Paz

The figure below shows diurnal wind speed at wind monitoring sites in Oruro department. The diurnal wind speed presented in the figure indicates the average from February 2000 to January 2001. The average wind speed between Comjo and Coipasa is 5.3m/s, however, the average wind speed from 13:00 to 23:00 is high at 7.4 m/s. In Chachacomani the average wind speed is 4.5 m/s, but the average during 13:00 to 23:00 is high at 6.2 m/s. In Caripe the average wind speed is 4.8 m/s, while the average during 13:00 to 23:00 is high at 6.6 m/s. The average wind speed in Salinas and Sevaruyo is relatively flat and low.



Diurnal Wind Speed in Oruro

3.3.4 Wind Direction

Study on the wind rose is very useful for planning wind power. If most of the wind blows from a particular direction, it is necessary to smooth the terrain or remove obstacles in that direction.

The wind direction during February 2000 to January 2001 in La Paz is shown in Figure 3.3. The wind direction during February 2000 to January 2001 at Chachacomani and Sevaruyo, and that during February to November 2000 at Caripe,Salinas and between Comjo and Sevaruyo in Oruro is shown in Figure 3.4.

The wind rose shows relative distribution of wind directions. The wind rose varies at locations and the primary wind direction at Achiri and Isla Taquiri is north. At Charaña, most of the wind blows from southwest and southwest west. The wind direction is steady at Ramon Gonzales, which is surrounded by high mountains. The wind comes from various directions at Santiago de Llallagua.

The primary wind direction between Comjo and Coipasa, Caripe and Chachacomani is west. The primary wind direction at Salinas is north-northwest while that at Sevaruyo is north.

3.3.5 Wind Speed Frequency

The variation in the wind speed is well described by the Weibull probability distribution with shape parameter "k" and the scale parameter "A". The value of "k" determines the shape of the curve while the value of "A" determines distribution of hours with higher wind speed. Typical histograms of wind speed are shown in Figure 3.5 and 3.6. The Figure shows a probability density distribution. The area under the curve is always exactly one or 100%.

At all of the monitoring sites, the shape parameter "k" is small due to the unique diurnal pattern of the wind speed. In La Paz, at all of the sites except Isla Taquiri, the peak of wind speed distribution is between 0 to 2 m/s and the parameter "k" is small. At Isla Taquiri, the wind speed distribution is 2 to 3 m/s. The peak of wind speed distribution in Oruro is higher than that of La Paz in average. Between Comjo and Coipasa, the peak of wind speed distribution is high at 3 to 5 m/s. At the other sites, the peak of wind speed distribution is between 1 to 3 m/s.

3.3.6 Solar Radiation, Temperature, Humidity and Barometric Pressure

Solar radiation, temperature, humidity and barometric pressure were also measured at each monitoring site. Barometric pressure was not recorded from February to May 2000 due to the problem on SIM card. Solar radiation data of Chachacomani, Salinas and Sevaruyo were not collected for a few months because of the problems on the sensor. The monthly data are shown in Table 3.1.

CHAPTER 4 WIND ENERGY POTENTIAL AND SELECTION OF PRE-FEASIBILITY STUDY SITES

4.1 Wind Power Potential in La Paz and Oruro

Wind data monitored by the meteorological agency of Bolivia are not reliable because of the monitoring system so the agency collected wind data manually only three times a day. Beside this, the data collected at the airport could not be provided to our study. Therefore, the number of reliable wind data in the project area is quite limited although more than hundreds of data are necessary for preparing the wind map all over the La Paz and Oruro.

Under this situation, the wind energy potential map was prepared preliminarily on the basis of the collected wind data throughout this study and available geographic data as presented in Figure 4.1 and 4.2.

This wind potential map indicates high wind potential area where estimated annual average wind speeds exceed 4.0 m/s, and the number in the circle shows annual average wind speed at 20 meters above ground level on the map. The result shows that the wind potential area in Oruro is larger than that of La Paz. The wind potential is high especially in west side of Oruro and southwest part of La Paz. On the other hand, the population of the non-electrified villages in the high wind potential area of La Paz is larger than that of Oruro.

4.2 Selection of High Potential Development Sites

Three potential sites for La Paz and Oruro are to be selected for further study based on the results of one-year wind monitoring and socio-economic data. As criteria for the selection, wind potential, Canton population and development priority on prefectures were take into consideration. At the site where average annual wind speed exceeds 4.0 m/s the highest score of 5 was given, and where annual average wind speed less than 2.5 m/s the lowest score 1 was given. Regarding demand potential, the site where the population is over 1000 the highest score of 5 was given. The site where high potential was given by prefecture the highest rank A with score of 5 was given. Details of the scoring rules are shown below.

1. Wind Potential

Wind Speed (m/s)	Scoring Point
4<=V	5
3.5<= V <4.0	4
3.0<= V <3.5	3
2.5<= V <3.0	2
V <2.5	1

2. Demand Potential

Population	Scoring Point
1000<=V	5
750<= V <1100	4
500<= V <750	3
250<= V <500	2
V <250	1

3. Development Priority

Recommendation	Scoring Point
A	5
B	4
C	3
D	2
E	1

The calculated scores estimated for the ten (10) candidate sites are presented in the following table.

Score Sheet for the Selection of Pre-F/S Candidate Sites

	ID No.	Site Name	Wind (m/s)	point	Population	point	Recommendation by Prefecture	point	Total Point	Rank
La Paz	1	Achiri	3.2	3	1642	5	B	4	12	2
	2	Charana	4.4	5	1037	5	A	5	15	1
	3	Gonzales	2.0	1	500	3	C	3	7	4
	4	Is. Taquiri	2.9	2	300	2	D	2	6	5
	5	Llallagua	3.0	3	1538	5	E	1	9	3
Oruro	6	Coipasa / Comjo	5.3	5	450	2	C	3	10	2
	7	Caripe	4.6	5	208	1	B	4	10	2
	8	Chachacomani	4.8	5	476	3	A	5	13	1
	9	Salinas	3.2	3	1603	5	E	1	9	4
	10	Sevaruyo	3.0	3	698	3	D	2	8	5

Source: JICA Study Team

On the basis of the above results, the following three Cantons, one in La Paz and two in Oruro are selected for pre-feasibility study.

La Paz	1	Charaña
Oruro	1	Chachacomani
	2	Caripe

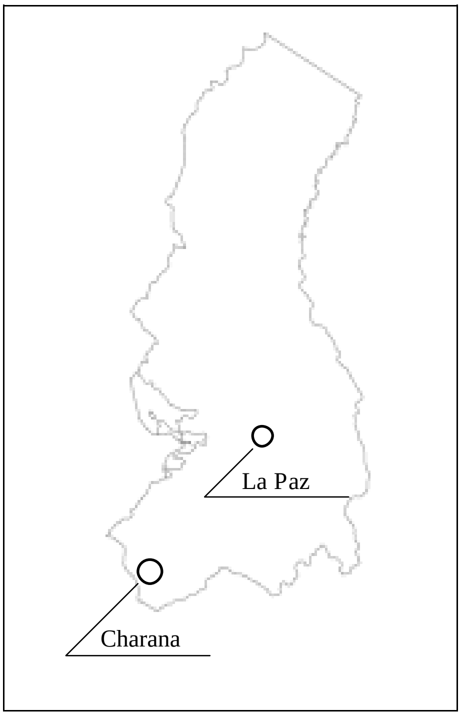
CHAPTER 5 PRE-FEASIBILITY STUDY ON CHARAÑA WIND POWER PROJECT IN LA PAZ

5.1 Location and Topography

Charaña is a border town between Bolivia and Chile and 233 km southwest from La Paz city. The location map and the picture are shown below. The temperature in Charaña is low being located at 4,054 meters above sea level and near the high mountains of 6,000 meters. Annual average temperature is 5.1 ℃ and minimum temperature is -18.4℃ in July. There are two different seasons, dry and rainy season. The annual precipitation is around 300mm at Charaña.

Location

Latitude: S 17°35’ 48”
Longitude: W 69°26’ 56”
Altitude: 4054 m



Location Map of Charaña

Wind Monitoring Tower of Charaña

5.2 Socio-economic Conditions and Demand for Electricity.

5.2.1 Socio-economic Conditions

Basic information on socio-economic condition of Charaña is shown in Table 5.1.

(1) Population

The population of Charaña was 1,037 in 1992, which decreased to 1,016 in 2000 according to the census.

(2) Local Economy

The main economic activity in Charaña is customs service and related activities. other economic activities are small factories producing clothes and livestock breeding.

(3) Electricity and Other Infrastructure

Electricity is being supplied by a diesel generator in Charaña. The installed capacity of the diesel generator is 135 kVA supplying electricity to 80 households from 19:00 to 21:30 every day. The diesel generator is operated by the Canton. The electricity tariff per household is 30 Bs per month, while the households without electricity spend around 25 Bs per month for gas lamp. The water supply system is being operated by the Canton. The system supplies water to 200 households with the water tariff of 5 Bs per month. There exist three schools in Charaña, namely, public elementary school, private elementary school and public secondary school. About 200 students are in public elementary school, about 150 in private elementary school and 60 in secondary school. All the schools have no electricity supply service. There is a health clinic with electricity supplied by PV system. Main purpose of the electricity supply is radio communication and lighting.

5.2.2 Demand for Electricity

The demand for electricity of the Charaña wind power project was estimated on the basis of the results of the community interview survey. Since there are commercial and public facilities in addition to residence, the demand was estimated for commercial activity, public service and household use, separately. The target year for the estimate of the demand was set at year 2005.

(1) Demand for Household Use

According to the result of the community interview survey, the existing household is divided into two types, namely, small household and large household. Different kinds of electric appliances were held by each type of household and accordingly, consumption of electricity differed. From the result of the survey, unit rates for electricity consumption were estimated both for small household and large household as summarized below.

Power Demand for Household

Household		Electric appliance	No.	Power (W)	Electric Consumption (hours/day)	Energy (kWh/day)	Total Power Consumption (kWh/day)	Annual Power Consumption (kWh/year)
1	Household (small)	CF Light	1	12	4	0.048		
		60W Light	2	60	4	0.48		
		Radio	1	15	8	0.12	0.65	260
2	Household (large)	CF Light	2	12	5	0.12		
		60W Light	2	60	5	0.6		
		AM/FM stereo	1	20	4	0.08		
		TV set(19"color)	1	60	4	0.24		
		Water pump	1	100	3	0.3	1.34	538

Source: JICA Study Team

(2) Demand for Commercial Use

As for commercial facilities, there are restaurant, store, office and small industrial facilities in Charaña. The demand for electricity is small in small restaurants, while it is large in large restaurants or large stores. The demand for electricity is high in offices, in general. Small-scale industries will be established after electrification by renewable energy. The unit rates of the electricity consumption for commercial use were estimated and are presented in the following.

Power Demand for Commercial

	Micro-enterprise	Electric appliance	No.	Power (W)	Electric Consumption (hours/day)	Energy (kWh/day)	Total Power Consumption (kWh/day)	Annual Power Consumption (kWh/year)
1	Cafe(small)	CF Light	2	12	5	0.12		
		60W Light	1	60	2	0.12		119
		Radio	1	20	6	0.12	**0.40**	(300days/year)
2	Cafe(large)	CF Light	3	12	5	0.18		
		60W Light	1	60	2	0.12		
		Blender	1	350	1	0.35		
		Stereo	1	55	2	0.11		330
		TV set(25"color)	1	120	2	0.24	**1.10**	(300days/year)
3	Store (small)	CF Light	2	12	3	0.072		
		60W Light	2	60	2	0.24		129
		Radio	1	20	4	0.08	**0.43**	(300days/year)
4	Store (large)	CF Light	2	12	3	0.072		
		60W Light	2	60	2	0.24		
		Radio	1	20	4	0.08		525
		Refridgrrator	1	120	10	1.2	**1.75**	(300days/year)
5	Office (small)	CF Light	2	12	3	0.072		
		60W Light	2	60	3	0.36		
		TV set(19"color)	1	60	2	0.12		
		Computer set	1	155	3	0.465		362
		Printer	1	500	0.5	0.25	**1.39**	(260days/year)
6	Office (large)	CF Light	4	12	6	0.288		
		60W Light	4	60	10	2.4		
		Computer set	3	155	6	2.79		
		Printer	1	500	1	0.5		
		TV set(25"color)	1	120	2	0.24		1813
		VCR	1	120	1	0.12	**6.97**	(260days/year)
7	Small Industry	60W Light	2	60	1	0.12		163
	(Sewing)	Sewing machine	1	75	5	0.375	**0.54**	(300days/year)

Source: JICA Study Team

(3) Demand for Public Facilities

Existing public facilities are community center, school and health clinic. The unit rates of electricity consumption for the public facilities were estimated as summarized in the following.

Power Demand for Public Facilities

	Public Facility	Electric appliance	No.	Power (W)	Electric Consumption (hours/day)	Energy (kWh/day)	Total Power Consumption (kWh/day)	Annual Power Consumption (kWh/year)
1	Community	CF Light	8	12	6	0.576		
	Center	60W Light	2	60	6	0.72		
	(large)	TV set(25"color)	1	120	3	0.36		
		VCR	1	120	1	0.12		524
		Stereo	1	55	1	0.055	**2.01**	(260days/year)
2	School	CF Light	44	12	6	3.168		
	(8 class room)	60W Light	6	60	12	4.32		
		TV set(25"color)	3	120	2	0.72		
		VCR	2	120	1	0.24		2151
		Stereo	1	55	1	0.055	**9.35**	(230days/year)
3	Health Clinic	CF Light	6	12	6	0.432		
	(large)	60W Light	2	60	6	0.72		
		Vaccine Refrige.	1	60	24	1.44		
		VHF radio(stand-by)	1	2	24	0.048		
		VHF radio	1	30	1	0.03		
		Vaporizer	1	40	2	0.08		1073
		Water Pump	1	100	5	0.5	**3.58**	(300days/year)

Source: JICA Study Team

(4) Total Estimated Demand

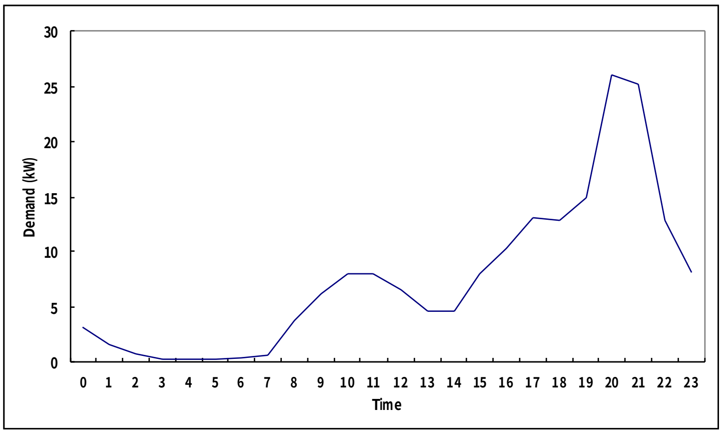
For estimating the total demand for electricity, numbers of the facilities were projected in due consideration of the future development in the project area.

The projected numbers of the facilities are as follows.

Item		Number
Households	large	30
	small	120
Café	large	3
	small	5
Store	large	2
	small	3
Office	large	3
	small	4
Small business	-	10
Community center	large	1
School	large	3
Health clinic	large	1

Source: JICA Study Team

Based on the above figures and the estimated unit electricity consumption, the total demand for electricity was calculated. The daily power demand curve was estimated as presented as follows. The peak demand is around 26kW, which occurs during 20:00 to 21:00. Table 5.2 shows the estimated daily power demand.



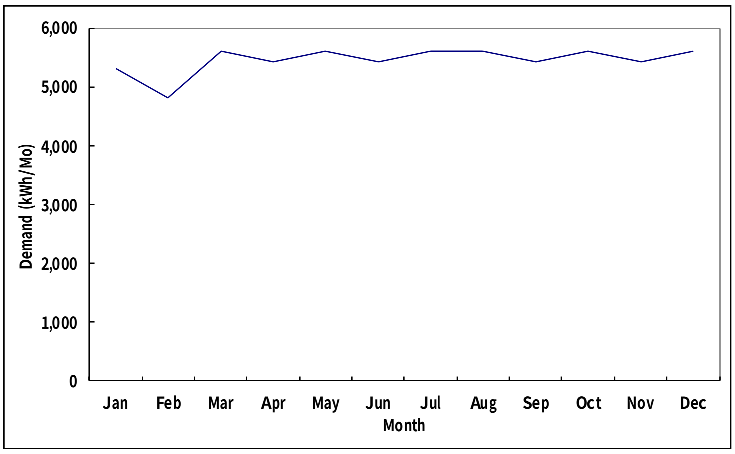
Estimated Daily Power Demand Curve

The monthly power demand was also calculated as presented in the following table and figure. As indicated, the total annual demand for electricity was estimated at 65,678kWh.

Monthly Power Demand of Charaña

Month	Demand kWh/Mo
Jan	5,328
Feb	4,812
Mar	5,626
Apr	5,445
May	5,626
Jun	5,445
Jul	5,626
Aug	5,626
Sep	5,445
Oct	5,626
Nov	5,445
Dec	5,626
	65,678

Source: JICA Study Team

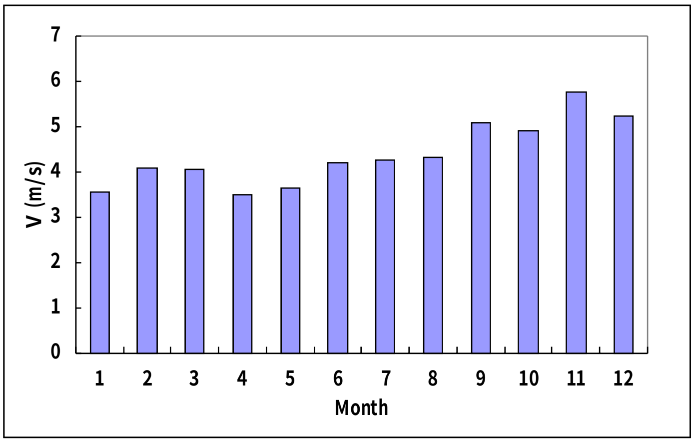


Estimated Annual Demand Curve

5.3 Wind Data Analysis

5.3.1 Analysis of Wind Data

The monthly and diurnal average wind speeds at 20 meters above ground level are shown in the next figure. The annual average wind speed at Charaña is 4.37 m/s. In Charaña, the monthly average wind speed from September to December is high at 5.2 m/s, while the average monthly wind speed from January to August is low at 3.9 m/s. This indicates that the power output differs from month to month.



Monthly Average Wind Speed (m/s)

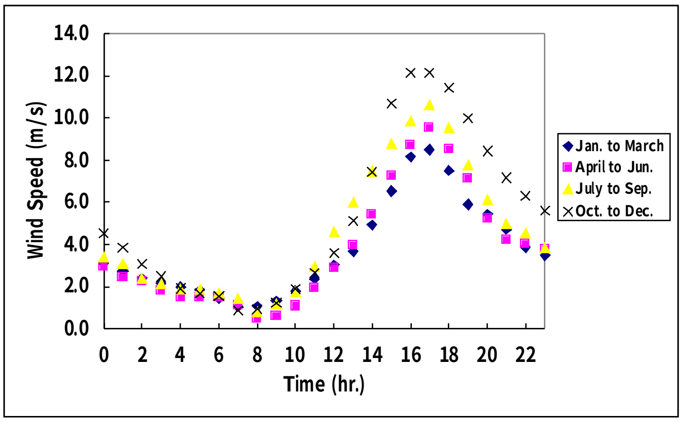
Monthly Average Wind Speed (m/s)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Average Wind Speed (m/s)	3.5	4.1	4.0	3.5	3.6	4.2	4.3	4.3	5.1	4.9	5.7	5.2

Source: JICA Study Team

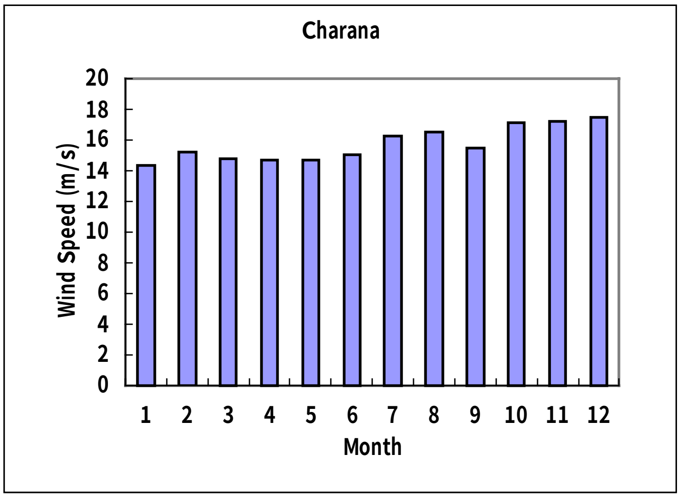
According to the diurnal wind pattern, the wind blows strong from 14:00 to 20:00 when demand for electricity is higher. On the other hand, the wind blows very weak from 0:00 to 12:00 for generating electricity.

Considering this, wind pattern at Charaña, a hybrid generation system with the other energy source is necessary for supplying stable power.



Diurnal Average Wind Speed (m/s)

The monthly maximum wind speed of 10 minutes average at 20 meters above ground level in Charaña is shown below. The annual average of the maximum wind speed is 15.8 m/s. The results indicate that there is no extraordinary strong wind such as typhoon or hurricane.



Monthly Maximum Wind Speed (m/s)

Monthly Maximum Wind Speed (m/s)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Average Wind Speed (m/s)	14.3	15.2	14.8	14.7	14.7	15.0	16.2	16.5	15.5	17.1	17.2	17.4

Source: JICA Study Team

The monthly average directional wind speeds at Charaña are shown in Figure 5.1. In Charaña, the average wind speed of southwest direction is the strongest throughout a year. Therefore, it is necessary to regulate construction of any building at the upstream.

Table 5.3 shows distribution of monthly wind speed directional frequency at Charaña. This figure shows directional frequency of high wind speed is high in south -southwest to west-west north direction.

The Figure 5.2 shows frequency distribution of wind direction. The frequency distribution of wind direction is high in southwest corresponding to the direction of the strongest wind speed. The frequency of wind direction is steady in Charaña.

Figure 5.3 shows Weibull probability density distribution at Charaña. The variations in the wind speed are well described by the Weibull probability distribution with shape parameter “k” and the scale parameter “A”. The value of “k” determines the shape of the curve. The value of “A” determines distribution of hours with higher speed. The annual average of the parameter k is 1.15 and A is 4.5. Since, strong wind blows only in the afternoon, the difference of average wind speed in the morning and afternoon makes the shape parameter “k” small.

Table 5.4 shows monthly wind energy density. The wind power varies linearly with the air density sweeping the blades. The air density varies with pressure and temperature. In general, wind energy density is small in Charaña due to the high altitude. The site with wind energy density over 150 W/m^2 at 10 meters above ground level is suitable for wind power development. The monthly average of wind energy density is small in Charaña, however the value from afternoon to evening is high because strong wind blows during that time.

Table 5.5 shows turbulence intensity that is relating wind speed and terrain. Turbulence intensity is defined as the ratio of standard deviation of the wind speed to the mean of the wind speed. The place with turbulence intensity under 0.3 at 20 meters above ground level is suitable for wind power development. The turbulence intensity of Charaña is under 0.3 in all directions.

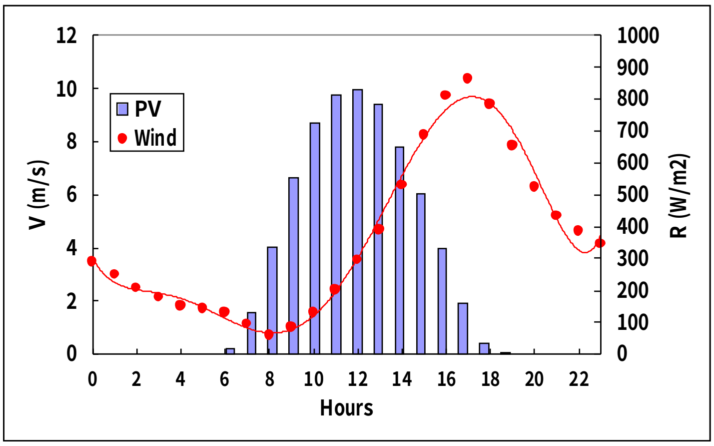
5.3.2 Complementary Relation between Wind and Solar Energies

There are seasonal and diurnal variations in the wind speed pattern. This makes it difficult to get steady energy from stand-alone wind generation system. However, there is a complementary relation between wind and solar energies in Charaña.

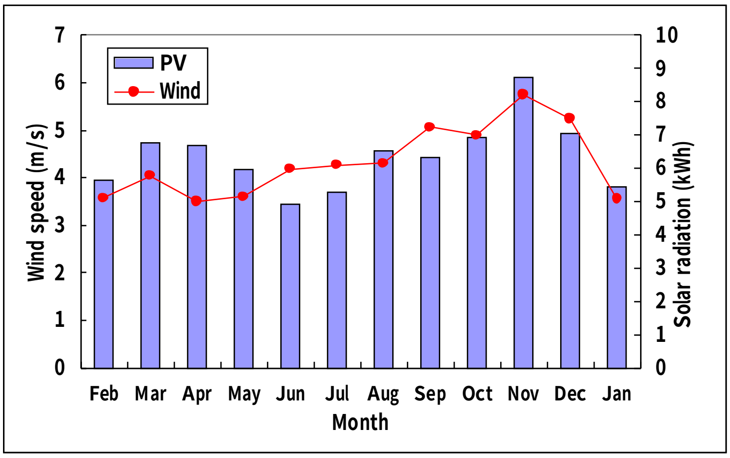
The following figure shows complementary relation between wind speed and solar radiation in Charaña. The energy potential of solar is high from 9:00 to 15:00 when the wind speed is still low, while the wind speed is high from 14:00 to 20:00 when the solar radiation is weak. Therefore, it is planned that the wind and PV be combined in a hybrid system to obtain stable energy.

In the second figure, the monthly average of wind speed and that of solar energy are presented summarizing the average monthly figure during February 2000 to January 2001. The complementary relation is not identified in this figure.

There is a geographical complementary relation between wind and solar energies caused by the high altitude. Wind potential in high altitude becomes lower because of the small value of the air density. On the other hand, solar radiation becomes higher at high altitude because of the clean air.



Diurnal Wind Speed vs. Solar Radiation at Charaña



Monthly Wind Speed vs. Solar Radiation at Charaña

5.4 Formulation of Optimum Development Scheme

Stand-alone wind generation system does not have enough capacity of generating electricity during daytime in Charaña, although there is high demand for electricity from offices and schools. To generate more stable electricity, the wind generation is to be combined with the other energy source.

The options of the combinations are:

1. Wind – Diesel Hybrid System
2. Wind – PV Hybrid System
3. Wind-Micro Hydro Hybrid System

According to the policy of VMEH, installation of diesel generator is not recommended for rural electrification due to the high operation cost and environmental effects. Micro-hydro is another alternative but there is no appropriate site suitable for micro-hydro power near Charaña. Therefore, wind and solar hybrid generation system was planned in Charaña because of the complementary relation between wind and solar. The optimum development scheme for the Charaña wind power was determined in the following procedure.

- The installed capacity of the wind-PV hybrid generation system was designed to generate enough electricity in January, the lowest power potential month of wind and solar.
- The wind potential is low in daytime. Therefore, the PV capacity was designed to generate over 80 % of power demand during 8:00 to 17:00 to compensate the low wind potential. The minimum PV capacity required in January was estimated at 12 kWp.
- Alternative development schemes with different combination of wind and PV were formulated in due consideration of the above.
- The most cost-effective wind and PV hybrid system was selected from the alternative schemes.

Five combination schemes were formulated and their cost comparison was made as summarized in the table below.

From this comparison, the combination of wind 80kW and PV 16kWp was selected as the optimum scheme with the lowest investment cost.

Investment Cost for the Alternative Schemes of Wind-PV Hybrid System

	1	2	3	4	5
Wind (kW)	100	90	80	70	60
PV (kWp)	5	11	16	22	28
Total (USD)	295,000	311,000	320,000	336,000	352,000

Source: JICA Study Team

5.5 Preliminary Design and Cost Estimate

5.5.1 Preliminary Design for Wind Turbine

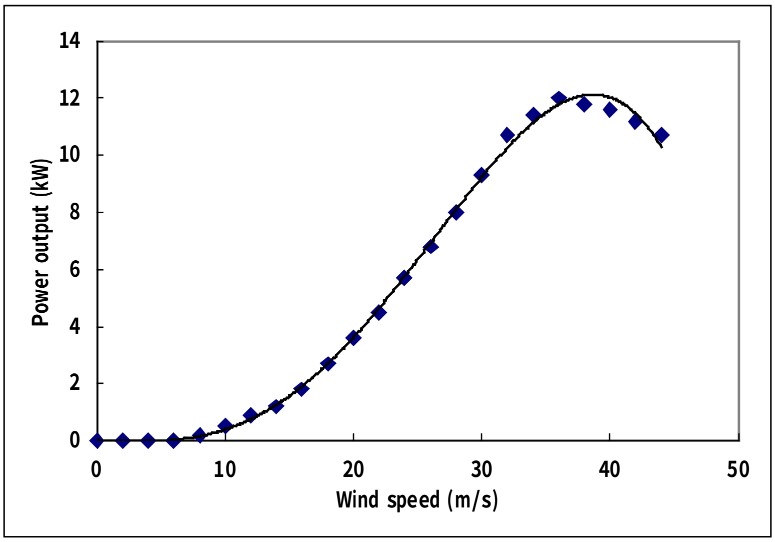
(1) Preliminary Design of Wind Power

Various types of wind turbines are available in the world. The selection of the wind turbine was made taking into account the following aspects.

- Wind tower is to be installed using winch considering the road condition to the project site and easy maintenance.

- The wind turbine is to have much experience of operation in developing countries.
- The turbine is to have enough experience with wind and solar hybrid system.
- The wind turbine is being sold by agents in Bolivia or South / North America.

From the reasons above the performance of BWC 10kW was selected to estimate power output from wind turbine. The performance curve and projected power generation of BWC 10kW are shown in the following figures.



Performance Curve of BWC 10kW

BWC 10kW

The power generation from the selected wind turbine is estimated as shown as follows.

Estimate of Projected Power Estimation

A : Input			V (mph)	kW	Wind Probability (f)	Net kW
Rated power output	10	kW	0	0	5.783%	0.00
Weibull shape parameter k	1.15		2	0	13.217%	0.00
Weibull scale parameter c	5.2		4	0	12.557%	0.00
Wind Speed at anemo. high	4.4	m/s	6	0	11.226%	0.00
Time period (Annual)	8760	hr	8	0.2	9.763%	0.02
Time period (Month)	744	hr	10	0.5	8.348%	0.04
Time period (Day)	24	hr	12	0.9	7.052%	0.06
Anemo. Height	20	m	14	1.2	5.903%	0.07
Altitude	4054	m	16	1.8	4.904%	0.09
Temperature	5.1	℃	18	2.7	4.048%	0.11
Barometric pressure	779	hPa	20	3.6	3.324%	0.12
Terrain roughness	0.2	m	22	4.5	2.716%	0.12
Hub height	36	m	24	5.7	2.210%	0.13
Pef. Safety Margin	5	%	26	6.8	1.792%	0.12
Standard air density	1.225	kg/m^3	28	8	1.447%	0.12
Std. Barometric pressure	1013	hPa	30	9.3	1.165%	0.11
			32	10.7	0.936%	0.10
B : Result			34	11.4	0.749%	0.09
Wind Speed at hub high	4.92	m/s	36	12	0.598%	0.07
Air density	0.976	kg/m^3	38	11.8	0.477%	0.06
Air density ratio	0.80		40	11.6	0.379%	0.04
Average power output	1.52	kW	42	11.2	0.300%	0.03
Annual energy output	10101	kWh/year	44	10.7	0.238%	0.03
Monthly energy output	858	kWh/Mo		Totals :	99%	1.52
Daily energy output	27.67	kWh/day				
Capacity Factor	11.5	%				
Availability	68	%				

Source: JICA Study Team

(2) Estimated Power Generation

Total power generation of Charaña wind power project including PV system was estimated at 122,560 kWh as summarized below.

Monthly Power Generation of Charaña

Month	Generation kWh/Mo
Jan	8,328
Feb	7,765
Mar	10,034
Apr	8,687
May	8,684
Jun	9,131
Jul	9,840
Aug	10,340
Sep	11,582
Oct	11,575
Nov	13,977
Dec	12,616
	122,560

Source: JICA Study Team

5.5.2 Proposed Wind Power System

As explained earlier, the power generation system at Charaña consists of wind turbine and PV system. The existing diesel generator is also planned to be used as a back up generator. According to the development policy of VMEH, electrification by diesel generator is not recommended. However, for high demand towns such as Charaña, a back up generator is necessary during periodical maintenance and/or for unexpected increase of power demand.

The table below shows specifications of the main generation system and the proposed system is as presented in Figure 5.4. The installation map is also presented in Figure 5.5.

Specification of Generation System in Charaña

Item	Capacity	
Wind Turbine	80	kW
Photovoltaic	16	kWp
Inverter	64	kVA
Converter	20	kVA
Battery	44	kAh

Source: JICA Study Team

5.5.3 Cost Estimate

(1) Condition of the Estimate

The cost estimate was made on the basis of the following assumptions and conditions:

1) All the costs were estimated at the price level of June 2001;
2) Equipment and materials imported were estimated based on the international procurement cost include tax related;
3) Construction work will be contract basis instead of under participation of local people;
4) Cost of the administrative and engineering services was estimated at about 9 % of the direct construction cost;
5) IVA (13%) and transaction cost (3%) were estimated and included in the cost; and
6) Applied exchange rates are; US$ = Bs6.53, US$= JPY 120.5.

(2) Total Construction Cost

The estimated financial cost for total construction is US$ 817,798 as summarized below. Table 5.6 indicates details of the construction cost.

Total Construction Cost

Unit : US$.

Item	Cost
1. Wind generator, PV system, etc.	**478,822**
2. Distribution Line	**35,885**
3. Installation Works	**144,000**
4. Transportation	**92,946**
5.Direct Cost Total	**751,653**
6. Administration and Engineering Service.	**66,145**
Total Construction Cost	**817,798**

Source: JICA Study Team

5.5.4 Construction Schedule

The construction schedule for the implementation of the Charaña wind power project was formulated based on the following conditions:

- Detailed design will be completed within 4 months.
- Construction of the major work for the wind power will be made during dry season.
- For the efficient implementation of the design work and construction supervision, experienced consultants will be employed.
- Including tendering period, erection for wind power will be completed within 8 months.

Assuming that the required time for design is 4 months, total period for completion of the project is around 12 months as proposed in Figure 5.6.

5.6 Implementation Organization and OM

Wind power project has not been implemented in Bolivia. The experience of the micro-hydro power project is possible to apply to the wind power project. The following implementation organization and operation and maintenance system are being proposed for the Charaña wind power project.

(1) Implementation Organization

A proposed organization for a project implementation of the Charaña wind power project is presented in Figure 5.7. Charaña municipality is responsible for the whole project. Local consultant/NGO plays a leading role in project implementation. However, since there exists no consultants/NGO in Bolivia having appropriate knowledge and experience in the wind power project, experienced foreign consultants are to be employed in the initial stage. The role of organizations related to the project implementation is summarized as follows.

DUF (fund source)

- to evaluate, approve and finance a project plan applied by Charaña municipality in cooperation with the VMEH

VMEH (technical support)

- to guide DUF for technical supports on rural electrification development when DUF evaluates the project plan applied by Charaña municipality

Charaña Municipality (implementing organization)

- to give a guidance of project scheme and user's responsibilities including initial payment and monthly fee for local people
- to make an agreement with the REC/cooperative after receiving the request of the rural electrification project
- to prepare a project plan with technical support of La Paz prefecture and/or consultants/NGO, and apply for the finance to DUF
- to select a private company or NGO which manages and supervises the whole project implementation. (However, Charaña municipality has the limited capacity to manage the project implementation. Consultants/NGO is to be employed by Charaña municipality, which provides necessary services such as selection of supplier/operator and procurement assistance and the supervision of the whole project.)

Engineering company / consultants (installation and training for operation and maintenance)

- to install the system and carry out training on the operation and maintenance for beneficiaries and technical assistants of REC/cooperative

REC/ cooperative (beneficiaries)

- to organize a rural electrification committee (REC) or cooperative after receiving the guidance of project scheme and beneficiary's responsibilities including initial payment and monthly fee through the municipality and/or consultants/NGO
- to request the rural electrification project and make an agreement with Charaña municipality
- to provide labor force and some materials prepared in the community in kind
- to receive the training on the operation and maintenance for beneficiaries and technical assistants of REC/cooperative

La Paz Prefecture (technical support or implementing organization)

- to support Charaña municipality for preparing the project plan when Charaña municipality applies the plan to DUF
- In case of a project implemented not through DUF, La Paz prefecture is to be responsible for the project implementation in cooperation with VMEH.

(2) Operation and Maintenance System

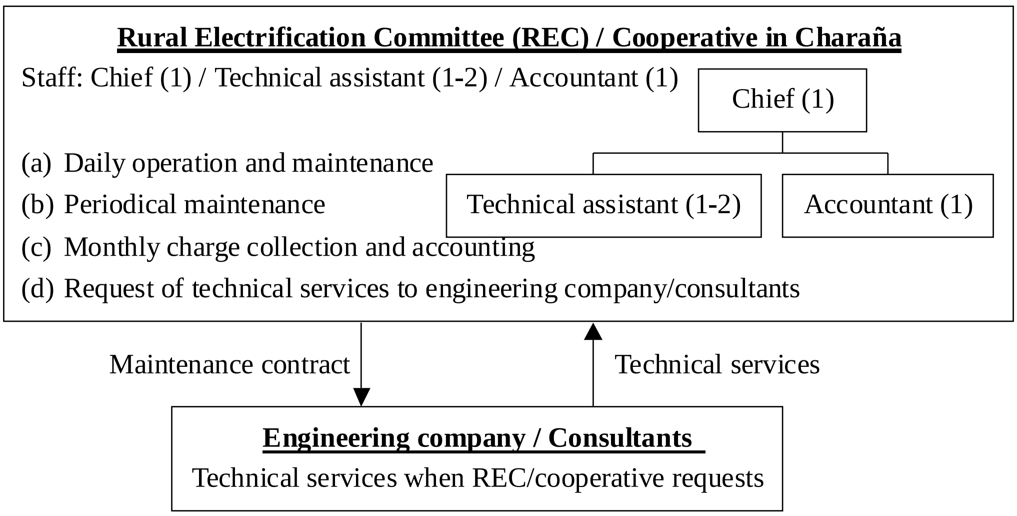
The local consultants/engineering company is to get the technology transfer of the operation and maintenance through experienced foreign consultants and accumulate the know-how for continuous operation and maintenance of the wind power projects in the project implementation stage. The technicians of the REC/cooperative are to be trained the technology of the operation and maintenance through the local engineering company/consultants. Proposed operation and maintenance to be conducted by REC/cooperative and engineering company/consultants is summarized as follows.

a) REC / cooperative

- to be responsible for the daily operation and maintenance
- to carry out the periodical maintenance
- to collect monthly charge and account
- to request technical services to engineering company / consultants

b) Engineering company / Consultants

- to provide REC/cooperative with technical services when requested (under a maintenance service contract).



The following inspections are to be conducted by the technical assistant of REC for the operation and maintenance.

Daily inspection:	• rotor (sound, rapid inspection) • tower (vibration, inclination, fastening of bolts) • battery (offensive smell, volume of liquid, rapid inspection) • control device (figure of meter, offensive smell, connected parts, rapid inspection) • preparation of daily working report
Periodical inspection (every month):	• battery (voltage, gravity, connected parts) • cleaning of control house (every week) • distribution lines (lines, telegraph pole)
Periodical inspection (every year):	• rotary engine (blade, edge tape, bolts, etc.) • tower (coating, bolts, etc.)

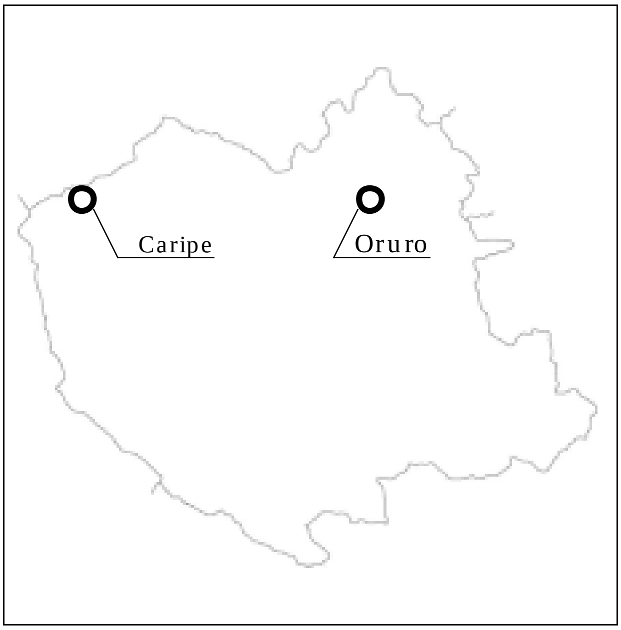
CHAPTER 6 PRE-FEASIBILITY STUDY ON CARIPE WIND POWER PROJECT IN ORURO

6.1 Location and Topography

Caripe is located 272 km west from Oruro-city, Oruro department. The location map and the picture are shown below. The temperature in Caripe is low located at 4,149 meters above sea level and near Mt.Sajama at 6,542 meters above sea level. Annual average temperature is 6.0 ℃ and minimum temperature is -12.0℃ in July. The weather has two different seasons, dry season and rainy season. The annual precipitation is around 400 mm at Caripe.

Location

Latitude:	S 18°00’46”
Longitude:	W 68°50’37”
Altitude:	4,149m



Location Map of Caripe

Wind Monitoring Tower of Caripe

6.2 Socio-economic Conditions and Demand for Electricity

6.2.1 Socio-economic Conditions

Basic information on socio-economic condition of Caripe is shown in Table 6.1.

(1) Population

The population of Caripe was 208 in 1992, which decreased to 206 in 2000 according to the census.

(2) Local Economy

The main economic activity is livestock breeding in Caripe. Around 300 cattles are held per household on an average and people are relatively rich.

(3) Electricity and Other Infrastructure

There is no electricity supply service in Caripe. People use candle, kerosene lamp and gas lamp for lighting instead of electricity. The cost of energy is around 10 to 30 Bs per month. There is an elementary school with 28 students. This school has no electricity supply service. There is no health clinic available in Caripe.

6.2.2 Demand for Electricity

The demand for electricity of the Caripe wind power project was estimated on the basis of the results of the community interview survey. Since there are commercial and public facilities in addition to residence, the demand was estimated for commercial activity, public service and household use, separately. The target year for the estimate of the demand was set at year 2005.

(1) Demand for Household Use

According to the result of the community interview survey, the existing household is divided into two types, namely small household and large household. Different kinds of electric appliances were held by each type of household and accordingly, consumption of electricity differed. From the result of the survey, unit rates for electricity consumption were estimated both for small households and large households as summarized in the following.

Power Demand for Household

Household		Electric appliance	No.	Power (W)	Electric Consumption (hours/day)	Energy (kWh/day)	Total Power Consumption (kWh/day)	Annual Power Consumption (kWh/year)
1	Household (small)	CF Light	1	12	4	0.048		
		60W Light	2	60	4	0.48		
		Radio	1	15	8	0.12	**0.65**	260
2	Household (large)	CF Light	2	12	5	0.12		
		60W Light	2	60	3	0.36		
		AM/FM stereo	1	20	4	0.08		
		TV set(19"color)	1	60	4	0.24		
		Water pump	1	100	3	0.3	**1.10**	442

Source: JICA Study Team

(2) Demand for Commercial Use

As for commercial facilities, there are restaurants and stores in Caripe. The demand for electricity is small in the small restaurants and stores. There are no offices and small-scale industries in Caripe. The unit rates of the electricity consumption for commercial use were estimated and are presented below.

Power Demand for Commercial

Micro-enterprise		Electric appliance	No.	Power (W)	Electric Consumption (hours/day)	Energy (kWh/day)	Total Power Consumption (kWh/day)	Annual Power Consumption (kWh/year)
1	Cafe(small)	CF Light	2	12	3	0.072		
		60W Light	1	60	3	0.18		123
		Radio	1	20	6	0.12	**0.41**	(300days/year)
2	Store (small)	CF Light	2	12	3	0.072		
		60W Light	2	60	3	0.36		169
		Radio	1	20	4	0.08	**0.56**	(300days/year)

Source: JICA Study Team

(3) Demand for Public Facilities

Existing public facilities are community center, school and health clinic. The unit rates of electricity consumption for the public facilities were estimated as summarized as follows.

Power Demand for Public Facilities

Public Facility		Electric appliance	No.	Power (W)	Electric Consumption (hours/day)	Energy (kWh/day)	Total Power Consumption (kWh/day)	Annual Power Consumption (kWh/year)
1	Community	CF Light	4	12	2	0.096		
	Center	60W Light	2	60	1	0.12		
	(small)	TV set(19"color)	1	60	1	0.06		
		VCR	1	120	1	0.12		129
		Stereo	1	55	1	0.055	0.50	(260days/year)
2	School	CF Light	12	12	3	0.432		
	(3 class room)	60W Light	4	60	2	0.48		
		TV set(19"color)	1	60	2	0.12		
		VCR	1	120	1	0.12		305
		Stereo	1	55	1	0.055	1.33	(230days/year)
3	Health Clinic	CF Light	5	12	5	0.3		
	(small)	60W Light	3	60	5	0.9		
		VHF radio(stand-by)	1	2	12	0.024		414
		VHF radio	1	30	1	0.03	1.38	(300days/year)

Source: JICA Study Team

(4) Total Estimated Demand

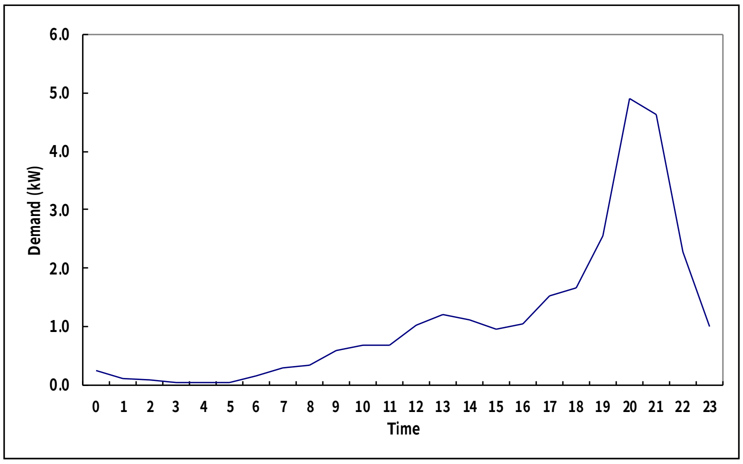
For estimating the total demand for electricity, numbers of the facilities were projected in due consideration of the future development in the project area.

The projected numbers of the facilities are as follows.

Item		Number
Households	large	3
	small	27
Café	small	3
Store	small	2
Community center	small	1
School	small	1
Health clinic	small	1

Source: JICA Study Team

Based on the above figures and the estimated unit electricity consumption, the total demand for electricity was calculated. The daily power demand curve was estimated as presented in the following. The peak demand is around 4.9kW, which occurs from 20:00 to 21:00. Table 6.2 shows the estimated daily power demand.



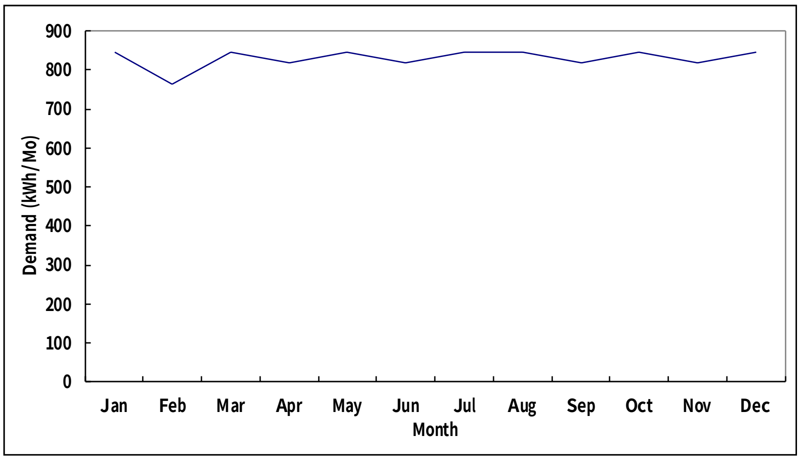
Estimated Daily Power Demand Curve

The monthly power demand was also calculated as presented in the following table and figure. As indicated, the annual demand for electricity was estimated at 9,951kWh.

Monthly Power Demand of Caripe

Month	Demand kWh/Mo
Jan	845
Feb	763
Mar	845
Apr	818
May	845
Jun	818
Jul	845
Aug	845
Sep	818
Oct	845
Nov	818
Dec	845
Total	9,951

Source: JICA Study Team

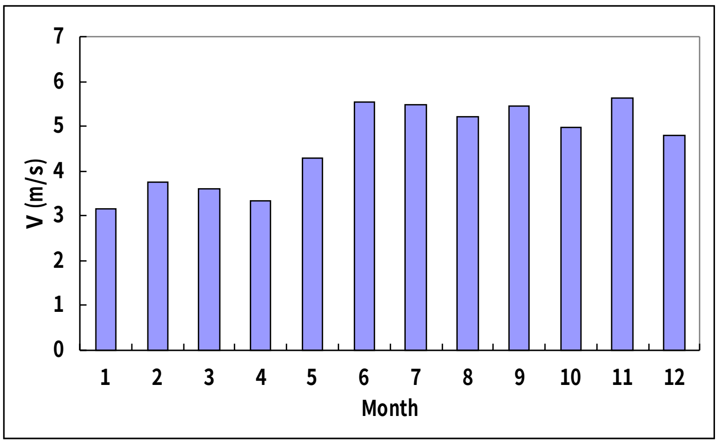


Estimated Annual Demand Curve

6.3 Wind Data Analysis

6.3.1 Analysis of Wind Data

The monthly and diurnal average wind speeds at 20 meters above ground level are shown below. The annual average wind speed at Caripe is 4.71 m/s. In Caripe, the monthly average wind speed from September to December is high at 5.5 m/s, while the average monthly wind speed from January to August is low at 3.6 m/s. This indicates that the power output differs from month to month.



Monthly Average Wind Speed (m/s)

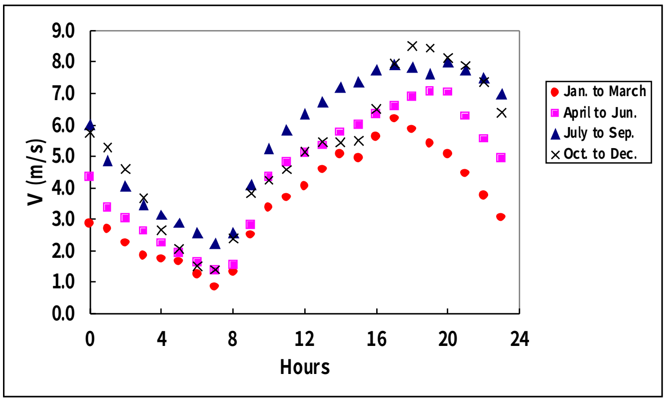
Monthly Average Wind Speed (m/s)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Average Wind Speed (m/s)	3.2	3.8	3.6	3.3	4.3	5.7	5.5	5.2	6.3	5.0	5.8	4.8

Source: JICA Study Team

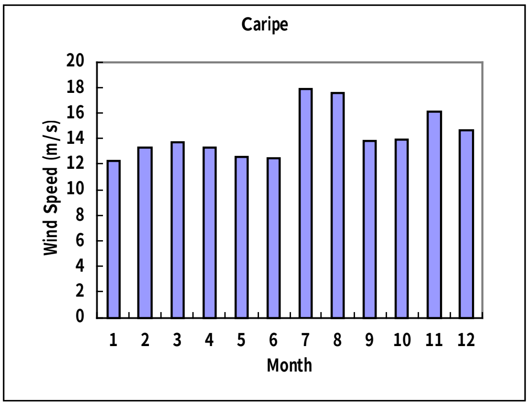
According to the diurnal wind pattern, the wind blows strong from 12:00 to 22:00 when demand for electricity is higher. On the other hand, the wind blows very weak from 4:00 to 8:00 for generating electricity.

Considering this wind pattern at Caripe, a hybrid generation system with the other energy source is necessary for supplying stable power.



Diurnal Average Wind Speed (m/s)

The monthly maximum wind speed of 10 minutes average at 20 meters above ground level in Caripe is shown in the following. The annual average of the maximum wind speed is 14.5 m/s. The results indicate that there is no extraordinary strong wind such as typhoon or hurricane.



Monthly Maximum Wind Speed (m/s)

Monthly Maximum Wind Speed (m/s)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Average Wind Speed (m/s)	12.2	13.3	13.7	13.3	12.6	12.5	17.9	17.5	13.8	13.9	16.1	14.6

Source: JICA Study Team

The monthly average directional wind speeds at Caripe are shown in Figure 6.1. In Caripe, the average wind speed of west direction is the strongest throughout a year. Therefore, it is necessary to regulate construction of any building at the upstream.

Table 6.3 shows distribution of monthly wind speed directional frequency at Caripe. This figure shows directional frequency of high wind speed is high in west - northwest to west-west north direction.

The Figure 6.2 shows frequency distribution of wind direction. The frequency distribution of wind direction is high in west to west - northwest corresponding to the direction of the strongest wind speed. The frequency of wind direction is steady in Caripe.

Figure 6.3 shows Weibull probability density distribution at Caripe. The variations in the wind speed are well described by the Weibull probability distribution with shape parameter “k” and the scale parameter “A”. The value of “k” determines the shape of the curve. The value of “A” determines distribution of hours with higher speed. The annual average of the parameter k is 1.48 and A is 5.4. Since, strong wind blows only in the afternoon, the difference of average wind speed in the morning and afternoon makes the shape parameter “k” small.

Table 6.4 shows monthly wind energy density. The wind power varies linearly with the air density sweeping the blades. The air density varies with pressure and temperature. Wind energy density is small in Caripe due to the high altitude. The site with wind energy density over 150 W/m^2 at 10 meters above ground level is suitable for wind power development. The monthly average of wind energy density is small in Caripe, however the average from afternoon to evening is high due to strong wind blows during that time.

Table 6.5 shows turbulence intensity that is relating wind speed and terrain. Turbulence intensity is defined as the ratio of standard deviation of the wind speed to the mean of the wind speed. The place with turbulence intensity under the 0.3 at 20 meters above ground level is suitable for wind power development. The turbulence intensity of Caripe is under 0.3 in all directions.

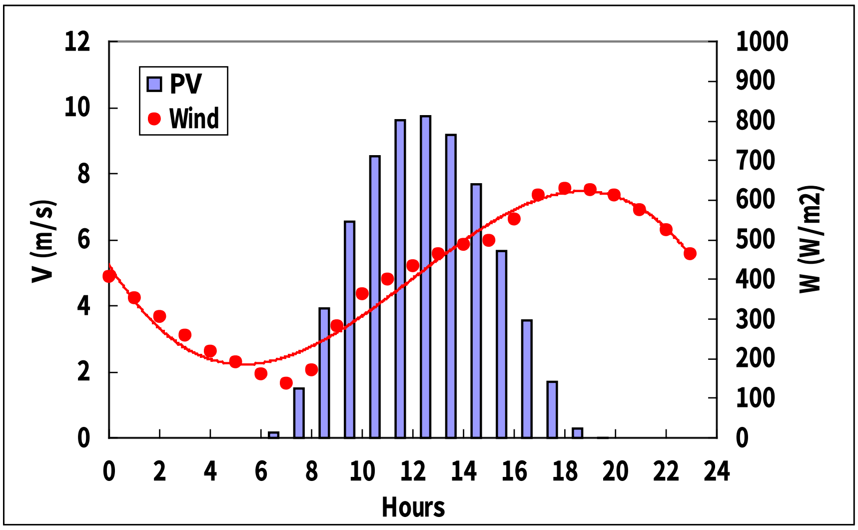
6.3.2 Complementary Relation between Wind and Solar Energies

There are seasonal and diurnal variations in wind speed pattern. This makes it difficult to get steady energy from stand-alone wind generation system. However, there is complementary relation between wind and solar energies in Caripe.

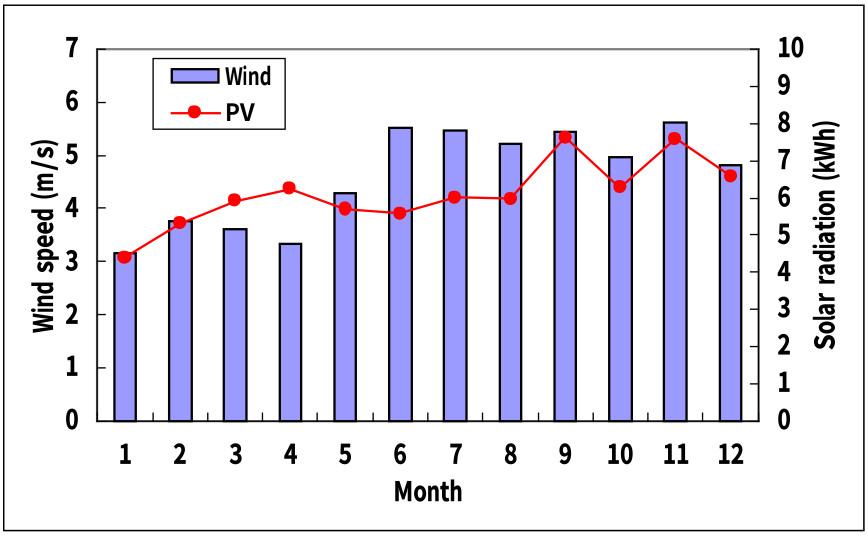
The next figure shows complementary relation between wind speed and solar radiation in Caripe. The energy potential of solar is high from 9:00 to 15:00 when the wind speed is still low, while the wind speed is high from 16:00 to 21:00 when the solar radiation is weak. Therefore, it is planned that the wind and PV be combined in a hybrid system to obtain stable energy.

In the second figure, the monthly average of wind speed and that of solar energy are presented summarizing the average monthly figure during February 2000 to January 2001. The complementary relation is not identified in this figure.

There is a geographical complementary relation between wind and solar energies caused by the high altitude. Wind potential in high altitude becomes lower because of the small value of the air density. On the other hand, solar radiation becomes higher at high altitude because of the clean air.



Diurnal Wind Speed vs. Solar Radiation at Caripe



Monthly Wind Speed vs. Solar Radiation at Caripe

6.4 Formulation of Optimum Development Scheme

Stand-alone wind generation system does not have enough capacity of generating electricity during daytime in Caripe, although there is high demand for electricity from offices and schools. To generate more stable electricity, the wind generation is to be combined with the other energy source.

The options of the combinations are:

1. Wind – Diesel Hybrid System
2. Wind – PV Hybrid System
3. Wind-Micro Hydro Hybrid System

According to the policy of VMEH, installation of diesel generator is not recommended for rural electrification due to the high operation cost and environmental effects. Micro-hydro is another alternative but there is no appropriate site suitable for micro-hydro power near Caripe. Therefore, wind and solar hybrid generation system was planned in Caripe because of the complementary relation between wind and solar.
The optimum development scheme for the Caripe wind development was determined in the following procedure.

- The installed capacity of the wind-PV hybrid generation system was designed to generate enough electricity in February, the lowest power potential month of wind and solar.
- The wind potential is low in daytime. Therefore, the PV capacity was designed to generate over 80 % of power demand from 8:00 to 17:00 to compensate the low wind potential. The minimum PV capacity required in January was estimated at 2kWp.
- Alternative development schemes with different combination of wind and PV were formulated in due consideration of the above.
- The most cost-effective wind and PV hybrid system was selected from the alternative schemes.

Two combination schemes were formulated and their cost comparison was made as summarized in the table below.

From this comparison, the combination of wind 10kW and PV 4kWp was selected as the optimum scheme with the lowest investment cost.

Investment Cost for the Alternative Schemes of Wind-PV Hybrid System

No.	1	2
Wind (kW)	20	10
PV (kWp)	0	4
Investment cost (USD)	54,000	55,000

Source: JICA Study Team

6.5 Preliminary Design and Cost Estimate

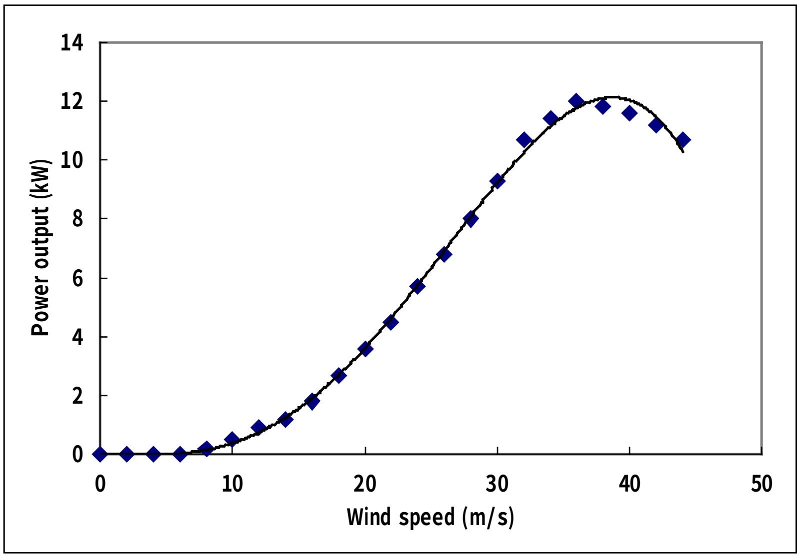
6.5.1 Preliminary Design for Wind Turbine

(1) Preliminary Design

Various types of wind turbines are available in the world. The selection of the wind turbine was made taking into account the following aspects.

- Wind tower is to be installed using winch considering the road condition to the project site and easy maintenance.
- The wind turbine is to have much experience of operation in developing countries.
- The turbine is to have enough experience with wind and solar hybrid system.
- The wind turbine is being sold by agents in Bolivia or South / North America.

From the reasons above the performance of BWC 10kW was selected to estimate power output from wind turbine. The performance curve of BWC 10kW are shown in the following figures.



Performance Curve of BWC 10kW

Estimate of Projected Power Estimation

A : Input			V (mph)	kW	Wind Probability (f)	Net kW
Rated power output	10	kW	0	0	2.091%	0.00
Weibull shape parameter k	1.48		2	0	8.094%	0.00
Weibull scale parameter c	6.0		4	0	10.264%	0.00
Wind Speed at anemo. high	4.7	m/s	6	0	10.920%	0.00
Time period (Annual)	8760	hr	8	0.2	10.706%	0.02
Time period (Month)	744	hr	10	0.5	9.967%	0.05
Time period (Day)	24	hr	12	0.9	8.933%	0.08
Anemo. Height	20	m	14	1.2	7.768%	0.09
Altitude	4149	m	16	1.8	6.587%	0.12
Temperature	6.0	°C	18	2.7	5.465%	0.15
Barometric pressure	765	hPa	20	3.6	4.448%	0.16
Terrain roughness	0.25	m	22	4.5	3.557%	0.16
Hub height	36	m	24	5.7	2.799%	0.16
Pef. Safety Margin	5	%	26	6.8	2.170%	0.15
Standard air density	1.225	kg/m^3	28	8	1.659%	0.13
Std. Barometric pressure	1013	hPa	30	9.3	1.252%	0.12
			32	10.7	0.933%	0.10
B : Result			34	11.4	0.688%	0.08
Wind Speed at hub high	5.44	m/s	36	12	0.501%	0.06
Air density	0.955	kg/m^3	38	11.8	0.361%	0.04
Air density ratio	0.78		40	11.6	0.257%	0.03
Average power output	1.73	kW	42	11.2	0.182%	0.02
Annual energy output	11241	kWh/year	44	10.7	0.127%	0.01
Monthly energy output	955	kWh/Mo		Totals :	100%	1.73
Daily energy output	30.80	kWh/day				
Capacity Factor	12.8	%				
Availability	79	%				

Source: JICA Study Team

(2) Estimated Power Generation

Total power generation of Caripe wind power project was estimated at 22,643 kWh as summarized below.

Monthly Power Generation of Caripe

Month	Generation kWh/Mo
Jan	1,750
Feb	1,239
Mar	1,508
Apr	1,341
May	1,673
Jun	2,157
Jul	2,164
Aug	2,057
Sep	2,551
Oct	1,971
Nov	2,332
Dec	1,899
Total	22,643

Source: JICA Study Team

6.5.2 Proposed Wind Power System

As explained earlier, the power generation system at Caripe consists of wind turbine and PV system.

The table below shows specifications of the main generation system and the proposed system is as presented in Figure 6.4. The installation map is also presented in Figure 6.5.

Specification of Generation System in Caripe

Item	Capacity	
Wind Turbine	10	kW
Photovoltaic	4	kWp
Inverter	8	kVA
Battery	8	kAh

Source: JICA Study Team

6.5.3 Cost Estimate

(1) Condition of the Estimate

The cost estimate was made on the basis of the following assumptions and conditions:

1) All the costs were estimated at the price level of June 2001;

2) Equipment and materials imported were estimated based on the international procurement cost include tax related;

3) Construction work will be contract basis instead of under participation of local people;

4) Cost of the administrative and engineering services was estimated at around 9 % of the direct construction cost;

5) IVA (13%) and transaction cost (3%) were estimated and included in the cost; and

6) Applied exchange rates are; US$ = Bs6.53, US$= JPY 120.5.

(2) Total Construction Cost

The estimated financial cost for total construction is US$ 147,296 as summarized below. Table 6.6 indicates details of the construction cost.

Total Construction Cost

Unit : US$.

Item	Cost
1. Wind generator, PV system, etc.	**88,405**
2. Distribution Line	**11,040**
3. Installation Works	**21,000**
4. Transportation	**14,938**
5.Direct Cost Total	**135,382**
6. Administration and Engineering Service.	**11,914**
Total Construction Cost	**147,296**

Source: JICA Study Team

6.5.4 Construction Schedule

The construction schedule for the implementation of the Caripe wind power project was formulated based on the following conditions:

- Detailed design will be completed within 4 months.
- Construction of the major work for the wind power will be made during dry season.
- For the efficient implementation of the design work and construction supervision, experienced consultants will be employed.

- Including tendering period, erection for wind power will be completed within 5 months.

Assuming that the required time for design is 4 months, total period for completion of the project is around 9 months as proposed in Figure 6.6.

6.6 Implementation Organization and OM

There is no experience of wind power project in Bolivia. However, after reviewing the existing organizations of the micro-hydro power system, the experience of the micro-hydro power project is possible to apply to the wind power project. The following implementation organization and system for the operation and maintenance are being proposed for Caripe wind power projects.

(1) Implementation Organization

Figure 6.7 presents proposed organization for a project implementation of the Caripe wind power projects. Caripe municipality is in charge of the whole project. Local consultants/NGOs are committed the project implementation. Similar implementation structure for the micro-hydro power project is possible to apply to the Caripe wind power project, but experienced foreign consultants are to be employed in the initial stage due to the quite limited knowledge and experience in the wind power project. The role of organizations related to the project implementation is summarized as follows.

DUF (fund source)

- to evaluate, approve and finance a project plan applied by Caripe municipality in cooperation with the VMEH

VMEH (technical support)

- to guide DUF for technical supports on rural electrification development when DUF evaluates the project plan applied by Caripe municipality

Caripe Municipality (implementing organization)

- to give a guidance of project scheme and user’s responsibilities including initial payment and monthly fee for local people
- to make an agreement with the REC/cooperative after receiving the request of the rural electrification project

- to prepare a project plan with technical support of Oruro prefecture and/or consultants/NGO, and apply for the finance to DUF
- to select a private company or NGO which manages and supervises the whole project implementation. (However, Caripe municipality has the limited capacity to manage the project implementation. Consultants/NGO is to be employed by Caripe municipality, which provides necessary services such as selection of supplier/operator and procurement assistance and the supervision of the whole project.)

Engineering company / consultants (installation and training for operation and maintenance)

- to install the system and carry out training on the operation and maintenance for beneficiaries and technical assistants of REC/cooperative

REC/ cooperative (beneficiaries)

- to organize a rural electrification committee (REC) or cooperative after receiving the guidance of project scheme and beneficiary's responsibilities including initial payment and monthly fee through the municipality and/or consultants/NGO
- to request the rural electrification project and make an agreement with Caripe municipality
- to provide labor force and some materials prepared in the community in kind
- to receive the training on the operation and maintenance for beneficiaries and technical assistants of REC/cooperative

Oruro Prefecture (technical support or implementing organization)

- to support Caripe municipality for preparing the project plan when Caripe municipality applies the plan to DUF
- In case of a project implemented not through DUF, Oruro prefecture is to be responsible for the project implementation in cooperation with VMEH.

(2) Operation and Maintenance System

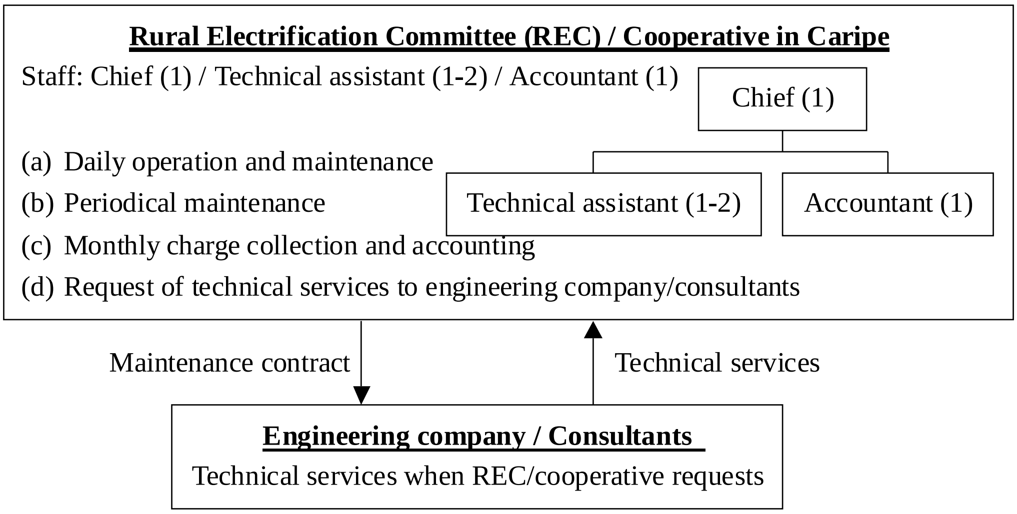
Technology transfer of the operation and maintenance is to be carried out between experienced foreign consultants and local consultants/engineering company. The technicians of the REC/cooperative are to be trained the operation and maintenance skill through the local consultants/engineering company. Proposed operation and maintenance to be conducted by REC/cooperative and engineering company/consultants is summarized as follows and presented in detail in the section 5.6 (2).

a) REC / cooperative

- to be responsible for the daily operation and maintenance
- to carry out the periodical maintenance
- to collect monthly charge and accounting
- to request technical services to engineering company/consultants

b) Engineering company / consultants

- to provide REC/cooperative with technical services when requested (under a maintenance service contract).



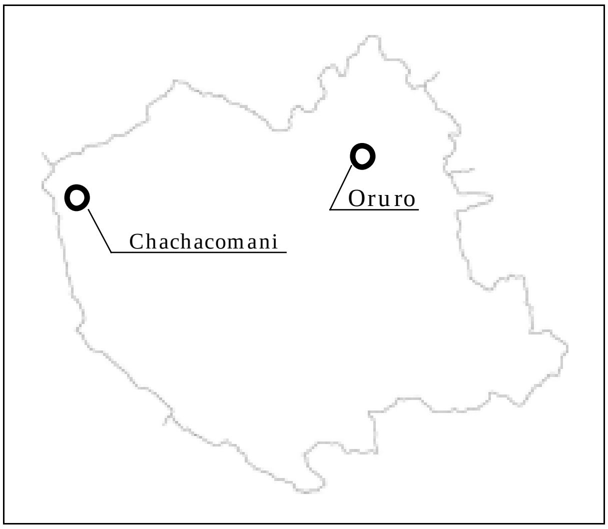
CHAPTER 7 PRE-FEASIBILITY STUDY ON CHACHACOMANI WIND POWER PROJECT IN ORURO

7.1 Location and Topography

Chachacomani is located 350 km west from Oruro-city, Oruro department. The location map and the picture are shown below. The temperature in Chachacomani is also low, located at 4,220 meters above sea level and near the border with Chile. Annual average temperature is 6.2 ℃ and minimum temperature is –7.4℃ in July. The weather has two different seasons, dry season and rainy season. The annual precipitation is little at around 400 mm at Chachacomani.

Location

Latitude: S 18 ° 21’ 33”
Longitude: W 68 ° 56’ 56”
Altitude: 4,220m



Location Map of Chachacomani

Wind Monitoring Tower of Chachacomani

7. 2 Socio-economic Conditions and Demand for Electricity.

7.2.1 Socio-economic Conditions

Basic information on socio-economic condition of Chachacomani is shown in Table 7.1.

(1) Population

The population of Chachacomani was 476 in 1992, which decreased to 470 in 2000 according to the census.

(2) Local Economy

The main economic activity is livestock breeding in Chachacomani. Many residents work in Tambo Quemado, the border town to Chile around 15km from Chachacomani.

(3) Electricity and Other Infrastructure

There is no electricity supply service in Chachacomani. People use candle, kerosene lamp and gas lamp for lighting instead of electricity. The cost of energy is around 10 to 30 Bs per month. There is an elementary school with 80 students. This school has no electricity supply service. There is a health clinic with electricity supplied by PV system. Main purpose of the electricity supply is radio communication and lighting.

7.2.2 Demand for Electricity

The demand for electricity of the Chachacomani wind power project was estimated on the basis of the results of the community interview survey. Since there are commercial and public facilities in addition to residence, the demand was estimated for commercial activity, public service and household use, separately. The target year for the estimate of the demand was set at year 2005.

(1) Demand for Household Use

According to the result of the community interview survey, the existing household is divided into two types, namely, small household and large household. Different kinds of electric appliances were held by each type of household and, accordingly, consumption of electricity differed. From the result of the survey, unit rates for electricity consumption were estimated both for small household and large household as summarized below.

Power Demand for Household

Household		Electric appliance	No.	Power (W)	Electric Consumption (hours/day)	Energy (kWh/day)	Total Power Consumption (kWh/day)	Annual Power Consumption (kWh/year)
1	Household	CF Light	1	12	4	0.048		
	(small)	60W Light	2	60	4	0.48		
		Radio	1	15	8	0.12	**0.65**	260
2	Household	CF Light	2	12	5	0.12		
	(large)	60W Light	2	60	3	0.36		
		AM/FM stereo	1	20	4	0.08		
		TV set(19"color)	1	60	4	0.24		
		Water pump	1	100	3	0.3	**1.10**	442

Source: JICA Study Team

(2) Demand for Commercial Use

As for commercial facilities, there are restaurants, stores in Chachacomani. The demand for electricity is small in the small restaurants and stores. There is no office nor small-scale industries in Chachacomani. The unit rates of the electricity consumption for commercial use were estimated and are presented below.

Power Demand for Commercial

Micro-enterprise		Electric appliance	No.	Power (W)	Electric Consumption (hours/day)	Energy (kWh/day)	Total Power Consumption (kWh/day)	Annual Power Consumption (kWh/year)
1	Cafe(small)	CF Light	2	12	5	0.12		
		60W Light	1	60	5	0.3		178
		Radio	1	20	6	0.12	**0.59**	(300days/year)
2	Store (small)	CF Light	2	12	3	0.072		
		60W Light	2	60	2	0.24		129
		Radio	1	20	4	0.08	**0.43**	(300days/year)

Source: JICA Study Team

(3) Demand for Public Facilities

The existing public facilities are community center, school and health clinic. The unit rates of electricity consumption for the public facilities were estimated as summarized in the following.

Power Demand for Public Facilities

	Public Facility	Electric appliance	No.	Power (W)	Electric Consumption (hours/day)	Energy (kWh/day)	Total Power Consumption (kWh/day)	Annual Power Consumption (kWh/year)
1	Community	CF Light	4	12	2	0.096		
	Center	60W Light	2	60	1	0.12		
	(small)	TV set(19"color)	1	60	1	0.06		
		VCR	1	120	1	0.12		129
		Stereo	1	55	1	0.055	**0.50**	(260days/year)
2	School	CF Light	12	12	3	0.432		
	(3 class room)	60W Light	4	60	3	0.72		
		TV set(19"color)	1	60	3	0.18		
		VCR	1	120	1	0.12		381
		Stereo	1	55	1	0.055	**1.66**	(230days/year)
3	Health Clinic	CF Light	5	12	5	0.3		
	(small)	60W Light	3	60	5	0.9		
		VHF radio(stand-by)	1	2	12	0.024		414
		VHF radio	1	30	1	0.03	**1.38**	(300days/year)

Source: JICA Study Team

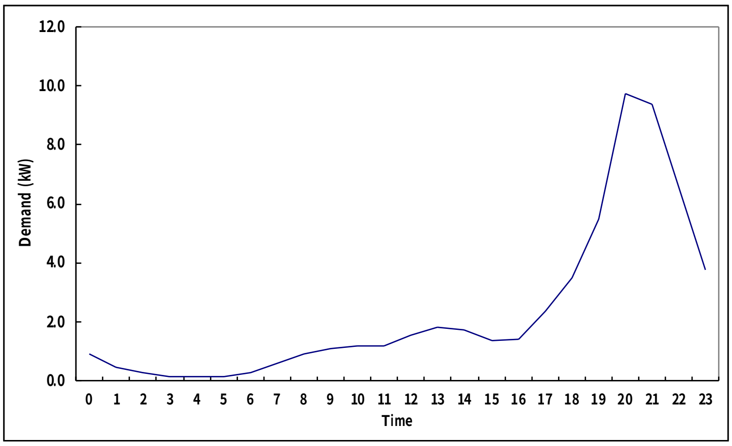
(4) Total Estimated Demand

For estimating the total demand for electricity, numbers of the facilities were projected in due consideration of the future development in the project area.
The projected numbers of the facilities are as follows.

Item		Number
Households	large	14
	small	56
Café	small	3
Store	small	4
Community center	small	1
School	small	1
Health clinic	small	1

Source: JICA Study Team

Based on the above figures and the estimated unit electricity consumption, the total demand for electricity was calculated. The daily power demand curve was estimated as presented in the following. The peak demand is around 9.7kW, which occurs from 20:00 to 21:00. Table 7.2 shows the estimated daily power demand.



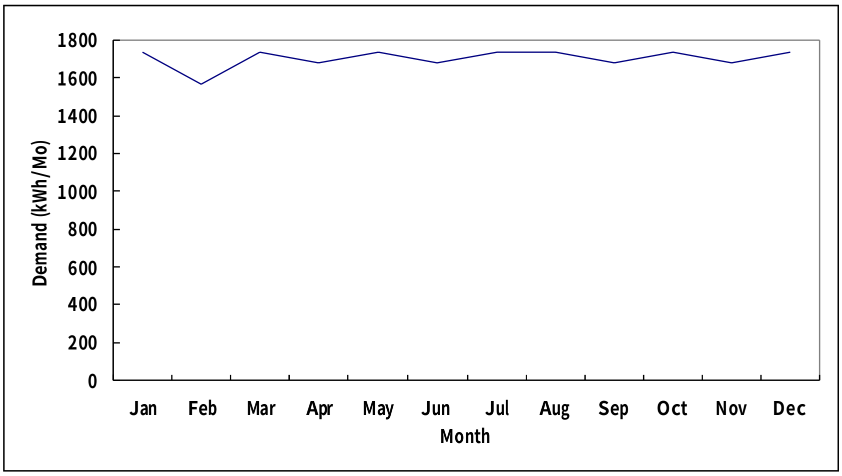
Estimated Daily Power Demand Curve

The monthly power demand was also calculated as presented in the following table and figure. As indicated, the annual demand for electricity was estimated at 20,440kWh.

Monthly Power Demand of Chachacomani

Month	Demand kWh/Mo
Jan	1736
Feb	1568
Mar	1736
Apr	1680
May	1736
Jun	1680
Jul	1736
Aug	1736
Sep	1680
Oct	1736
Nov	1680
Dec	1736
Total	20,440

Source: JICA Study Team

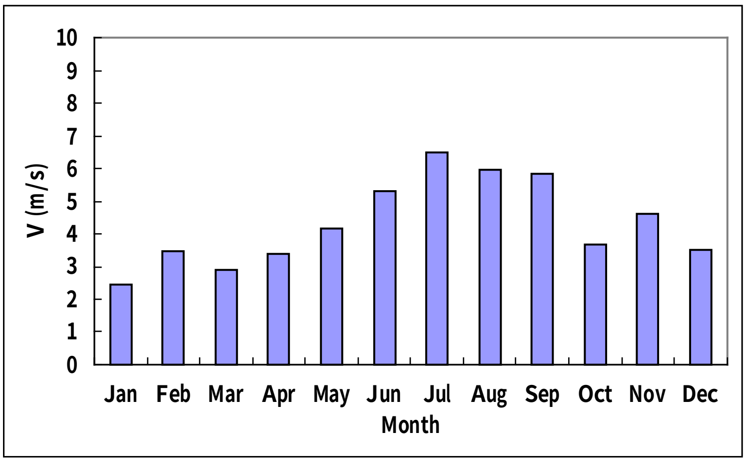


Estimated Annual Demand Curve

7.3 Wind Data Analysis

7.3.1 Analysis of Wind Data

The monthly and diurnal average wind speeds at 20 meters above ground level are shown below. The annual average wind speed at Chachacomani is 4.31 m/s. In Chachacomani, the monthly average wind speed from June to November is high at 5.3 m/s, while the average monthly wind speed from December to May is low at 3.3 m/s. This indicates that the power output differs from month to month.



Monthly Average Wind Speed (m/s)

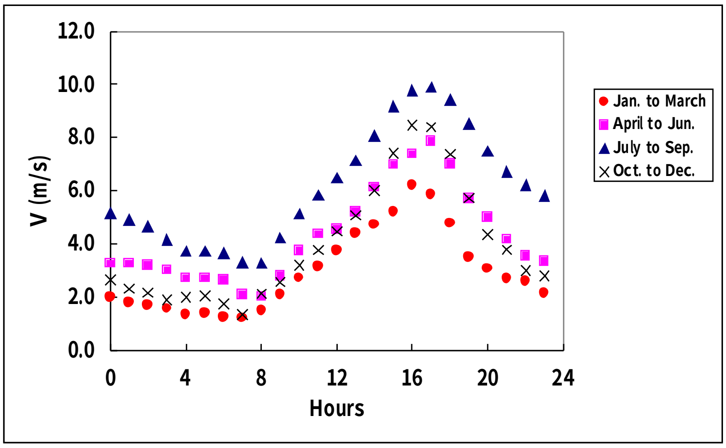
Monthly Average Wind Speed (m/s)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Average Wind Speed (m/s)	2.5	3.5	2.9	3.4	4.2	5.3	6.5	5.9	5.8	3.7	4.6	3.5

Source: JICA Study Team

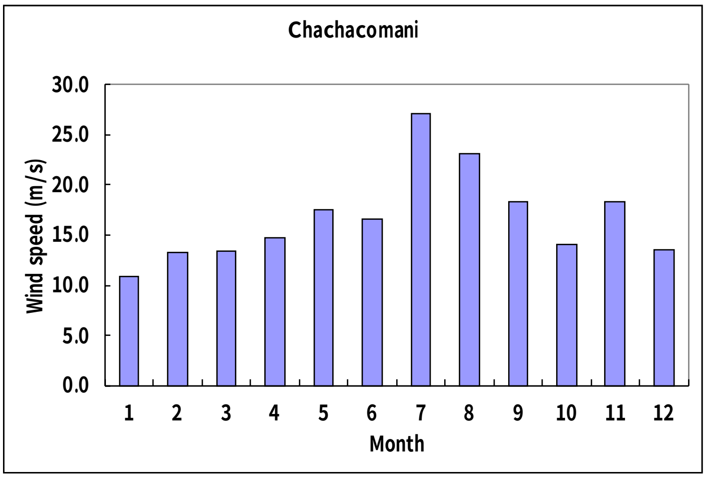
According to the diurnal wind pattern, the wind blows strong from 12:00 to 21:00 when demand for electricity is higher. On the other hand, the wind blows very weak from 0:00 to 9:00, particularly, from October to December and January to March.

Considering this wind pattern at Chachacomani, a hybrid generation system with the other energy source is necessary for supplying stable power.



Diurnal Average Wind Speed (m/s)

The monthly maximum wind speed of 10 minutes average at 20 meters above ground level in Chachacomani is shown below. The annual average of the maximum wind speed is 14.5 m/s. The results indicate that there is no extraordinary strong wind such as typhoon or hurricane.



Monthly Maximum Wind Speed (m/s)

Monthly Maximum Wind Speed (m/s)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Average Wind Speed (m/s)	10.9	13.3	13.4	14.8	17.5	16.6	27.1	23.2	18.3	14.1	18.4	13.5

Source: JICA Study Team

The monthly average directional wind speeds at Chachacomani are shown in Figure 7.1. In Chachacomani, there is no particular direction of strong wind from December to May. Average wind speeds of west to west-northwest directions are strong from June to November. Therefore, it is necessary to regulate construction of any building at the upstream.

Table 7.3 shows distribution of monthly wind speed directional frequency at Chachacomani. This figure shows directional frequency of high wind speed is high in west to northwest direction.

Figure 7.2 shows frequency distribution of wind direction. There is no particular wind direction from December to April. The frequency distribution of wind is high at west to west-northwest from May to November corresponding to the direction of the strongest wind speed.

Figure 7.3 shows Weibull probability density distribution at Chachacomani. The variations in the wind speed are well described by the Weibull probability distribution with shape parameter “k” and the scale parameter “A”. The value of “k” determines the shape of the curve. The value of “A” determines distribution of hours with higher speed.

The annual average of the parameter k is 1.03 and A is 4.1. Since, strong wind blows only in the afternoon, the difference of average wind speed in the morning and afternoon makes the shape parameter “k” small.

Table 7.4 shows monthly wind energy density. The wind power varies linearly with the air density sweeping the blades. The air density varies with pressure and temperature. Wind energy density is small in Caripe due to the high altitude. The site with wind energy density over 150 W/m2 at 10 meters above ground level is recommended for wind power development. The monthly average of wind energy density is small, however the average in during afternoon to evening is high due to the wind speed pattern.

Table 7.5 shows turbulence intensity that is relating wind speed and terrain. Turbulence intensity is defined as the ratio of standard deviation of the wind speed to the mean of the wind speed. The place with turbulence intensity under the 0.3 at 20 meters above ground level is suitable for wind power development. The turbulence intensity of Chachacomani is under 0.3 except the directions from east to southeast. There is a church in the directions of east to southeast and the effect of turbulence can be avoided by installing 200 meters away from the building.

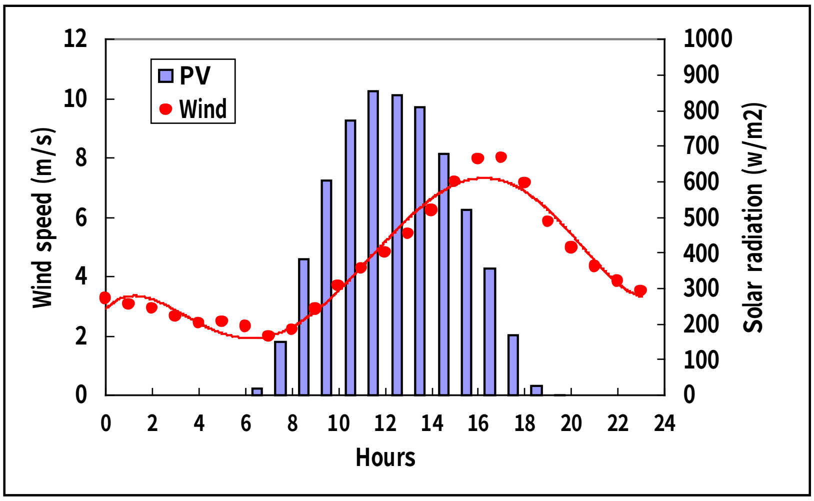
7.3.2 Complementary Relation between Wind and Solar Energies

There are seasonal and diurnal variations in the wind speed pattern. This makes it difficult to get steady energy from stand-alone wind generation system. However, there is complementary relation between wind and solar in Chachacomani.

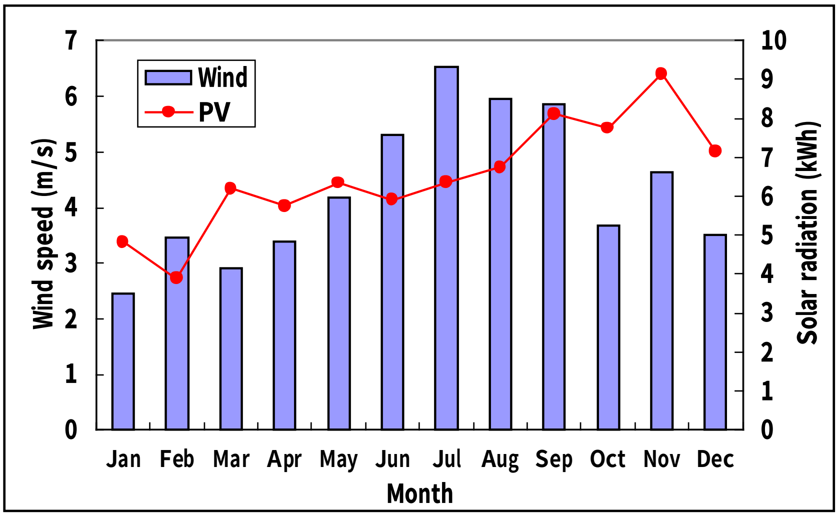
The figure below shows complementary relation between wind speed and solar radiation in Chachacomani. The energy potential of solar is high from 9:00 to 15:00 when the wind speed is still low, while the wind speed is high between 12:00 to 21:00 when the solar radiation is weak. Therefore, it is planned that the wind and PV are combined in a hybrid system to obtain stable energy.

In the second figure, the monthly average of the wind speed and the solar energy are presented summarizing the average monthly figure during February 2000 to January 2001. The complementary relation is not identified in this figure.

There is a geographical complementary relation between wind and solar energies due to the high altitude. Wind potential in high altitude becomes lower because of the low air density. On the other hand, solar radiation becomes higher at high altitude because of the clean air.



Diurnal Wind Speed vs. Solar Radiation at Chachacomani



Monthly Wind Speed vs. Solar Radiation at Chachacomani

7.4 Formulation of Optimum Development Scheme

Stand-alone wind generation system does not have enough capacity of generating electricity during daytime in Chachacomani, although there is high demand for electricity from offices and schools. To generate more stable electricity, the wind generation is to be combined with another energy source.

The options of the combinations are:

1. Wind – Diesel Hybrid System
2. Wind – PV Hybrid System
3. Wind-Micro Hydro Hybrid System

According to the policy of VMEH, installation of diesel generator is not recommended for rural electrification due to the high operation cost and environmental effects. Micro-hydro is another alternative and there is an appropriate site for micro-hydro power development near Chachacomani. Hybrid generation system with solar energy is also to be planned in Chachacomani because of the complementary relation between wind and solar.

Prior to comparing the two hybrid system, wind-microhydro and wind-PV system, the study for selecting the most optimum combination was made for each system.

For wind-microhydro hybrid system, selection of the best combination of the two energy sources was made on the basis of the hydrological analysis of the hydro scheme and result of the cost comparison of the combined system. The best combination of wind-PV system was chosen using the same method applied to the Charaña and the Caripe.

The evaluated best combination of the two hybrid schemes are:

1) Hybrid of wind – microhydro: wind power of 20 kW and micro-hydro power of 3 kW
2) Hybrid of wind – PV system: wind power of 40 kW and PV system of 9kWp

Estimated cost for the wind–microhydro power and the wind–PV system are US$ 326,536 and US$475,092 respectively, that indicates the hybrid system with micro-hydro is preferable. Beside this, the capacity of battery of the wind – microhydro is smaller than that of wind-PV system, that reduces maintenance cost of the hybrid system with micro-hydro.

Through this analysis, the wind-microhydro hybrid system was finally selected as the optimum development scheme for the Chachacomani wind power project.

7.5 Preliminary Design and Cost Estimate

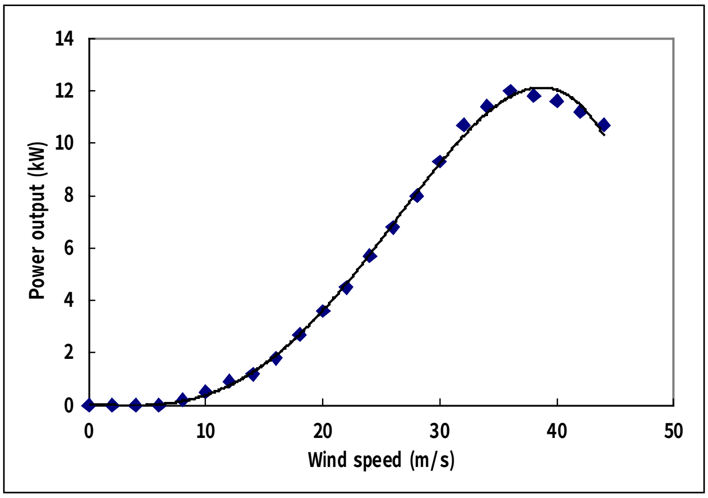
7.5.1 Preliminary Design for Wind Turbine

(1) Preliminary Design of Wind Power

Various types of wind turbines are available in the world. The selection of the wind turbine was made taking into account the following aspects.

- Wind tower is to be installed using winch considering the road condition to the project site and easy maintenance.
- The wind turbine is to have much experience of operation in developing countries.
- The turbine is to have enough experience with wind and solar hybrid system.
- The wind turbine is being sold by agents in Bolivia or South / North America.

From the reasons above the performance of BWC 10kW was selected to estimate power output from wind turbine. The performance curve and expected power generation of BWC 10kW are shown in the following figures.



Performance Curve of BWC 10kW

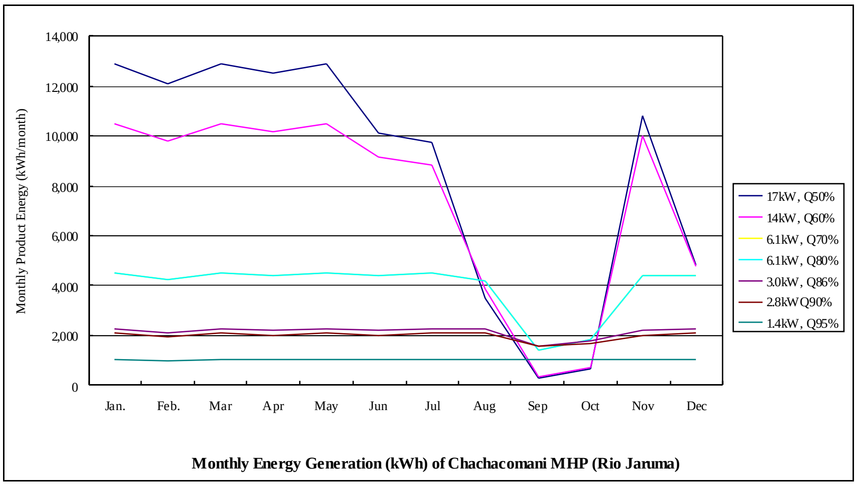
Estimate of Projected Power Estimation

A : Input			V (mph)	kW	Wind Probability (f)	Net kW
Rated power output	10	kW	0	0	8.102%	0.00
Weibull shape parameter k	1.03		2	0	14.944%	0.00
Weibull scale parameter c	4.9		4	0	12.766%	0.00
Wind Speed at anemo. high	4.3	m/s	6	0	10.768%	0.00
Time period (Annual)	8760	hr	8	0.2	9.033%	0.02
Time period (Month)	744	hr	10	0.5	7.552%	0.04
Time period (Day)	24	hr	12	0.9	6.298%	0.06
Anemo. Height	20	m	14	1.2	5.243%	0.06
Altitude	4220	m	16	1.8	4.359%	0.08
Temperature	6.2	°C	18	2.7	3.619%	0.10
Barometric pressure	758	hPa	20	3.6	3.002%	0.11
Terrain roughness	0.2	m	22	4.5	2.488%	0.11
Hub height	36	m	24	5.7	2.060%	0.12
Pef. Safety Margin	5	%	26	6.8	1.705%	0.12
Standard air density	1.225	kg/m^3	28	8	1.410%	0.11
Std. Barometric pressure	1013	hPa	30	9.3	1.166%	0.11
			32	10.7	0.963%	0.10
B : Result			34	11.4	0.795%	0.09
Wind Speed at hub high	4.84	m/s	36	12	0.656%	0.08
Air density	0.946	kg/m^3	38	11.8	0.541%	0.06
Air density ratio	0.77		40	11.6	0.447%	0.05
Average power output	1.49	kW	42	11.2	0.368%	0.04
Annual energy output	9561	kWh/year	44	10.7	0.303%	0.03
Monthly energy output	812	kWh/Mo		Totals :	99%	1.49
Daily energy output	26.20	kWh/day				
Capacity Factor	10.9	%				
Availability	63	%				

Source: JICA Study Team

(2) Preliminary Design of Micro-hydro Power

The figure below shows estimated monthly energy generation from the Chachacomani micro-hydro scheme. To reduce the investment cost of the hybrid scheme, the micro-hydro power is to be designed to produce steady power throughout a year. As the most optimum scheme, the installed capacity of the micro-hydro was designed to be 3.0 kW.



Estimate of Projected Power Estimation

(3) Estimated Power Generation

Total power generation of Chachacomani wind power project including micro-hydro power was estimated at 42,671 kWh as summarized below.

Monthly Power Generation of Chachacomani

Month	Generation kWh/Mo
Jan	3,417
Feb	2,648
Mar	3,087
Apr	2,965
May	3,270
Jun	3,609
Jul	3,812
Aug	4,695
Sep	3,787
Oct	4,256
Nov	3,236
Dec	3,888
Total	42,671

7.5.2 Proposed Wind Power System

As explained earlier, the power generation system at Chachacomani consists of wind turbine and MHP system.

The table below shows specification of the main generation system and the proposed system is as presented in Figure 7.4. The installation map is also presented in Figure 7.5.

Specification of Generation System in Chachacomani

Item	Capacity	
Wind Turbine	20	kW
MHP	3	kW
Inverter	14	kVA
Converter	10	kVA
Battery	4	kAh

Source: JICA Study Team

7.5.3 Cost Estimate

(1) Condition of the Estimate

The cost estimate was made on the basis of the following assumptions and conditions:

1) All the costs were estimated at the price level of June 2001;
2) Equipment and materials imported were estimated based on the international procurement cost include tax related;
3) Construction work will be contract basis instead of under participation of local people;
4) Cost of the administrative and engineering services was estimated at around 9 % of the direct construction cost;
5) IVA (13%) and transaction cost (3%) were estimated and included in the cost; and
6) Applied exchange rates are; US$ = Bs6.53, US$= JPY 120.5.

(2) Total Construction Cost

The estimated financial cost for total construction is US$ 294,674 as summarized below. Table 7.6 indicates details of the construction cost.

Total Construction Cost

Unit : US$.

Item	Cost
1. Wind generator, PV system, etc.	**209,242**
2. Distribution Line	**15,000**
3. Installation Works	**30,000**
4. Transportation	**16,598**
5.Direct Cost Total	**270,840**
6. Administration and Engineering Service.	**23,834**
Total Construction Cost	**294,674**

Source: JICA Study Team

7.5.4 Construction Schedule

The construction schedule for the implementation of the Chachacomani wind power project was formulated based on the following conditions:

- Detailed design will be completed within 4 months.
- Construction of the major work for the wind power and micro hydro will be made during dry season.
- For the efficient implementation of the design work and construction supervision, experienced consultants will be employed.
- Including tendering period, erection for wind power and micro-hydro will be completed within 8 months.

Assuming that the required time for design is 4 months, total period for completion of the project is around 12 months as proposed in Figure 7.6.

7.6 Implementation Organization and OM

Wind power project has not been carried out in Bolivia. The experience of the micro-hydro power project is possible to apply to the wind power project. The following implementation organization and operation and maintenance system are being proposed for the Chachacomani wind power project.

(1) Implementation Organization

As presented in Figure 7.7, an implementing organization for the Chachacomani wind power project is proposed. Chachacomani municipality is responsible for the whole project. Local consultants/NGO plays a leading role in the project implementation. However, since there exists no consultants/NGO in Bolivia having appropriate knowledge and experience in the wind power project, experienced foreign consultants are to be employed in the initial stage. The role of organizations related to the project implementation is summarized as follows.

DUF (fund source)

- to evaluate, approve and finance a project plan applied by Chachacomani municipality in cooperation with the VMEH

VMEH (technical support)

- to guide DUF for technical supports on rural electrification development when DUF evaluates the project plan applied by Chachacomani municipality

Chachacomani Municipality (implementing organization)

- to give a guidance of project scheme and user’s responsibilities including initial payment and monthly fee for local people
- to make an agreement with the REC/cooperative after receiving the request of the rural electrification project
- to prepare a project plan with technical support of Oruro prefecture and/or consultants/NGO, and apply for the finance to DUF
- to select a private company or NGO which manages and supervises the whole project implementation. (However, Chachacomani municipality has the limited capacity to manage the project implementation. Consultants/NGO is to be employed by Chachacomani municipality, which provides necessary services such as selection of supplier/operator and procurement assistance and the supervision of the whole project.)

Engineering company / consultants (installation and training for operation and maintenance)

- to install the system and carry out training on the operation and maintenance for beneficiaries and technical assistants of REC/cooperative

REC/ cooperative (beneficiaries)

- to organize a rural electrification committee (REC) or cooperative after receiving the guidance of project scheme and beneficiary's responsibilities including initial payment and monthly fee through the municipality and/or consultants/NGO
- to request the rural electrification project and make an agreement with Chachacomani municipality
- to provide labor force and some materials prepared in the community in kind
- to receive the training on the operation and maintenance for beneficiaries and technical assistants of REC/cooperative

Oruro Prefecture (technical support or implementing organization)

- to support Chachacomani municipality for preparing the project plan when Chachacomani municipality applies the plan to DUF
- In case of a project implemented not through DUF, Oruro prefecture is to be responsible for the project implementation in cooperation with VMEH.

(2) Operation and Maintenance System

In the project implementation stage, the local consultants/engineering company is to get the technology transfer of the operation and maintenance through experienced foreign consultants and accumulate the know-how for continuous operation and maintenance of the wind power projects. The technicians of the REC/cooperative are to be trained the technology of the operation and maintenance through the local engineering company/consultants. Proposed operation and maintenance to be conducted by REC/cooperative and engineering company/consultants is summarized as follows and presented in detail in the section of 5.6 (2).

a) REC / cooperative

- to be responsible for the daily operation and maintenance
- to carry out the periodical maintenance
- to collect monthly charge and accounting
- to request technical services to engineering company/consultants

b) Engineering company / Consultants

- to provide REC/cooperative with technical services when requested (under a maintenance service contract).