The Republic of Cabo Verde

Ministry of Economy and Employment

The Study of Information Collection and Verification Survey for Renewable Energy Introduction and Grid Stabilization in The Republic of Cabo Verde

Final Report

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Japan International Cooperation Agency (JICA)

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Abbreviations

Abbreviation	Standard Nomenclatures
【A】	
ADP	Águas de Portugal
AEB	Águas e Energia da Boavista S.A.
AFC	Automatic Frequency Control
AFC	African Finance Cooperation
AfDB	African Development Bank
APP	Águas de Ponta Preta
ARE	Agência de Regulação Económica
【C】	
CERMI	Centre of Renewable Energy and Industrial Maintenance
【D】	
DGE	Direção Geral da Energia (Directorate General of Energy)
DMS	Demand Management System
【E】	
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Regional Centre for Renewable Energy and Energy Efficiency
EDP	Energias de Portugal
EIB	European Investment Bank
Electra	Empresa de Electricidade e Água, SARL
Electric	Producao de Energia Eolica (Electric Wind)
EMS	Energy Management System
ENTSO-E	European Network of Transmission System Operators for Electricity
ESCJ	Electric Power System Council of Japan
EU	European Union
【G】	
GIS	Geographic Information System
GIZ	Gesellschaft für Internationale Zusammenarbeit
GMT	Ground Mounted Transformer
GPV	Grid Point Value
GSM	Global Spectral Model

Abbreviation	Standard Nomenclatures
【H】	
HV	High Voltage
【I】	
IEC	International Electrotechnical Commission
INMG	Instituto Nacional de Meteorologia e Geofisica (National Institute of Meteorology and Geophysics)
IPP	Independent Power Producer
ITC	Instituto Tecnológico de Canarias
【J】	
JICA	Japan International Cooperation Agency
【L】	
LV	Low Voltage
【M】	
MEE	Ministério da Economia e Emprego (Ministry of Economy and Employment)
MTIDE	Ministério do Turismo, Investimentos e Desenvolvimento Empresarial (Ministry of Tourism, Investment and Business Development)
MV	Medium Voltage
【O】	
OFID	OPEC Fund for International Development
ORET	Ontwikkelings Relevante Export Transacties
【P】	
PC	Personal Computer
PCS	Power Conditioner
PESER	Plano Estratégico Sectorial de Energias Renováveis (Renewable Energy Sector Strategy Plan)
PID	Potential Induced Degradation
PMT	Pole Mounted Transformer
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PS	Posto de Seccionamento
PT	Posto de Transformcao
PTDSD	Power Transmission and Distribution System Development Project
PV	Photovoltaic
【R】	

Abbreviation	Standard Nomenclatures
RFID	Radio Frequency Identification
RIAM-COMPACT®	Research Institute for Applied Mechanics, Kyushu University, COMputational Prediction of Airflow over Complex Terrain
【S】	
SCADA	Supervisory Control and Data Acquisition
SDTIBM	Sociedade de Desenvolvimento Turístico das Ilhas de Boa Vista e Maio
SESAM-ER	Serviço Energético Sustentável para Povoações Rurais Isoladas mediante Micro-Redes com Energias Renováveis (Sustainable Energy Supply Service to Isolated Small Villages by Micro-grid with Renewable Energy)
【U】	
UGPE	Unidade de Gestão de Projectos Especiais（Management Unit of Special Project)
【W】	
WB	World Bank
【Z】	
ZDER	Zonas de Desenvolvimento de Energias Renováveis (Renewable Energy Development Zone)

Executive Summary

1. Introduction

1.1 Background

The Republic of Cabo Verde (hereafter referred to as “Cabo Verde”) is an island nation and has limited water and energy resources. Fuels such as gas oil and heavy oil account for about 20% of the total merchandise import, are responsible for pushing up the energy cost, and have chronic and negative impact on the balance of payment of the country. In 2011, faced with the challenge, the Cabo Verde government set a goal to raise the rate of domestically procurable renewable energy sources (renewables) to 50% of the nation’s power sources by 2020. In the same year, the government issued an ordinance to promote renewables, and in 2012 Rio＋20 conference, President Fonseca gave a speech stating the country’s aim to go 100% renewables, followed by the creation of a roadmap toward achieving the plan in 2013. Thanks to the introduction of renewable facilities especially those harnessing wind power that started in earnest in 2011, the amount of gas oil import went down 15% and heavy oil 8% from 2012 to 2013 in spite of the increase in power generation, indicating a certain degree of reduction in fuel used for power generation.

1.2 Purpose

This Study aims to examine support measures that apply advanced infrastructure technologies of Japan and other sources for Cabo Verde that is developing its infrastructure using highly concessional donor support. In the Study, the Study Team verifies and examines the basic information through activities below with an eye on the introduction of renewables and batteries, etc.

(1) Collection and organization of basic information on the power sector

(2) Collection and analysis of information necessary for the review and examination of the roadmap for renewable facility introduction

(3) Collection and analysis of information necessary for the examination of renewables promotion measures which utilize advanced technologies of Japan and other sources, and proposal of measures, etc.

The scope of the Study is all nine inhabited islands of Cabo Verde.

The Study proceeded while keeping in mind the points below:

(1) Maximum use of knowledge and technology cultivated by supplying power to remote islands in Japan

(2) Proposal of a realistic and allowable renewable capacity to be introduced

(3) Economic comparison regarding potential fuel use reduction in diesel power generation

(4) Proposals based on Japan’s support policy

1.3 JICA Study Team Composition

The Study Team members and work content in Table 1.3-1.

1.4 Overview of the Field Survey

Three field surveys were conducted in March, May and September in 2016. At the 3rd survey in Cabo Verde, the draft final report of the study and described issues and countermeasures have been explained to DGE and MEE special advisor. Additionally, workshops for the power sector have been organizsed and the conclusion of the report has been shared with the sector (Figures 1.2-1 and 1.2-2).

2. Outline of the energy sector

2.1 Current Status of the Electric Power Sector

≪Overview of Electra≫

In Cabo Verde, electricity is supplied by Electra, which was established in 1982 as a state-run company to supply water and electricity (part of Sal receives power from a different private company APP and Boa Vista from AEB). Electra had suffered from chronic unprofitability since the time of its establishment and had trouble renewing its facility and equipment. To address the issue, the Cabo Verdean government privatized Electra by selling 51% of Electra shares to two Portuguese companies in 1999. However, Electra's negative earnings continued due to fuel price hike and policies that set the tariff below cost. In July 2006, a decision was made to nationalize the company in stages; however its underperformance still continues. Currently, the capital contribution by the government is 77.731%, the National Social Insurance Institute 16.592% and municipality 5.677%. The debt that the Portuguese companies took on was transferred to Electra upon nationalization, and the creditor is a commercial bank of Cabo Verde (the outstanding balance as of the end of fiscal 2014 was 4,394,025,000CVE). Electra concluded a concession-based contract for transmission/distribution business (the ownership of the transmission/distribution networks remains with the Cabo Verde government) with the Cabo Verde government in 2002, which spans 36 years between 2000 and 2035. Electra utilizes, maintains and manages the facility in accordance with the contract. It has separated the departments that served the northern and southern regions and set them up as two separate companies in July 2013 in order to speed up the managerial endeavors. The overview of the main company of Electra and two companies thus set up is given in Figure 2.1-1 and Tables 2.1-1 to 2.1-3.

From 2011 to 2014 when the crude oil price was high, the wind power facilities of Cabeolica that started operation in 2011 helped ease Electra's tight finances. On the other hand, in 2015 and 2016 when the crude price dropped to less than half of the peak price, the FIT for wind power weighed down Electra's finances. Electra's financial status based on its balance sheet is described below:

(1) Capital: the capital deficit has fluctuated around 1 billion CVE in spite of the capital injection using the emergency assistance

(2) Liabilities: the loss carried forward more than doubled to 5,789,170,000 CVE between the end of fiscal 2010 and the end of fiscal 2014, and the loans from the same period increased by 33% to 13,304,864,000 CVE. Especially the balance of the long-term loans doubled to 8,962,155,000 CVE between 2010 and 2015. Considering that the commercial banks' borrowing interest is high at 7% and the corporate debts or the loan from the Cabo Verde government have not been paid back in 2013 or 2014, it seems that Electra is unable to pay back its debts under the current condition.

(3) Asset: Accounts receivable were approximately 5,499 million CVE on average over the three years from 2012 to 2014, of which 70% are long-term receivables with high risk of not being collected. The accrued income from the government and municipality in addition to those from the private sector have a grave impact on the operation of Electra. Electra deems about 10% of the uncollected receivables (about 500,000,000 CVE) irrecoverable and record them as impairment loss, and these uncollected receivables are a grave risk factor.

≪Private Power Companies≫

Private water and power supply companies serve all the customers of Boa Vista and some hotels of Sal. The tourism industry prospers on these islands thanks to the advance of foreign-capitalized businesses. The power consumption of each island is large, following Santiago which houses Praia, the capital of the country, and power consumption per capita is about three times of the Cabo Verde average. The electricity sales and demand density are high on the islands while the loss factor is low (Table 2.1-9).

APP : On the island of Sal, a Spanish company Aguas de Ponta Preta (APP) supplies power and water to some hotels in the southern portion of the island, utilizing its power-generating capacity of about 5MW and desalination facility capable of producing 1,000m^3/day. APP is also involved in O&M of micro-grids that were created with the funds from EU and other donors in underpopulated villages on Santo Anatão. However, APP has no full-scale renewable facility such as a wind farm.

AEB : On the island of Boa Vista, in 2008 a Spanish private company (water & electricity) acquired Aguas e Energia da Boavista (AEB), which was engaged in water and electricity business. However, for the promotion of tourism on Boa Vista and Maio, the Cabo Verde government and Boa Vista contributed funds to create the Boa Vista and Maio Islands Tourism Development Corporation (SDTIBM), which bought back 60% of the AEB shares. As the result, AEB again became a government-controlled entity.

The Study Team interviewed the new president Mr. Ulisses Santos of the new AEB regarding the potential for the tourism industry. The explanation given is summarized below:

• The Cabo Verde government had been aware of the tourism potential of Boa Vista, however, it entrusted a Spanish private company to manage AEB for about eight years since 2008 due to financial and technical reasons.

• Since then, Boa Vista's tourism industry has prospered and the development of electrical facilities, roads and related infrastructure in an integrated manner became necessary. However, the former AEB was not able to meet the needs on its own; thus AEB was reacquired.

In fact, the hotel demand has recovered after the Lehman Shock in 2008 and the electricity demand of Boa Vista (power consumption) surpassed that of Sao Vicente and became the second largest. With the prospect of further population increase and the favorable wind condition, much is expected for the island in terms of economy and introduction of renewables.

Cabeolica: Cabeolica is a wind power IPP, which was established in 2008 as the first renewable IPP in sub-Saharan Africa financed by the Cabo Verde government, Electra, and private funds. With the additional funds from EIB and AfDB, Cabeolica was able to secure the total project cost of about 78 million USD. In 2011, it launched the wind power projects on four islands of São Vicente, Sal, Boa Vista and Santiago with the total capacity of 25.5MW (850kW×30 units). Thanks to the sound facility operation and favorable wind condition of Cabo Verde, Cabeolica has achieved its planned availability factor every year while producing stable income.

2.2 Energy-related Laws and Regulations

The Decree-Law No. 14/2006 ruling on Cabo Verde electricity system was formulated to provide a basic framework for Cabo Verde's electric power industry, with an aim to supply necessary electricity to all consumers, facilitate private investment, and promote normal market competition for the industry. Its goal is to maintain a sustainable system to supply necessary electricity at a reasonable price, not as a governmental undertaking but as a private business under normal market competition and based on concession and license, thus promoting economic growth. As of July 2012, concessioned electric power suppliers are Electra, AEB, and APP while IPPs include wind power producers, Cabeolica and Electric. Table 2.2-1 summarizes the decree.

Following the decree for the electricity system, another ordinance was established to set IPP-related rules, by dictating the rules for IPP license, performance guarantee and tariff. In 2011, yet another ordinance was issued to promote renewable energy with the creation of a master plan for renewable development that considers the system stability of each island and a long-term renewable plan (PESER) that stipulates the location and facilities of the renewable power station (Table 2.2-2). PESER is to be prepared so as to ensure coherence with the development plans and environmental protection plans of the municipality and by obtaining the cabinet approval. It is envisioned to select the project company through IPP bidding, based on PESER and renewable energy development plan (ZDER) prepared together for the respective regions. On this basis, the "Cape Verde 100% Renewable: A Roadmap to 2020," a roadmap for the realization of the plan, was drawn in 2013 (hereinafter described in detail).

2.3 Electricity Tariffs

The Economic Regulatory Agency (ARE) sets the uniform electricity tariffs and fuel prices for gasoline, etc. for all the islands. The electricity tariffs had been on the increase until April 2015 in line with the rise in crude oil prices. However, the tariffs went down following the drop in crude prices. The recent electricity tariffs and the change in tariffs and crude oil prices are shown in Table 2.3-1 and Figure 2.3-1.

2.4 Donors' Support

≪Status of support by country and donor≫

Since Cabo Verde was upgraded to a middle-income country, the only countries that still offer active support are Luxembourg, Portugal, Netherlands, France and Spain. Among international organizations, the World Bank (WB) offers support toward the diesel generator introduction in Santiago and policy support, and EU provided grant assistance for the introduction of micro-grids in the unelectrified areas of São Nicolau and San Antão. The recent support projects that were impactful due to the amount spent and scale were, (1) the Power Generation, Transmission and Distribution Capacity Building Project (2007-2010), which was carried out in Santiago in two stages, and (2) Electricity Transmission and Distribution Network Development Project implemented in Santiago and six other islands, which were made possible thanks to the co-financing by JICA, AfDB and others. In addition, Dutch ORET is implementing the (3) Reinforcement of Distribution of Electricity and Improvement of the Transmission System in Islands such as Santiago and Boa Vista (these three projects will be detailed later).

The recent support projects by JICA, EU, AfDB, EIB, EBID, IBRD, OFID and ORET for transmission/distribution, wind power and electricity policy for the benefit of the power sector of Cabo Verde are listed in Tables 2.4-1 and 2.4-2.

≪Feasibility Study by EU for renewable energy master plan and pumped-storage hydropower≫

EU recognizes that the urgent tasks for Cabo Verde's power sector are to secure appropriate profit and to develop regulatory framework. EU is preparing for a feasibility study (FS) starting in 2016 toward the creation of the renewable energy master plan and the introduction of large-scale pumped-storage hydropower in Santiago. Currently, European Investment Bank (EIB), AfDB and WB are interested in co-financing the seawater pumped-storage hydropower.

≪Deliberation of CERMI utilization≫

Centro para as Energias Renováveis e Manutenção Industrial, or Centre for Renewable Energy and Industrial Maintenance (CERMI) was built on Santiago thanks to the support from Luxembourg and offers a certificate recognized only in Cabo Verde. Thus, the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) of the Economic Community of West African States (ECOWAS) is leading the deliberation to upgrade CERMI from a facility that serves Cabo Verde exclusively to the region's certification authority for renewables technologies used widely by 15 West African nations (ECOWAS). EU agrees to support the effort.

3. Cabo Verde 100% Renewable: A Roadmap to 2020

In 2011, Cabo Verde set a goal to increase the rate of domestically procurable renewables to 50% of the nation's power sources by 2020 and issued an ordinance for the promotion of renewables. Following year in 2012 Rio＋20 conference, President Fonseca gave a speech stating the nation's aim to go 100% renewable by 2020, and in 2013, "Cape Verde 100% Renewable: A Roadmap to 2020," a roadmap toward achieving the plan, was created (hereafter "100% Renewable Roadmap 2020"). The 100% Renewable Roadmap 2020 was drawn by Institute for Applied Material Flow Management, Trier University of Applied Sciences, Germany.

3.1 Issues of the Renewable Roadmap

For the Study, the team organized the characteristics and issues of the existing Renewable Roadmap 2020 (Table 3.1-1). The evaluation of feasibility and cost must be conducted carefully including that of a future power storage technology, so as not to confuse the facility introduction with purpose. Movimento para a Democracia, or Movement for Democracy (MpD) is a right-center party that formed a stable administration after the election in March 2016. MpD's manifest lists the restoration of sound management of Electra through the promotion of private investment and the expansion of streetlights, but did not mention renewables. In the reshuffle of government ministries, the jurisdiction over energy has been transferred to Ministério da Economia e Emprego.

After the change of administration, it was decided to review the existing Renewable Roadmap. DGE plans to create a new Renewable Roadmap based on the renewable energy master plan that EU is preparing for and the result of the tentative calculation of renewables (wind and PV) potentials which will be offered to Cabo Verde as part of the result of the Study. The Cabo Verde government still holds the goal to go 100% renewable as before; however, it has dropped the target year of 2020 and plans not to set a particular target year.

4. Power Demand and Supply Situation

The Study Team compiled the data on the power supply/demand status for all islands in aggregate and each island individually, based on the 2015 supply/demand data collected. In Cabo Verde, the development of transmission/distribution facilities and the interconnection of the systems within each island is in progress thanks to the support from the international organizations. Thus, the explanations given hereafter are a snapshot of the situation at the time of the Study.

≪Electrification of other small villages≫

XaXa village: XaXa village is a mountain village with about 10 households, located in the northern part of Santiago. The demand scale is about 10kW, which is covered by 10kVA of wind and photovoltaic power generation. Batteries are also installed. The electricity provided to the village for free while the village is likely to be abandoned in 10 years.

Further aging and population decline are expected for mountain villages such as this located far away from cities, which will result in more deserted villages. One example given was that young people tend to move to the city where there are many opportunities for education and employment, and bring in their parents.

The government's policy on the electrification of small villages is to promote a micro-grid with small-scale PV and battery, instead of extending the distribution lines. The government is also searching for ways to reduce cost and to encourage self-sustenance of the contractor through an umbrella contract covering operation and maintenance of the micro-grid. When creating an isolated micro-grid, movable PV and battery systems are selected to avoid the investment risk, so that more facilities can be added when the village's electricity demand increased while the facilities can be removed to relocate if the village no longer has any demand.
The plan for Santo Antao covers the villages near and around the Agua River (Ribeira da Agua), Alta River (Ribeira Alta) and Figueiral River (Ribeira do igueiral).

4.1 Demand and Supply Situation

≪All islands of Cabo Verde≫

The power generated in Cabo Verde in 2015 was 419GWh, of which more than half was produced in Santiago. The four main islands of Santiago, São Vicente, Sal and Boa Vista account for 90% of the power demand of the country (Figures 4.1-1 and 4.1-2). To breakdown the power demand, the LV household demand accounts for about half, while the large customers receiving power at medium voltage is about 30% on the four main islands where hotels and tourism enjoy relative prosperity. Since the tourist industry is expected to grow more in Sal and Boa Vista, it is important to secure power sources. The power loss is high at about 25%, which calls for urgent investigation and response (Figure 4.1-3).

Figure 4.1-5 shows Cabo Verde's monthly power generation in 2015. The power demand is high during the tourist season from July to October, and is low from January to March. The wind is weaker when the load is high, while the wind condition is favorable during the light load period requiring the suppression of wind power output. Given the power source composition, the hybrid operation of renewable and diesel power is essential (Figure 4.1-5).

≪Power supply/demand by island≫

Santo Antão: Santo Antão has an area of 779km^2, population of 40,500, and annual power generation of 13 GWh, of which wind IPP Electric accounts for 1.7 GWh (rate of renewables 12.6%). As the undertaking to build one power station per island proceeds and the demand for the system increases, Electric is considering the expansion of wind power.

São Vicente: São Vicente has an area of 227km^2, population of 81,000, and annual power generation of 71 GWh, of which wind IPP Cabeolica accounts for 19 GWh (rate of renewables 26.7%). Approximately 7.8 GWh of Electra's auxiliary power consumption is for desalination and supply pumps. The demand starts increasing early in the morning, peaks at around 20:00, and hits the lowest point between late night and early morning.
The wind power facility probably has a potential to produce energy to cover about 63% of the demand when the wind condition is favorable. However, the actual power generated by renewable facility accounts for only about 45%, since the facility's output is suppressed to ensure system stability. The measures to utilize the suppressed output might include the increase of the margin of reduction for diesel power, review of sale prices for the electricity in excess of the amount set in the Take or Pay PPA, and installation of batteries for ensuring system stability. Compared to other months, the wind is weaker from July to October when power demand is high.

São Nicolau: São Nicolau has an area of 343km^2, population of 12,400, and annual power generation of 6 GWh (no renewables introduced). To supply reactive power, two generators of Cacimba Power Station are often operated even though their capacity is too great for the demand. However, Electra plans to install shunt reactors, which should solve the issue. Demand fluctuates little by season but is higher between 19:00 and 22:00.

Sal: Sal has an area of 216km^2 and population of 33,700. Electra's annual power generation is 57GWh, with wind IPP Cabeolica generates 19 GWh (rate of renewables 33.0%). About 6GWh of Electra's auxiliary power is used for desalination and supply pumps. When the wind condition is favorable, the wind power facility has a potential to produce more energy than the demand for Electra. However, the actual power from the facility accounts for 57%, since the facility' output is suppressed to ensure system stability. The measures to utilize the suppressed output might include the increase of the margin of reduction for diesel power, review of sale prices for the electricity in excess of the amount set in the Take or Pay PPA, and installation of batteries for ensuring system stability. The total power production on Sal including that by APP that supplies power to some hotels, etc. is 67.8GWh. Also in Sal, the wind tends to be weaker with less power produced from July to October when power demand is high. Demand is high around 10:00, 13:00 and 20:00 while the load stays relatively level throughout the day. APP supplies 1MW-3.2MW of electricity to the desalination facility.

Boa Vista: Boa Vista has an area of 620km^2, population of 14,500 and annual power generation of 30

GWh, of which wind IPP Cabeolica accounts for 7.6 GWh (rate of renewables 33.0%). AEB provides power to Boa Vista, and 3.9 GWh of its auxiliary power is used for desalination, sewage treatment and supply pumps. On Boa Vista where tourism and hotel industry prosper, demand tends to be high at around 10:00, 13:00 and 20:00, and there is a difference in power demand between peak tourism season and off-season. When the wind condition is favorable, AEB uses wind power as a base power source and does not always secure reserve power using diesel power generation. In January when the wind condition is favorable, the renewable facilities produce about 42% of power. When the wind condition is favorable, AEB suppresses output from wind power facilities to ensure system stability, in a similar manner as Electra. The measures to utilize this excess power (about 2.2GWh/year) might include the increase of the margin of reduction for diesel power, review of sale prices for the electricity in excess of the amount set in the Take or Pay PPA, and installation of batteries for ensuring system stability. However, diesel power is necessary to cover the period of weak wind (July to October).

Maio: Maio has an area of 269 km^2, population of 7,000 and annual power generation of 2.6 GWh (no renewables introduced). Demand is high between 19:00 and 22:00 but shows relatively small fluctuations the rest of the time.

Santiago: Santiago has an area of 991km^2, population of 29,400 and annual power generation of 212GWh, of which wind IPP Cabeolica produces 31.9 GWh (rate of renewables 15.0%). About 15GWh of Electra's auxiliary power is used for desalination, sewage treatment and supply pumps. Demand starts increasing early in the morning, peaks at around 20:00, and drops from late night to early morning. On Santiago, output from wind power facilities is suppressed based on the amount set in the Take or Pay PPA. However, Santiago has sufficient diesel power output in comparison to wind power output, thus output from wind power facilities is not suppressed to ensure system stability. Measures to expand the renewables might include the increase of the margin of reduction for diesel power, review of sale prices for the electricity in excess of the amount set in the Take or Pay PPA, and installation of batteries for ensuring system stability. However, diesel power is essential since power demand is high from July to October, when the wind is weaker also on Santiago just as on other islands.

Fogo: Fogo has an area of 476 km^2, population of 35,800 and annual power generation of 13.4 GWh. Power demand tends to be high between 19:00 and 22:00 but stays almost even the rest of the time.

Brava: Brava has an area of 64 km^2, population of 5,700 and annual power generation of 2.6 GWh. Demand is high between 19:00 and 22:00 but stays relatively during the day. Brava once had a 150 kW wind power facility which is currently decommissioned. Considering the timing for the facility renewal based on the demand scale and ageing of power stations and transmission facilities, there might be a need for a demonstration test to bring up the rate of renewables in stages with the use of an integrated battery system.

4.2 Power supply/demand loss

The systems on the islands are simple and have short transmission distance; therefore, the technical loss is rarely over 10%. However, Electra's loss factor is extremely high on eight islands in its supply area (excluding Boa Vista and Sal) at 33%, which suggests that much of the loss is non-technical in nature and instead is due to theft and illegal use of power. The loss factor is less than 20% on Sal and Boa Vista (served by AEB), which have high hotel demand often served by MV transmission.

The examination by island revealed that the power loss and loss factor are much higher on Santiago that houses the capital Praia and large population, which calls for urgent measures above all else. Once improvements are made in the area, the success should impart a great impact on the management, and by employing the same method on other islands, the company should be able to achieve the result from the measures in an efficient manner.

The reasons behind the illegal use of electricity might involve issues deeply rooted in the society. Also, Electra has not made much progress collecting unpaid receivables. The continuation of the past measures might just allow the illegal activities to go on without solving any fundamental issues. Thus, the Study Team assure that it is effective for the fundamental resolution of the loss factor issue to implement multiple measures such as those listed below together with the Cabo Verde government, by referring to the actions and measures taken in other nations and Japan:

- Increase staff for electric bill collection and facility patrol
- Prioritized installation of prepaid meters in areas with illegal power use and low collection rate
- Cooperation with the Cabo Verde government (see examples below)
    - Strengthening of laws, regulations and penalties
    - Safety net such as the provision of the prepaid cards to needy households
    - Education in school and area of poverty to prevent illegal use of electricity and other public services

The issue of power loss is not a problem of any single power company such as Electra, and the Cabo Verde government must tackle the issue proactively as a problem for the country.

4.3 Local electrification

≪Monte Trigo Photovoltaic micro-grid≫

Monte Trigo village is located on the coast in the southwest part of Santo Antão, and has a population of about 230. The power demand of the island includes 75 general households, 20 public lightings, an elementary school, a kindergarten, an ice factory, a guesthouse and several small restaurants. There is a plan to introduce several PCs in a library. The total length of LV distribution line is about 1 km.

The Monte Trigo Photovoltaic micro-grid (PVMG) started operation in February 2012, co-financed by EU and the city (EU: 75% and city: 25%). APP and GRUP SOLER (Spain) were responsible for the construction. The facility is owned by the city, and operated and maintained by APP (Figure 4.3-3 and Table 4.3-1).

‹Overview of micro-grid›

The micro-grid is comprised of two units of PV and open type lead storage batteries, and emergency diesel generator (20kVA). In 2014, PV panels (12 kW) were added due to power demand increase, and future addition (approx. 20 kW) is being planned. The batteries were designed to have a capacity equivalent to three-day power demand, but now only have two-days' worth of capacity because of the demand increase. The ice producing machines start automatically when the batteries reach full-charge and absorb surplus power. Produced ice is sold to fishermen, and the profit is used to cover the PVMG operation cost. The cost of generating electricity is around 30-35 CVE/1kW. The electricity tariff is collected through a prepaid payment card system. The power generation over three years was 127,972kWh, which helped reduce the diesel fuel use by 37,039 liters and suppress about 111 tons of CO_2 emissions.

‹Operation and maintenance›

The batteries are operated to ensure their remaining capacity is 35% or more, and when the capacity dropped below the level, the following measures are taken in the order listed:

① Turn the public lights off to control the battery discharge

② Charge the batteries with PV power generation

③ Charge the batteries with diesel power generation

The specific gravity and voltage of the batteries are measured during the monthly maintenance. Two local staff contracted by APP provides O&M services to PVMG (work hours: 8:00-17:00). The PV panels are cleaned over 2 days at the end of each month, and the PV power generation increases about 5% after each cleaning. APP's engineers visit the site once every two to three months (initially every month). Thanks to the design of the facility, data could be verified and collected from the remote terminal of the PC.

‹Findings during the site visit›

Battery: There was some sediment likely from sulfation, due to which the replacement of the batteries is planned. The cause must also be investigated. The operation data showed that the battery operation deviated from the rule regarding the remaining capacity (minimum of 35%) and the capacity reached zero. It indicates potential battery degradation due to over-discharge. The review of operation plan and optimization of operation will be required to protect the batteries. It is also necessary to consider the timing of replacement and procurement of spare parts.

Diesel generator for emergency use: An oil leak was found in the fuel injection nozzle of the engine. Joints must be tightened and other parts checked for similar occurrences during periodic maintenance, etc.

Others: It seems necessary to follow items such as voltage, frequency etc. and to maintain and manage instrumentation devices thoroughly from the viewpoint of ensuring the power quality.

≪Carriçal Photovoltaic micro-grid≫

Carriçal is a fishing village located on the southeastern coast on the island of São Nicolau and has a population of about 200. The main power demand includes 53 households, streetlights and an elementary school. The Carriçal Photovoltaic micro-grid was created under PPP (Public Private Partnership) and started operation in December 2015. The city owns the micro-grid and APP is responsible for its construction, operation and maintenance.

‹Overview of the micro-grid›

Table 4.3-3 lists the main specifications of the micro-grid. The PV panels are installed on the roof of the school and Central at a 16-degree angle facing west, with a solar radiation meter and thermocouple at each location. Reportedly, they gave up south-facing arrangement due to space limitations. The batteries used are the gel lead batteries of the sealed type.

The maximum demand is about 12 kW, and the electricity tariff collection with the use of the prepaid card (RFID system) is planned for after June 2016.

‹Operation and maintenance›

Two local contractors employed by APP operate and maintain the facility (work hours: 8:00-19:00). According to the local contractors, they clean the PV panels twice a month at the interval of 15 days (the 1st and 15th of the month) using a mop sponge, and PV power generation increases by up to 3kW after the panel cleaning.

As for the measurement data, the figures indicated on the PC which is used for monitoring and measurement are transcribed on paper every hour. The data thus transcribed are entered and managed in the EXCEL table in the PC. APP staff is to visit the site once every 6 months; however, since the micro-grid has not been in operation for 6 months, APP staff has not come to the site.

‹Findings from the site visit›

PV panel: The amount of dust on the surface seemed relatively small, but dust was seen on the cable connectors on the underside of the panels. Cleaning of the cable connectors might be necessary where possible, since salt, etc. could cause damage with the coast nearby.

Battery: No equipment to measure battery voltage has been delivered to the site. Assistance is recommended including technical guidance to local contractors on battery maintenance, etc.

Emergency generator: The generator was still in temporary storage unconnected to the grid. It might be necessary to connect it to the grid through switchgear so that it is ready for operation as a backup power source.

Frequency fluctuation: The operation data suggested a possibility that the frequency deviated from the stipulated value (50±2Hz). Measures for frequency fluctuation control might have to be considered for the future.

5. Power source and facility

5.1 Santo Antão

Santo Antão has a power demand of about 3,000kW, which is served by two diesel power stations and a wind power plant of Electra. The total output is 10,532kW (Figure 5.1-1).

5.2 São Vicente

São Vicente has an electricity demand of about 12,100kW. Electricity is supplied to the island by two diesel power stations of Electra and Cabeolica's wind power plant. The total output is 39,646kW (Figure 5.2-1).

5.3 São Nicolau

São Nicolau's demand for electricity is about 1,200kW. Electra's two diesel power stations with a total output of 7,672kW supply power to the island (Figure 5.3-1).

5.4 Sal

APP supplies power to the hotels on Sal while Electra and Cabeolica serve the rest of the island. The general demand excluding that of the hotels is about 9,800kW. The island's power is supplied by APP's diesel power station, Electra's diesel power station and photovoltaic power plant, and a wind power plant of Cabeolica. Their total output is 29,359kW (Figure 5.4-1).

5.5 Boa Vista

Boa Vista has a power demand of about 6,100kW, which is served by three diesel power stations of AEB and a wind power plant of Cabeolica. Their total output is 14,114kW. Currently, Norte Power Station supplies power through an independent system but is to be connected to the system of Chavez Power Station in 2016 (Figure 5.5-1).

5.6 Maio

The power demand of Maio is around 500kW. The power source of the island is Electra's diesel power station with a total output of 2,176kW (Figure 5.6-1).

5.7 Santiago

Santiago's demand for electricity is about 35,300kW. Power is supplied by four diesel power stations and a photovoltaic power plant of Electra, and Cabeolica's wind power plant. The total output is 100,965kW (Figure 5.7-1).

5.8 Fogo

Fogo has an electricity demand of about 2,400kW. Electra's two diesel power stations having a total output of 9,304kW supply power to the island (Figure 5.8-1).

5.9 Brava

The island of Brava has an electricity demand of around 600kW. Electra's diesel power station with a total output of 1,416kW provides power to the island (Figure 5.9-1).

6. Diesel power generation

On a remote island where the demand for electricity is not very large, diesel power is generally adopted to draw upon its strengths including quick startup and shutdown, excellent load-following capability, ability to meet ever-changing demand, simple system that can be downsized and cost advantage even when output is small. In Cabo Verde, diesel power is adopted as a key power source.

6.1 Diesel power facilities and operation status

≪Santo Antao≫

Santo Antao houses two diesel power stations of Electra (P.Novo Pwore Station and R.Grand Power Station), of which P.Nova PS was newly constructed in June 2015. MAN1 and MAN2 of P.Nova PS (1,672kW×2) are baseload units and boast quick response to short-term load fluctuations, thanks to the adoption of the isochronous control. They are capable of utilizing HFO with low unit cost but are fueled by gas oil, which is transported from the oil terminal on the island by tank truck. Although there is a plan to build an HFO storage facility on the island by the oil distributor, the time is undecided. Other units are used for peak-cutting (Table 6.1-1). On Santo Antao, Electlic's wind power generators (250kW×2) are interconnected but the output fluctuation seems to have almost no impact on the frequency.

≪Sao Vicente≫

Sao Vicente houses two diesel power stations of Electra (Lazareto Power Station and Matiota Power Station). In 2015, two most-advanced units manufactured by Wartsilla were added to Lazareto Power Station (Figure 6.1-2). At both power stations, the baseload units are fueled by HFO which has a low unit price and is transported from the oil terminal on the island by tank truck. War1 and War2 of Lazareto Power Station (5,520kW × 2) and Mak5 and Mak6 of Matiota Power Station (3,300kW×2) are baseload units and boast quick response to short-term load fluctuations, thanks to the adoption of the isochronous control. Others are used as peak-cut units (Table 6.1-2).

≪Sao Nicolau≫

Sao Nicolau houses two diesel power stations of Electra (Cacimba Power Station and Tarrafal Power Station). Cacimba Power Station is an advanced power station built in November 2015. Per1 and Per2 (1,707kW×2) serve as baseload units and boast quick response to short-term load fluctuations since the isochronous control is adopted for the governors. Even though the demand is about 1,100kW at the maximum, both units are operated to control reactive power, forcing the units to operate with extremely low output. At older Tarrafal Power Station, two failed units out of four are slated for dismantlement. There is a plan to relocate Cum5 to Cacimba Power Station and a unit from P.Novo Power Station on the island of Santo Antao to Cacimba Power Station. Both power stations are fueled solely by gas oil, which is transported from the oil terminal on the island by tank truck (Figure 6.1-3).

≪Sal≫

Sal houses Electra's diesel power station (Palmeira Power Station) and APP's diesel power station that supplies power to hotels in the neighboring areas. CAT1 and CAT2 (3,840kW×2) of Palmeira Power Station as well as War4 and War5 of APP (1,540kW×2) serve as baseload units and boast quick response to short-term load fluctuations since the isochronous control is adopted for the governors. These four units are fueled by HFO which has a low unit cost and is transported from the oil terminal on the island by tank truck. Palmeira Power Station plans to introduce 6MW HFO diesel units (1.5MW×4) in 2016 to meet the increasing demand from newly constructed hotels, which is financed by AFD (French Development Agency). The replacement of CAT (648kW×3) at APP's power station is being planned to upgrade it to 3,000kW.

≪Boa Vista≫

Boa Vista houses three diesel power stations operated and managed by AEB (Chavez Power Station, Lscacao Power Station and Norte Power Station). The independent system in the northern area receives power from Norte Power Station but is slated to be connected to the Chavez Power Station system as part of the ORET project. Figure 6.1-5 shows the diesel power facilities of Boa Vista. War1 and War2 (1,620kW×2) of Chavez Power Station serve as baseload units and the isochronous control is adopted for the governors. HFO is transported from the oil terminal on the island by tank truck. Others units are used for peak-cutting. There is a plan to add two 1,000kVA units and one 4,000kVA unit by Perkins to Chavez Power Station in 2016.

≪Maio≫

Maio houses Electra's diesel ower station (Tomil Power Station) fueled solely by gas oil. Cum1 (688kW) and CAT3 (600W) serve as baseload units while remaining CAT2 (200kW) and Cum3 (688kW) are out of order. Table 6.2-6 lists the power facilities of Maio. The control method is unknown since no Site Survey was conducted.

≪Santiago≫

Santiago houses Electra's four diesel power stations (Palmarejo Power Station, TRC Power Station, Gamboa Power Station and Assomada Power Station). Palmarejo Power Station welcomed two state-of-the-art units by Wartsilla in 2012 and two in 2015. Wartsilla and CAT of Palmarejo Power Station serve as baseload units and boast quick response to short-term load fluctuations since the isochronous control is adopted for the electrical governors. HFO is transported from the oil terminal on the island by tank truck. Other units are operated for peak-cutting. Gamboa Power Station and TRC Power Station are to be scrapped when the units suffer a major failure, but the actual time for scrapping is unknown. Assomada Power Station located inland is to be left as backup. There is a plan to move the facilities of TRC Power Station to Sal. On Santiago, eleven 850kW wind power units of Cabeolica are interconnected. On the day of the survey, the frequency fluctuation was 49.09 - 50.08Hz which fell within the operational target (49.0 - 51.00Hz) of Cabo Verde.

≪Fogo≫

Fogo houses two diesel power stations of Electra (Joan Pinto Power Station and Ponta Lapa Power Station). Joan Pinto Power Station welcomed two most advanced units by MAN in 2015. Fuel is gas oil and transported from the oil terminal of the island by tank truck. MAN1 and MAN2 of Joan Pinto Power Station (1,672kW×2) are baseload units and boast quick response to short-term load fluctuations thanks to the isochronous control by the electrical governors. These units are capable of utilizing HFO; however, they currently use gasoil since the island has no HFO storage facility. There is a plan to receive HFO directly from a tanker. Other units are operated for peak-cutting.

≪Brava≫

Brava houses a diesel power station of Electra (Favatal Power Station). The units are operated based on demand, except for Per2 which is out of order. The baseload units boast quick response to short-term load fluctuations thanks to the isochronous control by the electrical governors. Its only fuel is gasoil, transported by truck in oil drums.

≪Power generation cost by Island≫

Cabo Verde's average fuel cost for 2015 was 13.56CVE/kWh according to the tentative calculation carried out by the Study Team based on the data obtained from DGE, Electra, etc. As for the cost by island, four islands (Santiago, Sao Vicente, Boa Vista and Sal) that has relatively large demand and use HFO with low unit price have relatively small cost at 11.70 - 17.19CVE/kWh while remaining five islands that have smaller demand and use gasoil with higher unit price have high cost at 19CVE/kWh or more (Table 6.1-10, and Figures 6.1-10 and 6.1-11).

≪Operation and maintenance of diesel power facilites≫

The main properties of HFO (Fuel 180) used in the baseload units are very similar to those of C heavy oil that Kyushu Electric Power uses, and with C.C.A.I (calculated carbon aromaticity index) being 860 or less, there should be no problem with combustion. However, the fuel contains Aluminum plus silicon which is extremely hard and could cause abnormal wear; thus the filters and centrifugal oil purifier of the pretreatment system must be maintained and managed properly.

The operation and maintenance system of Cabo Verde's major power stations is very similar to that used by Kyushu Electric Power and it would be hard to further improve efficiency while ensuring a stable operation and passing down skills (Figure 6.1-12).

Efficient units are used for baseload operation, and the operation method seems appropriate as the majority of power stations are operated with an awareness of the adverse effect caused by low-output operation. However, it is advisable to carry out the performance confirmation test, measurement of specific fuel consumption and lubricant consumption, etc. on a regular basis to ensure stable operation and performance.

Generally, the inspection is conducted at intervals and for items as recommended by the manufacturer. Since the inspection work could vary depending on the environment and service condition, it is desirable to create optimal maintenance criteria based on the analysis and evaluation of past inspection records, to ensure stable operation and cost reduction (Kyushu Electric Power has established optimal maintenance criteria by analyzing and evaluating the record of past inspections).

6.2 Future challenges for diesel power

≪Key points and challenges towards renewables expansion≫

In order to increase the allowable renewables to be introduced, it is important to ensure ample frequency regulation capability and margin for reduction (minimum output) for diesel power, which serve as a base power source and regulated power source to balance the renewable output that fluctuates with weather.

≪Frequency adjustment control (aspect of short term adjustment)≫

Cabo Verde has adopted diesel generators that allow for governor-free operation and the country's wind condition is stable. Thus, it should be possible to absorb and control so-called short-term (a few minutes or less) fluctuations from wind power generation through governor-free operation of diesel power facilities. However, the frequent output change can negatively affect the service life of the diesel power facility. Upon actual operation, it is necessary to examine the output fluctuation of wind power facilities and consider and implement necessary measures.

≪Notes regarding minimum-output diesel power operation≫

In the low-output range, the diesel engine could experience a drop in temperature and scavenging action inside the cylinder, which worsens the fuel spray quality. It leads to poor combustion and generates unburned carbon. It must be noted that if the low-output operation continues for an extended period, unburned carbon could adhere to the cylinder and piston, leading to damage in the air intake/exhaust valves and piston (Figure 6.2-2).

≪Available Minimum Load Operation (aspect of long term adjustment)≫

Generally, the minimum output at which the diesel generator can operate stably is about 50% of the rated output; however, diesel devices that withstand low-output operation at about 30% of the rated output became available in recent years, thanks to the adoption of variable valve timing and intake air heating, etc. Kyushu Electric Power has adopted those devices when new power facilities were built or added. Recently, Cabo Verde witnessed the introduction of diesel generators that withstand low-output operation at about 30% of the rated output, such as those by Wartsila introduced at Lazareto Power Station on Sao Vicente and Palmarejo Power Station on Santiago. The renewables expansion should be possible by fully utilizing the potential of governor-free operation and low-output operation, and the reduction of fuel use should bring ample economic effect even though specific fuel consumption will worsen due to low-output operation.

≪Issues and measures toward renewables expansion≫

After the expansion of renewables, diesel power will become more and more important not only as a base power source but also as the regulated power source to balance output from renewable facilities, which fluctuates with weather. To this end, the diesel power facility must be operated and maintained in an appropriate manner to keep up with the renewables expansion. More specifically, it is desirable to implement measures below.

‹Operation-related measures›

- Select optimal units based on forecasted demand and renewables output
- Conduct patrol and inspection to better monitor the operation state such as exhaust temperature and to prepare for an increase in troubles
- Carry out voltage operation with consideration to the generator’s voltage regulation capability (PQ curve)

• Carry out cleaning operation to burn and eliminate unburned carbon after low-output operation

‹Maintenance-related measures›

Since, the state of diesel power generation changes with the operating condition, it is necessary to analyze and evaluate the inspection result, and review the maintenance intervals as needed. In particular:

• Maintain performance through regular performance confirmation tests and measurement of specific fuel and lubricant consumptions, etc.
• Establish and implement the optimal maintenance criteria through analysis and evaluation of the inspection result

‹Facility-related measures›

On most islands of Cabo Verde, the unit capacity and installed capacity are too large for the demand scale. It is desirable to optimize the capacity when new facilities are built or added in the future.

7. Wind Power Generation

In Cabo Verde, the wind power generation systems of Cabeolica started operation between October 2011 and April 2012 on the four islands of Sao Vicente, Sal, Boa Vista and Santiago. The systems' total installed capacity is 25.5MW which is about 13% of Cabo Verde's power generation facilities (approx. 204MW). The 0.5MW-wind power generation system that Electric owns on Santo Antao started operation in April 2011. Both companies are IPPs with a total power generation capacity of 26.0MW (Table 7.1-1).

Cabeolica is a commercial power producer that was established under PPP (Public Private Partnership) of Sub-Saharan Africa and with the investment by Electra and private investment funds. The European Development Fund (EDF) provided 30 million Euros and African Development Bank (AfDB) 15 million Euros in response to the Cabo Verdean government's measures to actively introduce renewables. The 30 wind turbines that Cabeolica has installed on the four islands are all 850kW per units and are model V52-850kW manufactured by Vestas, Denmark (Table 7.1-2).

The wind power generation system on Santiago with 9.35MW (850kW×11 units) is located on the southeastern end of the mountain ridge that extends from northwest to southeast at an altitude of about 230m - 270m. There is Electra's wind power generation system (Nordtank unit ×3) at the same location (currently shutdown).

Sao Vicente's wind power generation system (5.95MW: 850kW×7) is located slightly west to the center of the island on the mountain ridge that runs from north-northwest to south-southeast at an altitude of about 80m-100m. There is Electra's wind power generation system (Nordtank unit ×3) (currently shutdown) on the same site. There also were wind turbines built with the assistance of Denmark left in the northeastern side (details of the installation unknown).

Sal's wind power generation system (7.65MW: 850kW×9) is on the flat terrain that stretches from the center to the southeastern side of the island at an altitude of about 60m. There are two wind turbines by Nordtank left near Electra's Palmeira Power Station. The site is within the wind power development zone (SL.1), which was published in Cabo Verde's official gazette No. 7 in February 2012 in order to actively promote the introduction of renewable energy sources (Figure 7.3-19).

Boa Vista's wind power generation system (2.55MW: 850kW×3) is located on a cape at the northwestern edge of the island at an altitude of 80m-100m.

The electrical facilities at the sites (Santiago, Sao Vicente, Sal and Boa Vista) have the standard configuration, where 690V output from the generators is boosted to 20kV with the transformer inside the tower, collected in the 20kV underground cable and sent to the grind through the switching facility in the control building and 20kV transmission line. In the control building, all facilities required for grid connection are installed including the switching facility, a grid connection protection unit, and an integrating wattmeter for calculating the electric energy sold to Electra. As the countermeasure for grid power loss, DC power supply unit and emergency generator for the control unit are installed in the control building.

On Santiago, the wind power system is currently connected to Gamboa Power Station; however, it is planned to be connected to the São Filipe substation since 60kV and 20kV transmission systems are developed as part of the power generation and transmission reinforcement project co-financed by AfDB and JICA. On Sao Vicente, the wind power generation system is connected to Lazareto Power Station via the 20kV underground cable. On Sal, the system is connected to the grid via the 20 kV underground cable, while on Boa Vista, the system is connected to Sal Rei Power Station via the 20 kV underground cable.

7.1 Operation Status of the Wind Power Generation System

Cabeolica has concluded an O&M contract with Vestas. The operation status of the wind power generation systems is constantly and remotely monitored with the SCADA system (Vestas Online Business). Through the SCADA system, the head office and maintenance staff of Cabeolica, and maintenance staff of Vestas are able to verify in real time the data on wind turbine operation and alarms, which is required to oversee the operation status. The operation data (voltage, frequency, wind speed, and so on) are stored in the SCADA system, enabling data history management (Figure 7.1-17).

≪Cooperative operation with Electra and AEB≫

Electra receives electricity generated at the wind power facilities on Santiago, São Vicente and Sal, constantly monitors the wind turbine operation status through the Vestas SCADA system to ensure the quality of electric power, and adjusts the wind power output and voltage. AEB that supplies power on Boa Vista also practices similar operation. Electra and AEB have created specific standards in the areas of power quality (voltage and frequency) and operation of diesel power generation systems, and operate diesel power stations and wind power systems in a cooperative manner (details given hereinafter).

There are wind turbines by Nordtank that are shut down and left at the sites of Cabeolica's wind power generation systems on Santiago and São Vicente. This fact might indicate the advantages of the sites in terms of wind condition and transportation of equipment and materials. The specific history of site selection is unknown since the FS by InfraCo has not been obtained. The construction period until the completion of the respective wind power generation systems was about one year for the systems on Santiago and São Vicente, while the system on Sal was completed two months later and Boa Vista's system 5 months afterward. The construction of all the systems took less than 2 years in total (Table 7.1-7). The construction cost was about 60 million EURO for the four sites (Table 7.1-8) and the operation cost (O&M cost) is estimated to be 2 million EURO/year. There is no rehabilitation work done or expansion planned for any of the sites.

Cabeolica has provided 10-minute operation data including voltage (V), frequency (Hz), wind speed (m/s) and temperature (℃) for the four sites (Santiago, São Vicente, Sal, and Boa Vista). Data on power output (kW), reactive power (kVar), generated energy (kWh), power factor (%), SetPoint output (kW), and wind direction (°) has not been provided.

The average wind speed in 2015 at the wind turbine hub height (55m aboveground) was in the 8.1 m/s - 8.4 m/s range on Santiago. The monthly average wind speed in summer (July - October) drops to about 5m/s - 6 m/s. The peak of the annual frequency of occurrence by wind speed scale was 8m/s - 9 m/s and the frequency of occurrence of less than 4 m/s, which suspends power generation, was about 12% (around 1,039 hours in a calendar year). The frequency of occurrence of high wind speed of 25 m/s or more that stops power generation was 0%. The electrical energy sold in 2015 was 32,341,175 kWh, with capacity factor of 39.5% (Table 7.1-11).

According to Electra during the discussions at Palmarejo Power Station:

- The wind condition in Praia is favorable and the grid has not been subjected to trouble caused by sudden output fluctuation
- Wind power systems and diesel power plants are operated to the ratio of 7:3 based on energy generated. Each diesel generator is operated based on the minimum output of 55% and the economic performance of 60% as the guideline.

At the time of the inspection, the output of the wind power generation system was set to 9.35 MW and the power factor to 0.95, lagging on the grid side. The actual output fluctuated within the range of 5 - 7.5MW based on the wind speed. Hardly any voltage fluctuation was observed.

The average wind speed of 2015 at the wind turbine hub height (55m aboveground) was 9.9m/s - 11.1 m/s on Sao Vicente. The monthly average wind speed in summertime (July – October) dropped to about 7 m/s - 9 m/s. The peak of the annual frequency of occurrence by wind speed scale was 9m/s - 10 m/s. The frequency of occurrence of less than 4m/s, which causes power generation to halt, was about 6% (around 482 hours in a calendar year). The frequency of occurrence of high wind of 25 m/s or more that halts power generation was 0%. The electrical energy sold in 2015 was 19,458,089 kWh, with capacity factor of 37.3％ (Table 7.1-13).

According to Electra during the discussions at Lazareto Power Station:

- Even though the wind power output on São Vincente is constant, diesel power generation is to be utilized as the base power source.
- To ensure the grid stability, the wind power output (kW) is to be restricted to 50% of the total demand (kW) at the maximum.

During the inspection, the output from the wind power generation system was set to 4.5MW and the power factor to 0.95, lagging on the grid side. The wind power output was constant at 4.5MW due to output control operation performed. There was hardly any voltage fluctuation.

The average wind speed of 2015 at the wind turbine hub height (55m aboveground) was 8.2 m/s - 9.5 m/s on Sal. The monthly average wind speed in summertime (July – October) dropped to 6m/s - 7m/s. The peak of the annual frequency of occurrence by wind speed scale was 9m/s - 10m/s and the frequency of occurrence of wind less than 4m/s, which causes power generation to halt, was about 5% (around 403 hours in a calendar year). The frequency of occurrence of high wind of 25 m/s or more that halts power generation was 0%. The electrical energy sold in 2015 was 19,171,213 kWh, with capacity factor of 28.6% (Table 7.1-15).

During the inspection of Electra's Palmeira Power Station, the output of the wind power generation system was set to 2 MW and the power factor to 0.98, lagging on the grid side. Although output was controlled, the wind power output fluctuated gradually within the range of 1 - 2MW. There was hardly any voltage fluctuation.

The average wind speed of 2015 at the wind turbine hub height (55m aboveground) was 8.1m/s - 9.4m/s on Boa Vista. The monthly average wind speed in summertime (July – October) dropped to about 5m/s - 7m/s. The peak of the annual frequency of occurrence by wind speed scale was 10m/s - 11m/s and the frequency of occurrence of wind less than 4m/s, which causes power generation to halt, was about 7% (around 638 hours in a calendar year). The frequency of occurrence of high wind of 25m/s or more that halts power generation was 0%. The electrical energy sold in 2015 was 7,812,829 kWh, with capacity factor of 35.0% (Table 7.1-17).

During the inspection of Chavez Power Station of AEB, the output of the wind power generation system was set to 1.2 MW and the power factor to 0.97, lagging on the grid side. Since the wind power output was controlled, it was constant at 1.2 MW. Voltage hardly fluctuated.

≪Comparison between actual power generation and theoretical power generation≫

Since output is controlled at Cabeolica's four wind power generation sites (Santiago, Sao Vicente, Sal, and Boa Vista) for grid stabilization, the theoretical power generation was calculated based on the wind speed data (10-minute values from 2015) provided by Cabeolica. Next, the output control status was verified by comparing the figure with the actual power generation provided by Cabeolica. Since output is not controlled on Santiago, the team calculated the amount of energy that could be generated realistically on the three islands excluding Santiago. For the calculation, the total loss factor of 10% was used, which was estimated based on the actual power generation and theoretical power generation (assuming that the total loss factor of 10% includes all losses including control loss, maintenance loss, etc.). The result indicated that about 40% of energy is suppressed on São Vincente and Sal for the purpose of grid stabilization (Tables 7.1-19 to 7.1-27 and Figure 7.1-26).

≪PPA-based annual power generation plan and result≫

Cabeolica and Electra have concluded a Take-or-Pay PPA (Purchase Price Agreement) that guarantees to recover capital investment of wind power (Table 7.1-28).

≪Operational status≫

Cabeolica and Vestas have concluded a maintenance contract for the wind power generation systems (guaranteed availability factor of 95%). The systems had to shut down due to minor problems but the guaranteed availability factor (95%) has been met since the systems have not had any long-term shutdown due to major troubles. According to Cabeolica, there are some concerns regarding strong wind, sand and corrosion caused by salt.

≪Management structure and maintenance status≫

The Head Office of Cabeolica is in Praia, the capital of Cabo Verde. Cabeolica has 10 employees, of which a sales contact is stationed in each island that has the wind power generation system, who operates and maintains the system in coordination with the specialists of Vestas. The six specialists of Vestas (four are stationed on Santiago and two on Sal) carry out maintenance of the wind power generation systems on the four islands in a cooperative manner. Vestas proposes the annual maintenance schedule and contents for the wind power generation systems to Cabeolica and implements work accordingly.

≪Electric wind power generation system≫

Electric is an IPP founded in 2010 and is engaged exclusively in wind power generation. It owns the 0.5MW wind power generation system (250kW×2) on the island of Santo Antão (Table 7.1-32). The facilities were about 12 years old when they were installed and were about 18 years old at the time of the inspection, even though the system only started commercial operation in April 2011. The system is located at the eastern end of Santo Antao and the wind turbines are positioned at an altitude of about 240m (Figure 7.1-31). After the boost of the generator voltage of 400V to 10kV outside the wind turbine towers, the power is collected in an underground cable which is connected to the grid through the switching facility inside the electric room. All the necessary facilities for grid interconnection are installed in the electric room, including the switching facility and grid connection protection units. The system is constantly and remotely monitored using the SCADA system at the Head Office of Electric (São Vicente). However, the system is older than that of Cabeolica, and fewer items are monitored and operation data are not accumulated. The system of Electric utilizes stall control, which is incapable of output control. Therefore, cooperative operation such as output control and voltage adjustment is not done, and the system operates with irregular output that change with the wind condition.

Wind conditions have been observed (at 12m aboveground) for about one year since May 2008. The observation revealed excellent wind conditions with the annual average wind speed of 9m/s and frequency of occurrence of the predominant wind direction (north-northeast) of 60% or more, indicating the reasons for the site selection. The commercial operation commenced in April 2011; however, the specific construction period such as the construction schedule (actual) as well as cost for construction and operation are unknown.

Accordingto Electric, the grid on Santo Antao will be enhanced by the installation/extension of a 20kV transmission line, and the addition of two wind power units is planned for next year. The wind turbines of the same model as the existing ones are to be added for maintainability. Reportedly, there is a plan to install a wind power generator as an independent power source for the seawater desalination plant at São Nicolau and for which the wind condition is being examined. The team calculated the annual capacity factor based on the monthly/annual power generation data from April 2011 to December 2015 provided by Electric. The figure thus obtained was about 26% - 40%.

Unlike the case of Cabeolica, the PPA to guarantee capital investment of wind power has not been concluded. There have been no major faults that caused long-term system shutdown from the time of the commencement of operation up until now, even though there have been minor faults such as wind direction/velocity sensor and electrical faults. Towers and nacelles have been repainted due salt damage and the hydraulic system for stall control has experienced some troubles. However, there has been no impact from lightning.

The Head Office of Electric is located on São Vicente. Two out of three operators stationed on Santo Antão take turn and carry out operation from 8 a.m. to 5 p.m. Regular preventive maintenance is performed every three months. Wind turbines are stopped and maintained every six months by waiting for the time when the wind is weak. The maintenance is carried out over one week.

A wind turbine manufactured by Nordtank is left unused on Brava. It probably had an output of 150kW and was connected to the power distribution facility at the port via an underground cable, using up energy with dummy load (resistance) when there is excessive energy. The tower is a holding tower type. Apparently, GESTO Energy Consulting (GESTO), Portugal's energy consultant, has conducted research on the wind condition in 2015.

7.2 Issues of wind power generation

The size of wind turbines has been increasing in recent years (2MW or more). The team examined the issues that might arise when installing wind turbines in the wind power generation development zones (published in Cabo Verde's Official Gazette No.7 (2012)), in addition to other wind power-related issues found during the site inspection.

Current issues: The towers of the wind turbines installed by Cabeolica have the same salinity tolerance as those for offshore wind turbines. During the site inspection, the team found repairs that were made to the paint on part of the tower where the paint came off when stones carried by strong wind collided into the tower. Since the topsoil of Cabo Verde tends to contain a high amount of pebbles and the land faces the ocean, measures against salt damage at the time of installation and regular repairs of the tower surfaces might be necessary. Cabeolica is also concerned about the issues of sand and impact of salt damage on operation.

Issues regarding the wind power generation development zone: In Cabo Verde, the areas for renewable energy development have been published in Official Gazette No. 7 (2012), where the construction of residential buildings and agricultural operations are restricted. The team examined the wind power potentials for the wind power generation development zones which are specified among the renewable energy development areas. The wind condition map (analysis by the Riso National Laboratory of Denmark in 2007) used for the wind condition evaluation adopted the hourly-average wind speed and cannot be used to evaluate the impact of terrain turbulence, which has become evident as a cause of wind turbine failures and accidents. Cabo Verde has many areas with a gradient in excess of 10%, which calls for proper evaluation of the impact of terrain turbulence when considering the installation of wind turbines. The impact of terrain turbulence is a serious issue when working to avoid failures of wind turbines and accidents, since the blade diameter increases as the wind turbine size increases.

Environmental aspect: The 850kW-class wind turbine (the same as those installed by Cabeolica with the blade diameter of 52m and blade tip height of 81m) was used to examine the potential for wind power development in Cabo Verde. However, the 2MW type, which is currently the main stream, has blades with a diameter of about 100m and height of 120m at the blade tip, and has greater impact on the landscape. For example, a plan for large-scale resort development is progressing in the area near the wind power generation development zone (SL.1) on Sal. Therefore, reevaluation might be necessary in the environmental aspect including the impact on the landscape and noise.

Aspect of transportation: Cabo Verde has two international ports (Paria Port on Santiago and Mindelo Port on São Vicente). Both ports have many structures in the section connecting the unloading wharf to the exit, which could interfere with transportation of equipment and materials for wind turbines. Therefore, detailed examinations might be necessary regarding the transportation route leading to the construction site, countermeasure construction, and transportation vehicles for equipment and materials for large wind turbines. The transportation from the unloading port to the wind turbine construction site is also a serious issue on the other seven islands.

Aspect of installation and maintenance: The installation or maintenance such as the replacement of a blade of a 2MW-class facility requires a crane of 500t capacity or more. However, there is no such crane in Cabo Verde, and the procurement of the crane is necessary.

Operating characteristics: In Cabo Verde, the wind speed drops significantly during summertime (July – October) when demand for energy is high, especially on Sal and Boa Vista where the tourist industry is flourishing. The team calculated the number of hours when wind turbines' power generation was ceased for Sal and Boa Vista, based on the 10-minute wind speed data of 2015 provided by Cabeolica (the number of hours was calculated by assuming that power generation ceased in hours during which the wind speed was less than 4m/s or 25m/s or more). According to the calculation result, the power generation ceased for the most number of hours in July for both islands, with 147 hours (equivalent to about 6 days) for Sal and 256 hours (equivalent to about 11 days) for Boa Vista. Electra sets the upper output limit for Cabeolica's wind power generation systems at the internal combustion power plant. However, Electra might not be able to handle the halt of wind power generation due to sudden drop in wind speed. Although a diesel power generation system is set aside as a standby system, it takes about one hour for it to start. Therefore, it is necessary to examine the measures for grid stabilization including the number of diesel generators and their operation method in case wind turbine generation stops suddenly.

Ensuring power quality associated with the expansion of wind power generation systems: On São Vicente, Electra's wind turbines manufactured by Nordtank were shut down as excess facilities. On Brava, one wind turbine by Nordtank was installed, but part of the power generated was wasted in dump load operation. Since output control is possible for Cabeolica's wind power generation systems, they are operated along with diesel power systems in a cooperative manner for grid stabilization. However, on São Vicente and Sal, about 40% of the energy is suppressed annually. At the same time, the bidding system for wind power IPPs is being developed in Cabo Verde. As the precondition, it is necessary to calculate the wind power generation capacity that can be introduced on each island, after examining grid stabilization measures such as the cooperative operation with diesel power generation systems, reinforcement of the transmission network, and installation of batteries, based on the future demand and grid status. It is also necessary to examine the specifications of the wind power generation systems to be connected, to see if they could pose a problem in ensuring the power quality (frequency and voltage) set forth in the grid code of Cabo Verde (scheduled to become effective in February 2016). According to Cabeolica, private companies are not financially capable of installing facilities for grid stabilization such as batteries. Therefore, the bidding procedure must clearly indicate the party responsible for the facility installation if such facility is required and the cost allocation between the wind power IPP and the grid operator.

7.3 Study of wind power potential

The team studied the potential of wind-power generation for three areas (Mindelo on São Vicente, Sal, and Praia on Santiago) where INMG (National Institute of Meteorology and Geophysics) (hereinafter INMG) of Cabo Verde conducts meteorological observations. The study was carried out by obtaining meteorological statistical data and based on the wind condition data (wind speed and direction) (see Figure 7.3-1).

≪Observation overview≫

Measurement is taken at about 30 meters aboveground (building rooftop) in Mindelo and at 10 meters aboveground (observation pole) on Sal, and approximately 30 meters aboveground in other locations according to INMG (Figures 7.3-2 and 7.3-3).

≪Analysis result of 2015 a average annual value and the normal value≫

The team evaluated the 2015 wind speed data given by Cabeolica, based on the daily average wind speed (m/s) over the past ten years (from January 2006 to December 2015) for Mindelo, Sal, and Praia provided by INMG. The average wind speed in Mindelo, Sal, and Praia for the past ten years was 6.1m/s, 5.9m/s, and 6.4m/s, respectively. As the wind speed data provided by Cabeolica for the investigation was for one year of 2015 only, JICA Study Team compared the average wind speed from 2015 and that from the other nine years (from 2006 to 2014). The result was that the average wind speed from 2015 was slightly higher than the normal value. However, the year 2015, which the wind condition data provided by Cabeolica covered, does not seem particularly unusual compared to other years (Table 7.3-1).

≪Potential evaluation according to the wind condition map≫

The team created a wind condition map using the wind (u: east-west direction, v: north-south direction) of the sea-level physical quantity from January to December 2015 from the GSM data (Tables 7.3-4 and 7.3-5 and Figures 7.3-6 and 7.3-7). As for the long-term wind direction change, the team evaluated the wind direction characteristics of Cabo Verde based on the wind direction data provided by INMG (the statistical data from the observation at the Rabil airport on Boa Vista and the ten-minute values for the past three years (2013 to 2015) for Mindelo on Sao Vicente and Sal). Based on the statistical data of the monthly wind direction from the past six years observed at the Rabil airport, the main wind direction was northeast (NE) throughout a year (Table 7.3-6). Also, the frequency of occurrence of the northeast (NE) wind in Mindelo and Sal was 51.7%-54.3% and 37.3% - 40.1%, respectively, which indicate predominance of the wind direction (Table 7.3-7 and 7.3-8 and Figure 7.3-14).

It is stipulated that when evaluating the feasibility of installing wind-power generation facilities in Japan, it is desirable if the average annual wind speed at 30 meters aboveground is 6 m/s or more and the wind direction can be considered stable if the annual frequency of occurrence of the wind direction along the wind axis is 60% or more. Also, as a result of creating the 2015 wind condition map of Cabo Verde, the average annual wind speed at the wind turbine hub height (55 meters aboveground) exceeds 8m/s in the entire area of Cabo Verde and the frequency of occurrence of the wind direction in Mindelo and Sal from 2013 to 2015 was constant at 60% or more; thus it was determined that Cabo Verde has favorable wind conditions that are highly accommodating to the introduction of wind power generation systems.

≪Evaluation of potential of the wind-power generation development zone≫

In Cabo Verde, the renewable energy sector strategic plan that identifies the renewable energy development zones (ZDER) has been approved in accordance with Law No1 (effective on January 3, 2011), and the second paragraph of Article 265 of the Constitution. For this investigation, the team converted the area map (image) of the wind-power generation development zone obtained from DGE into GIS data and used the data for the potential evaluation. However, it should be noted that the number of development zones shown in the area map obtained from DGE is different from the number of zones indicated in the official gazette (Tables 7.3-11 and 7.3-12 and Figures 7.3-16 to 7.3-24). Cabo Verde has favorable wind conditions where the average annual wind speed exceeds 8 m/s (55 meters aboveground) (Figure 7.3-25).

≪Evaluation of wind power potential in each island≫

As to the wind-power generation development zones obtained from DGE, the team studied theoretical arrangement of wind turbines and calculated the number of wind turbines to be arranged. Next, as trial calculation of expected available quantity, the team calculated the number of wind turbines that can be realistically arranged by taking into consideration the terrain slope angle and the offset distance from existing wind turbines (Figure 7.3-26). An area downwind from a wind turbine where wind conditions are disturbed is referred to as a wake area. If multiple wind turbines are to be installed, the prevailing wind direction must be considered when deciding on the arrangement. The wake area ranges 3D (D: diameter of rotor) along the direction perpendicular to the wind direction and approximately 10D along the downwind direction. Here, the team studied theoretical arrangement of wind turbines in the wind-power generation development zone and calculated the number of units theoretically arranged by regarding the offset distance [520 meters (diameter of 52 meters × 10 times) × 156 meters (diameter of

52 meters × 3 times)] from the existing wind turbines (single-unit capacity of 850 kW) as a criterion (Tables 7.3-14 and 7.3-15 and Figure 7.3-35).

Further, the expected available quantity was estimated based on the number of units theoretically arranged as described above. The terrain slope angle of 10% or less in the wind-power generation development zone was evaluated based on 100m mesh by using SRTM (Shuttle Reader Topography Mission) 90m mesh elevation data (Figures 7.3-37 to 7.3-45). For the five islands (Santo Antao, Sao Vicente, Sal, Boa Vista and Santiago), the offset distance was considered based on the existing wind turbine wake area (Figures 7.3-46 to7.3-50 and Table 7.3-16). Next, the wind speed rank and the turbulent intensity was analyzed with the use of an unsteady, non-linear wind condition simulator (RIAM-COMPACT®) (Figures 7.3-51 to 7.3-53, Figures 7.3-58 to 7.3-60, Figures 7.3-63 to 7.3-65, and Figures 7.3-67 to 7.3-69). Lastly, the appropriateness of wind turbine installation was evaluated by taking into consideration the distance from the 66kV Transmission Line or 20kV Transmission Line (Figures 7.3-54 and 7.3-61). Then, wind turbines with an evaluation point above the existing Cabeolica wind turbine average were extracted (Figures 7.3-36, 7.3-55, 7.3-57 and 7.3-62, and Tables 7.3-19, 7.3-21 and 7.3-22). The development zones on Santo Antao, Sao Vicente, Maio, Santiago, Fogo and Brava have large topographical relief (over 10%), and the potential quantity was lower than that in the data provided by DGE. It seems necessary to thoroughly examine the wind turbine arrangement for the development zones on Sao Vicente and Fogo. Although the potential quantity of Sal was four times that shown in the data provided by DGE, the environmental evaluation including that for impact from noise might be necessary given the progress of large-scale resort development in the surrounding area.

≪Future issues of potential evaluation≫

As mainstream wind turbines have a single-unit capacity of 2MW or more, it is necessary to confirm transportation conditions and to examine the possibility for road construction and cost for foundation work with the use of detailed terrain data. In the development zone (ST.1) on Santiago, it was found that the velocity of the prevailing northeast wind decreases due to topographical features. Therefore, it is necessary to simulate and analyze wind conditions including disturbance of wind when investigating the wind turbine arrangement plan.

7.4 Collaboration between diesel and wind power generation

Electra (Santiago, São Vicente and Sal) and AEB (Boa Vista) accept wind power under a long-term power purchase agreement (PPA) with Cabeolica, while monitoring the power system status (power demand, available diesel power output, voltage, and frequency) and the wind farm status (wind speed and direction, electricity output and voltage), and using wind power output forecasts provided by Vestas. The PPA includes a Take-or-Pay provision that defines the purchase quota and prices.

≪Basic operation rules≫

Under PPA, Electra and AEB control the upper output limit (Set Point) and power factor for Cabeolica's wind power generation systems by the hour, via remote monitoring terminals (general-use PCs, etc.) at the power plants. Wind power output control and the basic operation of diesel generators are as follows:

- Electric power from renewable energy sources covers 30% of the forecasted demand
- Wind power generation is obtained by subtracting the forecasted mega solar output from the renewable power generation.
- In order to respond to the drop in renewable output, disel power facilities produce 70% of the forecasted demand so that diesel power can cover 50% of the renewable power generation capacity to secure the reserve capacity or output margin equivalent.
- Operate diesel power facilities with the minimum output of 50%.

However, renewable power generation could be around 50% based on the experience of operating power stations, etc.

≪The Wind electricity output forecast system≫

At Electra and AEB power plants, a power generation plan is created based on the one-week wind power output forecast (by the hour) sent by Vestas once a week. They also check 15-day wind power output forecast data provided by Vestas every 3 days and review their power generation plan (ratio of wind power output to demand, etc.) at least a day prior to that covered in the plan. On the day of the plan, they check and change in case of emergency the setting for the Set Point every hour based on the demand status, wind condition change, forecasted wind power output, etc. Among the items of the Set Point (installed capacity (kW) base output, average (AVE) output, and minimum (MIN) output), the AVE output is used.

≪Operating status of Palmaregio Power Station (Santiago)≫

The diesel power generation systems and wind power systems are operated at the ratio of 7:3 based on the electricity output (kW). Since the wind power generation systems of Santiago can be operated without output control, the diesel generators are operated at 85 to 95% in general. At the time of the site inspection, the Set Point was set to 9.35MW, which is the rated capacity of the wind farm. However, with wind speed remaining low, the actual output was 5.0 - 7.5 MW. The frequency fluctuation range was 49.08 - 50.08 Hz which is within the operational target range (49.0 to 51.0 Hz) set by Electra.

Based on the load curve by power source as of the time of the inspection, the wind power output exceeded 9.0 MW which was more than 1/3 of the power demand at times, indicating that the operational practice was to accept as much wind power as possible. Reportedly, the wind power output was not controlled on Santiago in 2015 (Figure 7.4-2). With regard to the diesel power generation cost (variable cost), HFO was about 7.5 euro/kWh in February 2016. Although the wind power purchase price was relatively high at 15 euro/kWh, Electra accepts wind power as much as possible under the Take or Pay provision of the PPA.

≪Operation status of Lazareto Power Station (São Vicente)≫

Lazareto Power Station accepts wind power up to 50% of the demand (kW) provided that wind conditions are stable at high levels. In this case, it lowers the reserve capacity of diesel power plants from 50% to 40% to address the wind power variation (surplus) and the demand variation (shortage). The power station has operated with the reserve capacity of approximately 12% of the planned wind power generation. It is evident that Cabo Verde has stable wind conditions and its wind power outputs are constant. During the inspection, the frequency was kept at around 50 Hz. The wind speed was 13 m/s or more and wind conditions were favorable. The wind power output was restricted to 4.5 MW and remained stable during operation.

The rate of meeting the purchase quota in 2016 was 80% in January, 115% in February, 109% in March, and 112% in April. Electra takes various measures to achieve the purchase quota of wind power under PPA while lowering the diesel power generation costs. For example, in the first half of every month, it continues single operation of its main HFO diesel generator (Wartsila, etc) without operating costly standby generators (LFO types), in order to purchase wind power as much as possible by assuming 10% of wind power capacity as reserve.

≪Operating status of Palmeira Power Station (Sal)≫

During the inspection, the wind power output was restricted to 2 MW (rated 7.65 MW), supplying 1.0 to 2.0 MW of electricity. The rate of achieving the purchase quota in 2016 was 80% in January, 115% in February, 109% in March, and 112% in April.

≪Operation status of AEB Chavez Power Station (Boa Vista)≫

During the inspection, the wind power output was restricted to 1.2 MW (rated 2.55 MW), and power supply was constant at 1.2 MW.

According to AEB, the wind power is accepted on Boa Bista as described below:

- PPA regarding wind power was concluded between Electra and Cabeolica (no direct contract between AEB and Cabeolica).
- AEB pays Electra for wind power purchased and Electra makes settlement with Cabeolica.
- AEB has recently accepted more wind power than the purchase quota(Take or Pay) because it does not have enough power sources.
- In some time periods, its wind power accounted for more than 60% (output base). Even in the light-load period (January and February), the Set Point has been continuously set close to the rated value which exceeded the value based on the wind condition forecasts.

The team had an opinion exchange at Electra's head office (São Vicente) about the diesel and wind collaboration and issues under the Take-or-Pay provision of PPA as follows:

- Cebolica wind power generation systems are running on 4 islands (Santiago, São Vicente, Sal and Boa Vista) but there is only one PPA between Electra and Cabeolica.
- Electra prepares power supply plans based on the wind power purchase quota set for each month up to 2034.
- Electra so far has not paid any penalty for not meeting the purchase quota.
- Electra's operation aims to meet the purchase quota in the first half of each month.
- The price at which Cabeolica sells wind power to Electra is in principle fixed until 2034. The price is adjusted up to the yearly upper limit of 3.5% (Table 7.4-2).
- Electra negotiated with Cabeolica and adjusted the PPA content. For example, if it is clear that its purchase quota for Sal will not be met, the portion unmet for Sal can be added to the quota for Santiago.
- The settlement for the purchase quota is done on a 3-month basis (March, June, September and December) (item not in the original PPA but later adjusted). Yearly settlement has not been accepted due to the accounting standards of some of Cabeolica's foreign investors' home countries.

Generally, using more renewables such as wind power can reduce fuel cost for diesel power generation, but more wind power purchase does not necessarily lead to cost reduction because the fuel unit price has been fluctuating at low levels (approximately 7 escudos/kWh for HFO).

≪Current issues regarding accepting more wind electricity≫

Cabeolica's wind power generation systems maintain the availability factor of 95% or higher since their operation commenced, contributing to the introduction of renewables in Cabo Verde. Meanwhile, Electra's power plants accept as much wind power as possible from Cabeolica by following their own judgment based on their experience operating power plants and the basic rules, while placing priority on the electricity quality and system stability. The background of such operation is the Take-or-Pay PPA that sets minimum purchase quantity. Electra and AEB power plants constantly monitor the wind power output upper limit (Set Point) based on the grid status. Especially in São Vicente and Sal, approximately 40% of electricity is suppressed to ensure system stability. Discussions are underway to amend the content of PPA according to the operating status on each island. The Cabo Verdean government has set its policy of actively introducing renewables. Big challenges for the government include the establishment of operating procedures that allow both the expansion of renewables and system stabilization, as well as the appropriate method of sharing profit with IPPs.

8. Solar Power Generation

In Cabo Verde, mega-solar plants have been in operation since 2010 on Santiago (4.28MW) and Sal (2.14MW) thanks to the funding by the Portuguese government. However, the scale of solar power generation is small compared to wind power generation. See the solar power equipment outlined in Figure 8.1-1 and Tables 8.1-1 and 8.1-2. Even though the solar radiation in Cabo Verde is favorable, the solar panels are covered with dust which is not washed off by rain, resulting in the decline in power generating capability. There are signs of corrosion and degradation due to salt damage, for which adequate maintenance and repair are not performed. The SCADA system for monitoring equipment is out of order and unutilized.

8.1 Solar Power Generation Equipment and Operating Conditions

≪Power generation facilities≫

The solar power generation system on Santiago started operation in September 2010, on a site north of Electra's Palmarejo Power Station facing almost due south (Figures 8.1-2 and 5.7-1). There are approximately 20,000 modules (made in China), which are connected in series to form units of 24 modules, a nd generate peak power of 4.44MW. The output (DC current of about 800V) is converted to 270V or 315V AC current with the inverter (rated output of 4.28MW), and connected to the bus line of Palmarejo Power Station after the voltage boost to 20kV by the transformer. An effort is made to reduce the auxiliary power by not using an air conditioner in the inverter/transformer hut, and filters are installed at the air intake to prevent salt damage.

The solar power generation system on Sal started operation in October of 2010. Sal's system has similar configuration and equipment specifications as that of Santiago but at half the scale (Figures 8.1-5 and 5.4-1). Approximately 10,000 modules are capable of producing peak power of 2.23 MW. The rated output of the inverter is 2.14 MW. The connection point to the grid is not at the bus line of the power station but located some distance away, which prevents the direct measurement of the output.

The initial plan called for 5MW for Santiago and 2.5MW for Sal. However, Electra was not able to raise adequate funds even though it was responsible to cover 10% of the equipment; thus the output turned out to be about 10% smaller. The solar power generation system is owned by the Cabo Verdean government, and Electra pays fees to the government for using the systems.

≪Operation (Power Generation Performance)≫

Solar power output, voltage, current, frequency and weather data of Santiago were not stored due to the malfunction of the SCADA system; however, output was determined by analyzing the value obtained at the connection point to Palmarejo Power Station.

The capacity factor of 2015 was 10.7% which is lower than Japan's 12-14%, and that from July to November dropped sharply from the figure from the year after the start of operation (2011). The reasons could be the cloud cover, major equipment failures, etc. The power generation between December 2015 and June 2016 was 20% less than that in 2011, suggesting aging deterioration of cells or failure of some equipment. On the other hand, the capacity factor of 2011 was 18.4%, which indicate a fairly good solar radiation. There are a small number of days with smaller generated energy and capacity factor, which is indicative of stable power generation in general. The peak power of 3,467kW is 78.1% of the modules' rated output of 4,440 kW, which is reasonable overall for a figure under normal conditions.

The capacity factor of the solar power generation system on Sal is relatively low at around 11% every year, except for 13% which was observed in 2010 after the start of operation. Especially from September 2011 to November 2011, from May 2012 to January 2013, and from May 2014 to March 2015, generated energy shrank significantly. According to Electra, the causes are as listed below:

- Solar power output was suppressed in 2011 and 2012 due to an issue with load-following capability of diesel generators but has been normalized since 2013.
- In 2014, the solar panel connectors were burned and their repair was delayed due to difficulty procuring parts. They were replaced in February 2015.
- Generated energy decreased in 2016 since the solar panels are not cleaned adequately due to budgetary reasons.

As aforementioned, Sal's solar power generation system is connected to the grid; thus, the output was determined by obtaining the data (15-minute values) collected by the local server (only the data available at the time of the inspection was from September 2015 to April 2016). The daily power generation was stable at 3,000 kWh-7,000 kWh, and the average capacity factor was 10.7% (Figures 8.1-14 and 8.1-16). Compared to Santiago, there are much fewer days when the capacity factor is 14% or higher. The maximum peak power is 1,261 kW (56.5% of the module rated output of 2,230 kW), which is significantly lower than the commonly-seen figure (around 70-80%). It is likely that there are problems with the system itself, not aging deterioration (described hereinafter).

≪Maintenance≫

Electra maintains the solar power generation systems, with two workers tending each site. However, it is difficult for the company to secure funds to conduct repairs, meaning that failures cannot be immediately addressed when they occur.

On Santiago, power transformation equipment undergoes preventive maintenance six times per year. Concerning solar panels, if sufficient budget can be acquired, cleaning is done a maximum of four times between February and June at an annual cost of CVE 660,000. In 2014 and 2015, a repair budget of approximately CVE 770,000 was secured; however, it was not enough to acquire all the necessary materials due to the need for consumable parts and maintenance.

Equipment-related issues include decline in the insulation resistance at times of rainfall leading to persistent occurrence of the PID phenomenon (described later), burning of connectors (MC4 connectors) between modules that occurs with high frequency during the rainy season, and power loss due to inverter tripping. To address the burning of the connectors, the connectors were replaced with those that offer high waterproof properties. Ever since the SCADA system failed and is unable to detect system abnormalities, the maintenance crews check the system for faults by taking measurement manually. So far, 12 out of 50 replacement modules have been used. Apparently, the ventilation fans for the building also have broken down.

On the island of Sal, the ratio of solar power generation relative to renewable energy overall is small. Moreover, since there is the requirement to receive energy from Cabeolica wind power system, repairs of the solar power generation system is given lower priority and tends to be postponed. As the solar power generation site is located some distance away from a major diesel power station (Palmeira), it can be inspected only once every month or two. The panels are washed by an outside contractor 3-4 times per year, with washing carried out over 1-2 weeks. Dust tends to be heavy in January and February and washing requires about 10 tons of fresh water. Currently, cost reduction is being examined since the washing water tank (100 tons) installed underground can be utilized. Sal's SCADA monitoring system is out of order, the same as that of Santiago. Electra considers this a very serious problem since they cannot check the state of the breakers and fuses from mobile phones. However, the problem has not been corrected since they have not been able to secure adequate funds. Sal experiences serious salt damage, which results in corrosion of many frames, connectors, etc. The building ventilation fun filters also are subject to corrosion and have to be washed frequently. Only one out of 40 replacement modules has been used.

8.2 Issues in Solar Power Generation

≪Dust≫

Solar power-related issues include the accumulation of dust on the panels. It is caused by dry weather and soil, sand carried by heavy wind from the continent throughout the year, dirt and scarcity of rainfall not enough to wash off dust. The dust settled on the panels sticks on them after being exposed to moisture such as dew, which makes the dust hard to wash off.

On Sal, the solar power plant is located to the south of an unpaved road. Large vehicles that travel the road and dominant wind from north add to the dust accumulation (the team confirmed that dust has notable effect on the site during the site inspection). The impacts of dust include overall reduction in generated energy, as well as shorter service life due to the emergence of hot spots, which is reverse bias caused by a badly stained panel that exists within a module.

≪PID Phenomenon≫

The phenomenon of PID (Potential Induced Degradation) could be one of the equipment-related issues.

In the PID phenomenon, when high voltage is exerted on silicon crystal modules, depending on conditions such as high humidity and salt content, leakage current flows from the metal frames to the cells causing output to decline. The reason why the output measured in July is smaller than that from April was thought to be the deterioration due to PID phenomenon. After measures such as the installation of inverter negative electrodes (PT1, PT8) and repositioning of modules through changing the series connections, output measured three weeks later in August showed an improvement. Solar panel manufacturers implement ample tests and PID measures; therefore, it should be enough to address PID-related issues by taking measures at the time of installation or for respective panels.

≪Comparison with Wind Power Generation≫

Wind power systems tend to produce more electricity in winter and less in summer as the wind condition change with season. However, solar power tends to be more constant throughout the year with little seasonal changes. Since solar power could be one of the options when introducing renewables in Cabo Verde, the team compared solar power and wind power by focusing on cost, which is one of the critical components for decision making. The result revealed that the cost for solar power could be similar to that of wind power if facilities could be constructed inexpensively and the good capacity factor maintained. However in reality, solar power is likely to be more expensive than wind power due to transportation cost, etc. (Tables 8.2-2 and 8.2-3).

8.3 Examination of Solar Potential

Cabo Verde's official gazette NO7/2012 identifies areas of the country specified for renewable energy development (ZDER), and claims that the solar radiation of 1,800-2,000 kWh/m^2 can be expected annually in most areas. JICA Study Team independently created an average solar radiation map by conducting simulation with the use of 2015 GSM data, and then evaluated the validity of ZDER in the gazette (Figure 8.3-2 for the procedure). The result indicated that the solar radiation map of JICA Study Team showed more variation in solar radiation of the islands compared to that in the gazette, but the difference was not significant. Also, ZDER takes into consideration the tendency of cloud formation based on topography, environment, geography, access to power grid, etc. and seems reasonable overall. JICA Study Team also calculated the annual power generation based on the solar radiation, temperature and solar panel arrangement that optimizes solar power generation for each ZDER. The calculation indicated that Cabo Verde as a whole has capability to produce 2,700GWh annually (Table 8.3-2). The team further took into consideration the corrections that were made through simulation based on the GSM data, using the estimated annual power generation for each ZDER. It was found that it might be possible to meet power demand of the islands by installing solar power systems in ZDER.

8.4 Harmonization of Diesel Power Generation and Solar Power Generation

If output from renewable energy sources is not stable, it will affect the operation of diesel power plants. Especially with solar power generation, output will fluctuate (drop) sharply when sunlight is obstructed by clouds. If the fluctuation is great and sudden, diesel power plants are unable to keep pace, leading to power supply-demand imbalance and frequency fluctuations. The problem will be more pronounced if the demand is small and the rate of renewables is high.
Santiago utilizes renewable energy, which include 9.35 MW of wind power and 4.28 MW of solar power in equipment rated capacity. Solar power accounts for 31% of all renewable capacity. Since solar power generation can only provide a maximum output corresponding to around 80% of rated output, the impact of solar power output fluctuation is smaller than that of wind power generation. When JICA Study Team analyzed the power supply/demand data from the days when the solar power fluctuated greatly, demand was small and rate of renewables was high. The team found out that even at around 13:00 when solar power output is likely to fluctuate most, wind power output was rather stable, and thus diesel power plants were operated in a stable manner. On the other hand, when wind power output is unstable, diesel power plants had to start and stop frequently. In other words, under the current energy mix, the fluctuation of wind power output rather than solar output has a greater impact on diesel power operation (Figure 8.4-1). For the analysis, the team used one-hour values of solar power output but was not able to ascertain the impact of fluctuations on the frequency.

Sal's renewables are 7.65 MW of wind power and 2.14 MW of solar power in equipment rated capacity, which means that solar power accounts for 22% of all renewable capacity. Since solar power generation can only produce energy equivalent to about 60% of the rated output, the impact of the solar output fluctuation must be even smaller than that seen in Santiago. The team evaluated the impact of the fluctuations of renewable output on Sal, by applying the same method used in Santiago. It was found that solar output fluctuation does not influence the starting and stopping of diesel power plants (Figure 8.4-2). However, the wind condition was favorable on that day and the fact that output from wind power generation system was suppressed and stayed at the same level is likely to contribute to the stability. The impact on frequency was not confirmed as was the case for Santiago.

9. Transmission and distribution facilities

The standard voltage of the transmission & distribution system in Cabo Verde is 20kV (60kV is used in part of Santiago Island). Although 6kV and 10kV are still used in some areas, it is desirable to unify voltage to 20kV. Due to strong wind and little rain, overhead distribution lines are susceptible to damage caused by flying debris and salt. To address the situation, the installation of underground cables has been promoted.
Transmission/Distribution facilities in Cabo Verde have been renewed and modernized through "Santiago Generation & Transmission Enhancement Program (P1)", "Electricity Transmission and Distribution Network Development Project (Target: 6 islands) (P2)", and reinforcement of electrical

power production and distribution system for the four islands, which were made possible by yen loan, grant aid from Dutch ORET program and OPEC loan. Specific work includes increasing distribution voltage from 10kV to 20kV, elimination of radial networks, replacement of overhead lines with underground cables, increasing distribution capacity by replacing conductors, and installation of optical fibers for better telecommunication. Currently, transmission/distribution facility construction is almost complete and grid reliability has improved. Meanwhile, Boa Vista Island served by AEB needs reinforcement of its aged distribution/transmission facilities. In the P2 Project, the introduction of the SCADA system is promoted for Santiago, São Vicente and Sal. The SCADA system can only control switchgears and monitor distribution demand for the time being. However, the plan is to connect the SCADA system to diesel and renewable power systems and give functions of EMS (Energy Management System) and DMS (Demand Management System). According to a source, diesel power generation systems of Cabo Verde differ from the global standard and are hard to control. Currently ALSTOM, a SCADA supplier, is working to customize the existing SCADA systems used in other nations to suit Cabo Verde, but the system specifications were unknown at the time of the inspection. Electra has a plan to give the SCADA new functions to collect metrological data, forecast demand, and automatically select units to start accordingly. The coordination with the renewable energy companies will require some time.

Cabo Verde's policy is to concentrate diesel power stations on one site on each island, and close aged plants. In order to achieve it, the radial transmission/distribution systems must be changed to loop systems. On Maio and Fogo, the islands' systems now form a loop and reliability has improved, thanks to the loan. However, other islands still have radial systems. The 60kV system introduced on Santiago uses an overhead double-circuit line. It is necessary to keep the 20kV system as an alternate route in case the 60kV system fails due to flying debris.

≪Requirement of the locations for energy storage system≫

If an energy storage system is created near an existing diesel power plant or large-scale renewable power plant, the reinforcement of load supply systems will be unnecessary. On the other hand, if a storage system is located far from renewable power sources or high demand area, it could be costlier in the end because construction work will be needed to access the grid, reinforce the existing grid and replace protection equipment even if the land-related cost is small. An energy storage system will require a large space (for example, a 50MW NAS battery system needs an area equal to two football fields) and the site must be decided based on comprehensive consideration of not only the cost (cost for land and construction, etc.) but also operation, maintenance and environment. If a storage system and renewable power plant can be built on the same site, it is advantageous in terms of economy and operation such as collaborative control of the renewable power plant and energy storage system. On Santiago, it is desirable to connect a storage system to a 60kV system or a bus on the 60kV side of a substation, which have sufficient thermal capacity and system stability.

9.1 Outline of transmission and distribution facilities

Cabo Verde's transmission and distribution facilities have been developed through support projects by the World Bank, AfDB and other nations including the Netherlands and Japan. Even at present, the development of transmission and distribution systems is ongoing through the Netherland's OERT Project and PTDSD Project (Power Transmission and Distribution System Development Project) (planned construction period: March 2012 – 2017). The PTDSD Project covers six islands of Santo Antão, São Vicente, Sal, Maio, Santiago and Fogo, and three islands (São Vicente, Sal and Santo Antão) will receive the SCADA system.

In Cabo Verde, underground transmission and distribution lines are used in many instances except for mountains or rural regions. Pole-mounted transformers (PMT) are seen in some regions' electrified areas, but ground-mounted transformers (GMT) are utilized in most cases. Most utility poles for overhead lines are made of wood; however, some concrete or steel poles have been used to mount transformers and long-span cables. The conductors for MV overhead lines are aluminum wires. The glass insulators for transmission and distribution lines are being replaced with silicone ones. The insulators used at substations are the ceramic type.

≪Santo Antão≫

Through ORET and PTDSD projects on Santo Antão, New Port Nova Power Station now supplies full power, and supply reliability has improved by the connection between the Porto Novo system and Riberia Grande system. The work for the Porto Novo system included the expansion, extension and addition of Medium Voltage and Low Voltage lines, and installation of protection relay and other systems (Figure 9.1-4).

≪São Vicente≫

São Vicente welcomed an addition to Lazareto Power Station, construction of a wind power plant, voltage increase, and reinforcement and renewal of transmission lines by the World Bank, AfDB and PTDSD projects (Figure 9.1-5)

≪São Nicolau≫

On São Nicolau, the construction of Cacimba Power Station and reinforcement and renewal of substations and transmission lines were carried out through the ORET Project (Figure 9.1-6).

≪Sal≫

For Sal, the most important task was to ensure adequate power supply to satisfy the demand from hotels, etc. With the support offered through PTDSD, a 20kV underground transmission line was added between Palmeria Power Station in the north and Santa Maria, a resort area in the southern region, which improved the supply reliability. Also, Agence Francaise de Developpement and African Development Bank (AfDB) helped with the addition at Palmeria Power Station and the construction of a new wind power system (Figure. 9.1-9).

≪Boa Vista≫

Boa Vista was experiencing voltage-related issues since Chavez Power Station and Lacação Power Station at the southern tip were connected with 25km-long underground cables (400mm2 aluminum). Currently, AEB is examining the installation of voltage stabilization systems. For the southern area where hotels, etc. are planned and demand is expected to increase, addition of diesel generators is considered. The 20kV overhead line from Chavez Power Station to Central Sal Rei is a weak section of the system, due to aged deterioration and salt damage. There has been no power failure caused by Cabeolica’s wind farm which is further down the route. There is construction underway to connect electrified areas by building small-scale independent systems through the ORET Project (Figure 9.1-10).

≪Maio≫

For the island of Maio, the PTDSD project helped with the looping of the Medium Voltage transmission lines and renewal of degraded Medium Voltage and Low Voltage distribution lines (Figure 9.1-17)

≪Santiago≫

The work implemented on Santiago includes an addition to Palmarejo Power Station by AfDB and JICA, development of 60kV HV transmission lines and 20kV MV transmission lines, voltage increase and renewal of transmission lines through PTDSD. Other developments include a system to collectively control the island’s power supply/demand at Palmarejo Power Station, protection relay system, etc. There are plans to achieve central control with the SCADA system and to build an addition to the wind power plant (10MW) by AfDB (Figure 9.1-18).

≪Fogo≫

Fogo is going through the construction of Joan Pito Power Station and 20kV transmission line development supported by ORET, and voltage increase, extension and renewal of transmission lines through PTDSD. As for the Medium Voltage lines, the voltage is unified to 20kV and the transmission and distribution networks were developed to form a loop around the island to enhance system reliability (Figure. 9.1-22).

≪Brava≫

Brava has not seen any transmission/distribution network renewal, etc. since 2008. There, the replacement of 6kV Medium Voltage transmission lines must be considered (Figure 9.1-26)

9.2 System operation status

In Cabo Verde, the number and duration of blackouts have overall decreased since 2013 on eight islands excluding Boa Vista. However, the number increased on Maio and Fogo. The specific causes are unknown, however, it might have been the effect of natural disasters such as the cyclone in 2015. On Boa Vista, both the number and duration of blackouts are less in 2015 than in 2014, but the number of blackouts as of April 2016 was already about half that which occurred in 2015. The causes might mainly be the trouble with diesel generators in the power stations.

9.3 Grid Code

In Cabo Verde, work is being advanced on the formulation of grid interconnection requirements, i.e. a Grid Code, to ensure grid stability and power quality in preparation for the future expansion of renewable energy sources. With the support from GIZ (Gesellschaft für Internationale Zusammenarbeit) of Germany, the Grid Code was created in February 2016 to come into effect after it is approved by the government. The code addresses target power sources, voltage classes, power source categories, grid interconnection requirements, voltage operation/reactive power operation, frequency operation and remote control function (Tables 9.3-1 to 9.3-6 and Figure 9.3-1).

9.4 Problems of transmission and transformation facilities

≪Boa Vista≫

The small-scale independent systems on Boa Vista are being connected to the grid through the ORET project, but the 10kV systems are still used in the northeastern part of the island. Although it is desirable to switch to 20kV, the cost is the problem since the demand is small. The systems suffer serious aging deterioration and salt damage, and utility poles were knocked down by the cyclone in September 2015. In the areas served by 10kV systems, non-technical loss (power theft and fraudulent meter manipulation) accounts for about 50 % of all losses, and non-payment of the electricity charges is also seen. Upon voltage increase, the LV distribution facilities must be renewed and developed including the replacement of meters for households.

The aged overhead transmission line from Chavez Power Station in the north to Sal Rei has suffered salt and other damage, and needs to be renewed or replaced with cables (Figure 9.4-1).

Chavez Power Station in the north and Lacacao Power Station in the south are connected via a long-distance underground cable (about 25km). Since grid voltage tends to rise or become unstable when the load is small, the number of diesel generators is limited. The installation of shunt reactors, etc. might be effective; however, the installation locations must be considered carefully.

Substantial demand increase is expected on Boa Vista due to large-scale development of hotels, etc. To meet the demand, additional diesel generators might be necessary. There is a plan to move three seawater desalination plants to one site.

Based on such situation, it is important to comprehensively examine the system development on Boa

Vista while taking into consideration the current condition and issues as well as future plans, etc. so that there will be no need to redo any work.

≪Brava≫

The island suffers 3-4 blackouts a month. The causes include breakage of aged overhead lines and earth faults caused by salt damage. If the cause is salt damage, insulators are cleaned. The recovery from a blackout takes about 5 minutes for cities and about 20 – 40 minutes for suburbs, with seven maintenance crews.

During distribution line faults, a sound circuit could trip at times. Therefore, it will be necessary to install protection relays and switchgears and to appropriately set the protection relays and implement protective coordination to prevent further faults.

Brava's power demand is relatively small and is not expected to grow much. However, a comprehensive replacement including that of 6kV transmission lines is necessary since the transmission and distribution systems have not been renewed since 2008.

One of the options for improvements might be to upgrade the 6kV system left in Nova Sintra Substation to a 20kV system and to install 20kV switchgear between buses (Figure 9.4-2). With this, existing 20/0.4kV and 0.4/6kV transformers will become unnecessary and reliability and maintenance efficiency could be improved.

≪Santiago≫

On Santiago, the blackout frequency went down and reliability increased thanks to the improvements made on the transmission/transformation facilities with the support of donor countries.

About half of the glass insulators for transmission lines were replaced with silicon insulators, which reduced the need for cleaning work as well as insulator damage caused by the residents.

The SCADA system was introduced in São Filipe and Calheta Substations, which resulted in unmanned substation operation and more efficient operation and maintenance of grid facilities.

On the three islands of Santiago, São Vicente and Sal, transmission/distribution network monitoring as well as optimal operation of diesel generators and wind power facilities are carried out on a trial basis with the use of the general-purpose SCADA system. However, the direct control of diesel generators is technically difficult, and the consent of the renewable energy companies must be obtained before the full-scale system introduction.

In São Filipe Substation, transformers (20MVA x 2) have been installed through the JICA support, and there is a space to house 2 more transformers and an incoming panel installed assuming the connection of 3 wind farms. Currently, Cebeolica is connected to Gamboa Substation via a 20kV transmission line (1 circuit), but will be connected São Filipe Substation instead. It might be better to connect wind power systems, etc. to a 60kV or 20kV bus of a substation considering future introduction of renewables (Figure 9.4-3).

The diesel generator at Sta.Catarina (made in 2009) is to be left as a backup power supply facility. However, it is necessary to consider measures for when it fails and becomes unusable or when it is to be decommissioned. One of the measures could be to connect Palmarejo 60/20kV SS or Sao Filipe 60/20kV SS to Calheta 60/20kV SS via a 20kV transmission line, as an alternative route in case of a 60kV transmission line fault. One option for the connection might be to a spare circuit of 20kV bus at Calheta (Figure 9.4-4).

10. Approach to Expanding Introduction of Renewable Energy

10.1 Examination for Expanding Introduction of Renewable Energy

In examining the expansion of renewable energy introduction, it is important to study ways to effectively utilize existing equipment, particularly to make use of the suppressed output of the existing wind power by expanding the operating scope (reducing minimum output) of diesel power generators based on the supply and demand status and conditions of power facilities, so that excessive advance investment can be avoided. Moreover, the effect of renewables expansion on the reduction of diesel fuel costs must also be considered. Here, before going into the examination on expanding introduction of renewable energy, the following paragraphs sum up the situation regarding electric power facilities of Cabo Verde, in particular wind power generation facilities, which is important in expanding the use of renewable energy.

Construction of transmission and distribution facilities: The construction includes the integration of transmission and distribution networks that have differing supply areas on islands, resolution of non-electrified areas (raising the electrification rate), unification of voltage classes (20 kV and 60 kV), promotion of underground cables (if overhead lines are adopted, then adoption of insulators with strong resistance to salt damage) and looping of transmission networks in built-up areas, and installation of SCADA systems and other systems for monitoring and information collection.

Construction of power station: The construction includes the establishment of a power supply setup of one power station per island (however, the JICA Study Team believes that, in advancing the expansion of renewable energy, the unit capacity of diesel power generation equipment is too large for the scale of demand), and improvement of system stability and efficiency and expansion of operating scope based on the use of latest-model diesel power generators. Many of the diesel power generators installed on the islands are relatively new models introduced from 2010 onwards.

Power supply by wind power IPPs: Cabeolica sells electricity generated from wind power on the islands of Santiago, São Vicente, Sal and Boa Vista. For the purpose of securing system stability, Electra and

AEB suppress wind power output according to necessity. Electra suppresses generated energy that exceeds the PPA purchase quota (Take or Pay).

In light of the above preconditions, the examination for expanding introduction of renewable energy will be conducted (Table 10.1-1).
In examining the potential for renewable energy facility introduction without output suppression, the calculation method adopted for studying the grid interconnection potential of renewable energy based on system stability on remote islands in Japan will be used. KEPCO conducts calculations of output fluctuations over certain periods, specifically short-cycle fluctuations (20 minutes or less) and long-cycle fluctuations (more than 20 minutes), utilizing the results that have a smaller value (Figure 10.2-1). With regard to the impact of the "short-cycle fluctuations" and "long-cycle fluctuations" on the power system, the former is related to frequency fluctuations, and the latter to demand and supply operation (generation of excess power) (Table 10.2-1).

10.2 Calculation from the short-cycle fluctuation viewpoint

≪Calculation from the short-period fluctuation viewpoint≫

Step 1: Estimation of demand cross section: When connecting renewable energy to the grid, the hardest conditions occur during minimum demand when the diesel power generation adjustment capacity decreases. Thus, the minimum demand was confirmed based on Cabo Verde's demand pattern. In Cabo Verde, wind power IPPs have already installed facilities and cooperative operation is conducted between wind power and diesel power generation; moreover, because there is extremely high potential for wind power generation, which is more cost advantageous than solar power generation in terms of equipment cost, the daily minimum demand will be used in the examination here.

Step 2: Selection of the actual system analysis model: The calculation of the introduction potential of renewables is done using the algebraic method that entails balancing of the permissible fluctuation of renewable energy and demand with LFC adjustment capacity (load frequency control of diesel power generation in Cabo Verde) and permissible adjustment residual of the system (Figure 10.2-2). The particulars required for the examination (demand cross section, demand fluctuation, LFC adjustment capacity, frequency characteristics of power generation equipment and on the demand side, and permissible frequency) were decided based on the inspection and estimate (Table 10.2-2).

Step 3: Estimation of renewable output fluctuations: Since Cabo Verde's wind conditions are stable and wind power output can be forecast with high accuracy, 50% of the forecast wind power generation output is assumed to be stable power supply in operation. Accordingly, the renewable output fluctuation in this calculation is also assumed to be 50% (Figure 10.2-3).

Step 4: Combination of renewable output fluctuation, demand, and adjustment capacity: The renewable output fluctuation constituting 50% of the forecast wind power output, demand constituting the minimum demand of the target area, and the LFC adjustment capacity of zero are combined.

Step 5: Calculation of the introduction potential of renewables without output suppression: Based on Step 4, the introduction potential of renewables without output suppression is calculated.

≪Calculation from the long-period fluctuation viewpoint≫

The share of renewable energy can be raised by suppressing the output of diesel power generators; however, when the output of diesel power generators reaches the minimum output, it becomes necessary to suppress the renewable energy power sources. Accordingly, the introduction potential of renewables will be calculated upon taking the constraints of the minimum output of diesel power generators into account (Figure 10.2-4). Incidentally, the particulars in conducting calculation were established, such as demand cross section, reserve capacity and wind power fluctuation (Table 10.2-3). Since the introduction potential of renewables is raised by lowering the minimum output, calculation is conducted on both the currently applied minimum output (50% of nominal capacity) and 30% of the nominal capacity, which is within the operable range (Figures 10.2-5 to 10.2-12).

≪Examination result≫

Since power systems are operated with ample frequency margin of 50±2Hz in Cabo Verde, the value calculated from the viewpoint of long-cycle fluctuations, not short-cycle flluctuations, was the constraint on introduction potential of renewables without output suppression. In fact on Sao Vicente, Boa Vista and Sal, the introduction potential is already exceeded to the point that wind power output is suppressed. On Santiago, the renewable power exceeds the introduction potential of renewables if solar power is included. However, the wind power output rarely exceeds 50%; thus the output is not suppressed (Table 10.2-4). It must be noted that measures for short-cycle fluctuations might become necessary once a detailed study of the system constants and confirmation of the permissible frequency on the demand side are performed.

10.3 Effective Utilization of Existing Electricity from Wind Power with Output Suppression

As was indicated earlier (Table 10.2-4), wind power output suppression is being implemented on 3 islands of Sal, São Vicente and Boa Vista. In this section, simulation is conducted to learn the effect of expanding the introduction of renewables based on increasing the reduction margin of diesel power generators (minimum output: 70%→50%→30%) while keeping as close as possible to the actual operating conditions. Also, the effect of expanding the rate of renewables based on the introduction of storage batteries is explained (Table 10.3-1, Figure 10.3-1 to 10.3-11 and Table 10.3-2).

10.4 Simulation for renewable energy expansion

Even though Cabo Verde has favorable wind conditions, wind power generation is currently suppressed due to supply and demand balance and economic reasons. Usually, when wind power output is likely to exceed 50% of the demand, the system operator will set the setpoint to limit the wind power output. Moreover, wind power output is suppressed even when it is less than 50%, in order to keep the diesel power output to 70 – 85% aiming for high combustion efficiency and because the purchase price of wind power is relatively high. In this light, if surplus energy that would have been suppressed is stored in a battery system and supplied during the time of peak demand to supplement the diesel generator output as a stable energy source, it might lead to the reduction of fuel use. Thus, the team simulated the maximum utilization of the existing wind power facilities and optimal battery introduction (output/capacity) using the latest performance data and wind potential of the islands. In addition, the examination was carried out on the effect of adding wind power generation facilities.

Currently, wind power is suppressed on São Vicente, Sal and Boa Vista. As for Santiago, even though wind power is not suppressed, it has the largest demand in Cabo Verde. Therefore, the examination was conducted for four islands by estimating future demand growth and considering the increase of the rate of renewables. The objectives and outline of the simulation are given below:

Objective: The optimal facility introduction for each island is investigated. It is done by examining the effects of raising the introduction potential of renewables in stages (50%→70%) according to system operation policy, wind power facility reinforcement and diesel fuel reduction achieved through battery installation, as well as by determining the resultant yearly rate of renewables (energy basis) and economic performance (period of investment recovery, etc.).

Data used: 2015 demand of each island, actual output of wind power generation systems and theoretical output calculated from the meteorological data (24h x 365days)

Target islands: Sao Vicente, Sal, Boa Vista and Santiago

Timing and conditions for charge/discharge of the battery:

- When wind power output exceeds the wind power introduction potential (50-70% of the demand of the island) during non-peak hours, wind power surplus is used to charge batteries. It will be suppressed if the batteries are fully charged.
- When wind power output is less than the wind power introduction potential during peak hours, batteries will discharge to supply power to make up for the shortfall. Diesel generators will increase output if the batteries are completely depleted.

Since a battery cannot charge/discharge beyond its capacity (kWh) or output (kW), if the wind power output exceeds what is needed to charge the battery, the output will be suppressed. On the other hand, if the discharge from the battery is not enough, diesel generators will be operated at higher output (Figure 10.4-1).

Power loss: By assuming charge/discharge loss of about 30%, only 70% of charged energy is supplied to the grid.

Parameters: The team studied the optimal facility composition by using parameters such as the upper limit to the rate of renewables (%), additional wind power output (kW), battery output (kW), and battery capacity (kWh) while checking their sensitivity.

≪Simulation of renewable energy expansion on São Vicente≫

The demand scale of the island is approximately 12,100kW but existing wind power generation systems only produce 5,950kW (approx. 50%). Even though the island's wind condition is favorable, the operation of wind power systems is restricted to a maximum of about 50% of the demand. Because of this, the actual energy generated at the wind power generation systems is only 19.5GWh while the theoretical wind generation potential is 29.8GWh, meaning that about 1/3 of the wind potential is suppressed and unutilized. Measures to improve the rate of renewables might include those listed below (Tables 10.4-1 and 10.4-2):

① Increase the introduction potential of renewables (operating ratio) (→ effective utilization of surplus energy)
② Introduce power storage facility (→ effective utilization of surplus energy)
③ Add wind power facilities (→ increase of wind power generation)

Since wind power output is already suppressed, significant effect can be expected only by implementing ① to increase the operating ratio of renewable energy. However, the sensitivity was analyzed for 3 cases of ①+②, ①+③, and ①+②+③ (Figures 10.4-6 to 10.4-8 and Tables 10.4-3 and 10.4-5). The result shows that increasing the operating ratio of renewables is the most effective measure and the introduction of a power storage facility has limited effect.

≪Simulation of renewable energy expansion on Sal≫

Even though the demand of the island is approximately 10,700kW, the existing wind power generation systems only produce 7,650kW (approx. 70%). In spite of favorable wind conditions on Sal, the upper limit on the operating ratio is set to about 50% of the demand. It means that about 40% of wind power output is suppressed, considering that the energy that was actually generated is 19.2GWh while theoretically 31.0GWh of electricity could be produced. Measures to improve the operating ratio of renewables might include those listed below (Tables 10.4-6 and 10.4-7):

① Increase the introduction potential of renewables (operating ratio) (→ effective utilization of surplus energy)
② Introduce power storage facility (→ effective utilization of surplus energy)
③ Add wind power facilities (→ increase of wind power generation)

Since around 40% of wind power that could be produced at the existing wind power systems is already suppressed, ① to increase the operating ratio of renewables is most effective. Also, the sensitivity was analyzed for 3 cases of ①+②, ①+③, and ①+②+③ (Figures 10.4-9 to 10.4-11 and Tables 10.4-8 to 10.4-10). The result revealed that increasing the operating ratio of renewables is the most effective measure while the introduction of a power storage facility has limited effect on Sal, where 40% of theoretical power output is already curtailed.

≪Simulation of renewable energy expansion on Boa Vista≫

While the island's demand is around 6,100kW, the output from the existing wind power generation systems is 2,550kW (approx. 40%). In spite of favorable wind conditions on Boa Vista, the upper limit on the operating ratio for wind power is set to about 50% of the demand. Because of this, about 20% of wind power output is suppressed based on the fact the actual energy generated is 7.8GWh while theoretically 9.8GWh of electricity could be produced. Measures to improve the operating ratio of renewables might include those listed below (Tables 10.4-11 and 10.4-12):

① Increase the introduction potential of renewables (operating ratio) (→ effective utilization of surplus energy)
② Introduce power storage facility (→ effective utilization of surplus energy)
③ Add wind power facilities (→ increase of wind power generation)

Since around 20% of electricity that could be produced at the existing wind power systems is suppressed, ① to increase the operating ratio of renewables is most effective. For comparison, the sensitivity was analyzed for 3 cases of ①+②, ①+③, and ①+②+③ (Figures 10.4-12 to 10.4-14 and Tables 10.4-13 to 10.4-15). The findings were that increasing the operating ratio of renewables is most effective and the introduction of a power storage facility has limited effect.

≪Simulation of renewable energy expansion on Santiago≫

For the island's demand of around 35,300kW, the existing wind power generation systems produce 9,350kW (approx. 25%). In 2015, the wind power output exceeded 50% of the demand and produced surplus power for 162 hours (1.8%) out of a year (24 hours x 365 days). The wind power output was rarely suppressed. Based on the facts, it can be said that the wind power systems are fully utilized. To further improve the operating rate of renewables, the measures below could be taken (Tables 10.4-16 and 10.4-17):

①Add wind power facilities (→ increase of wind power generation)

②Increase the introduction potential of renewables (operating ratio) (→ effective utilization of surplus energy)

③ Introduce power storage facility (→ effective utilization of surplus energy)

Unlike the other three islands, the wind power generation systems are fully utilized on Santiago. Therefore, the priority will be placed on ① to expand the introduction of renewables by adding wind power facilities. For comparison, the sensitivity was analyzed for 3 cases of ①＋②, ①＋③, and ①＋②＋③ (Figures 10.4-15 to 10.4-17 and Tables 10.4-18 to 10.4-20).

Since wind power output is not controlled on Santiago, the effect from wind power facility introduction can be expected if the operating ratio of renewables could be raised to 70%. Even though the installation of batteries might be difficult when the cost-effectiveness is taken into account, the use of batteries might be beneficial in other applications such as for emergency or grid stabilization and should be considered.

≪Examination of power storage facilities≫

Since wind power facilities of Cabo Verde can produce a constant amount of energy throughout a day, the excess power can be stored during light-load hours at night and morning and discharged during peak hours after evening to supplement output from other power sources. However, the simulation for renewables expansion revealed that the peak-shift effect of the power storage facility might be limited since power demand does not fluctuate greatly in the country. Thus, care must be taken to be cost effective when selecting output and capacity (time) of the power storage facility, so that they are not excessive. The Lithium-ion battery is generally recommended if a measure with a quick response is needed against short-cycle fluctuations, while the NAS battery is proposed as the long-cycle fluctuation measure based on cost and ease of installation. Pumped-storage hydropower could be one of the candidates for large-scale power storage since it has a good track record and knowledge accumulated over the years. However, the issue is the large-scale construction, coupled with long work period time and high cost. This section describes the introduction and operation cost of the NAS battery, with 4.8MW (28.8MWh) and 1.6MW (9.6MWh) calculated as the optimal scale for Santiago and São Vicente based on the simulation result above. It then compares it with 5MW (30MWh) pumped-storage hydropower as an alternative power storage system for Santiago.

For this comparison, the NAS battery was selected after comprehensive assessment, since it can have a large capacity to respond to long-cycle fluctuations for over 4 hours, and boasts long life, record of worldwide utilizations and reliability. The NAS battery is compact-sized and easy to transport and has the best price per capacity since containerized transportation is possible (Table 10.4-21). Between 2002 when the NAS battery became commercially available and 2015, those equivalent to 530MW (3700MWh) have been installed all over the world. The applications include frequency fluctuation control for renewables, output correction, load leveling, and micro-grid stabilization. With abundant resources available for NAS battery materials, cost reduction through mass production and market expansion are expected (Table 10.4-21 and Figure 10.4-18).

[Pumped-Storage Hydropower]

The pump-storage hydropower facilities tend to require large-scale development as well as environmental surveys and protection measures. Thus, this type of undertaking faces issues such as a long development period and high cost. Island areas, however, generally have smaller systems, and in such cases, the cost tends to be rather high since economies of scale do not apply. If the plan is to adopt seawater pumped-storage hydropower, it could raise many issues different from those associated with facilities intended for fresh water and could add to the cost. Given these facts, JICA Study Team thinks it reasonable to choose the storage method that uses freshwater reservoir tank rather than the dam even if the introduction of pumped-storage hydropower is to be considered. For the economical operation of a pumped-storage hydropower plant, enough excess power is needed for pumping, along with a load pattern that allows for efficient and frequent power generation (discharge). It must be noted that the pumped-storage hydropower plant cannot be operated efficiently if the gap between peak demand hours and non-peak hours is small and renewable output is even. In the government's vision for renewables expansion "Cabo Verde 100% Renewable: A Roadmap to 2020," an idea was listed to use renewable-based electricity that is stored in a large-scale power storage system during seasons of unfavorable wind condition. The specific measures included pumped-storage hydropower and methanation. However, the seasonal power interchange through power storage will incur enormous investment cost, which will be hard to recover. JICA Study Team believes that the idea needs to be set aside as an issue for future consideration.

In this section, the construction and operation cost is tentatively calculated for the NAS battery with 4.8MW (28.8MWh) and 1.6MW (9.6MWh) which were determined to be optimal for Santiago and São Vicente, and the 5MW (30MWh) reservoir-type (freshwater circulation) pumped-storage hydropower plant as an alternative power storage facility for Santiago (Tables 10.4-23 and 10.4-24). The result revealed that both the construction cost and power supply cost of the 5MW-class pumped-storage hydropower plant (with reservoir and freshwater circulation) are almost twice as those of the battery (NAS battery). In the examination, the desalination cost for the freshwater stored in the reservoir was not included in the calculation and will further increase the operation cost of the pumped-storage hydropower plant. Also it can be assumed that if seawater pumped-storage hydropower is adopted, there will be more disadvantages in terms of construction period, environmental protection, salinity measures, etc.

Thus, for JICA Study Team, it is hard to choose pumped-storage hydropower as an option for power storage to promote renewables expansion, considering Cabo Verde’s demand scale. The battery (NAS battery) is more desirable. The options for the battery include the lithium-ion battery, which has been used widely to address short-cycle fluctuations as explained earlier (Table 10.4-21 Comparison of battery characteristics). However, JICA Study Team decided not to examine this battery in the Study since the cost of the lithium-ion battery with the same capacity (4.8MW/28.8MWh) is higher by more than 50%. The 1.6MW-class NAS battery without advantages of scale has somewhat higher cost than the 5MW-class battery, but not to the level of the 5MW pumped-storage hydropower.

≪Sensitivity Analysis for Battery’s Economic Performance≫

In this section, the sensitivity analysis is conducted to see how the 4.8MW/28.8MWh-NAS battery’s economic performance such as electricity supply unit price and capital cost recovery changes with the three parameters of ①capacity factor, ② wind power purchase price and ③ diesel fuel unit price (see Table 10.4-25). The specs other than the three parameters are the same as those used earlier (see Table 10.4-23).

The economic performance was analyzed based on whether the electricity supply cost using the battery (average cost over a 20-year operation period (Euro Ct./kWh)) is less than Cabo Verde’s electricity tariff (23 Euro Ct./kWh) when the capacity factor is 17% (see Table 10.4-26 and Figure 10.4-19). According to the analysis result, the battery offers no economical advantage unless the crude oil price rises or wind power purchase price goes down. If the battery operates with a capacity factor of 8% and at half-capacity (3-hour discharge at full output) or less on daily average, it will be very hard to achieve economic performance.

≪Overall Evaluation≫

The Study Team summarizes the findings from the simulation of renewables expansion, and proposes specific measures for renewables expansion most feasible for Cabo Verde, together with issues associated with their implementation. JICA Study Team compiled the scenarios where wind power use is increased to 50% and 70% of the demand of the four islands included in the simulation (Tables 10.4-27 and 10.4-28). As for solar power generation, it suffers technological, operational and economical inferiority, whereas wind power boasts excellent wind condition and developmental potential. Thus, the Study is focused on wind power. The supplemental and situational introduction of solar power should be considered for the future from the viewpoint of ensuring energy security by dispersing energy resource suppliers.

Santiago has an ample room for wind power introduction and can bring in additional 10MW or so, which will raise the rate of renewables by 11%. However, without this addition, the rate of renewables will hardly increase. The battery that stabilizes long-cycle fluctuation can store excess wind power output for later use, but it can contribute only a few percent to the rate of renewables. The level of contribution was also just a few percent even when three islands were included and when the wind power use was increased to 70% of demand.

On São Vicente, any addition of wind power facility seems difficult at this point, due to restrictions in terms of wind conditions and facility construction. On the other hand, the island practices output control. Therefore, by switching to 50% wind power operation, the island can increase the rate of renewables by 10% without incurring extra cost.

Sal and Boa Vista can expect the rate of renewables to go up by 10% or more by raising the wind power use to 50% and adding wind power facilities of about 7MW and 5MW, respectively.

Next, if the wind power use is raised to 70% and the wind power facilities of the same scale as the 50% use scenario are added to the islands, the rate of renewables exceeds 50% for both Sal and Boa Vista. For Santiago, additional wind power of 10MW was assumed like the previous scenario; however, the rate of renewables only increased to about 30% from the current 15%.

To summarize the findings, if the wind power use is 50%, the rate of renewables for the four islands is about 33.4% (weighted average based on the amount of energy for each island) even with additional wind power. It is short of 50%, which is the current goal of Cabo Verde (Table 10.4-2).

Even if the rate of renewables for Sal and Boa Vista exceeds 50% after raising the wind power use to 70% as described earlier, the rate of renewables for Cabo Verde will be only 39.9%. Since Santiago accounts for 50% of the country's demand (based on power generation), the rate of renewables will not reach 50% even when the other three islands use up the diesel power operation margin (reduction margin), unless Santiago's rate of renewables goes up drastically (i.e. major addition in wind power is made) (Table10.4-30).

To achieve Cabo Verde's renewable goal of 50%, the Study Team proposes adding a 100MW wind farm (or facilities distributed over the island) on Santiago. With this measure, the rate of renewables will reach 55% on four-island average (Figure 10.4-20).

As described above, JICA Study Team examined the renewables expansion for the main four islands that seem to offer room for the introduction of renewables in terms of operation and facility. The expansion of renewables is possible without imposing too much burden. To give full weight to economic performance, the full-fledged battery introduction must be considered while utilizing the wind condition and regulation capability of diesel power. The following angles must be included in the consideration: ① increasing wind power use from 50% to 70% in stages, ② adding wind power, and ③ verification of system stability, maintenance of power quality and output correction by diesel power as the rate of renewables goes up. Especially, the cost and advantage of the battery must be examined from the medium- to long-term standpoint by focusing on the fact that the battery for short-cycle fluctuation stabilization has produced more result worldwide when used in the grid. Also for pumped-storage hydropower, care must be taken not to confuse the introduction with the goal, since it involves issues such as high cost.

≪Obstacle to Going 100% Renewable≫

In this Study, JICA Study Team reviewed the characteristics and issues of the Renewable Roadmap 2020, which was announced by Cabo Verde in 2013. This section presents the challenges for going 100% renewable using the current technology and cost as a reference.

The wind condition varies greatly by season in Cabo Verde. For example, the capacity factor of the wind power generation system on Santiago reached 68% in January 2015 when it was windiest, but it went down to 10% in July, which is about 1/7 of the January figure. The additional wind power needed to meet the island’s entire demand with wind power generation was calculated by simulation, assuming that the wind condition does not change by season. The calculation yielded 95,000kW (about 2.7 times the island’s demand scale of 35,300kW). Then JICA Study Team calculated the capacity of the battery, which is charged using the excess power including that from the new additions between November and April the following year and is discharged in July – October when power is insufficient. The capacity obtained was 50GWh. KEPCO’s NAS battery (50MW/300MWh) is one of the world’s largest batteries at present; however, the battery for Santiago would need a capacity 167 times that of KEPCO’s battery. The space required will be at least an area equivalent to 300 soccer fields and construction cost will be several trillion yen at the minimum.

Since the island welcomed two cutting-edge diesel generators in 2012 and again in 2015 with the support from the World Bank and other donors, the need to increase the operating ratio of renewables seems small especially when considering the huge investment. The team estimated the additional wind power and battery capacity needed to achieve 100% renewable on the main islands (Table 10.4-32).

After examining items above, JICA Study Team believes that going 100% renewable (wind power) is technically achievable on islands of Santiago’ scale even though it is not a realistic option when cost-effectiveness is taken into consideration.

When discussing renewables expansion, emphasis on the goal tends to diminish the importance of level-headed examination of the options with thorough consideration of alternatives, maturity of technologies and economic performance. In Europe and other developed countries, many cases have been reported, where political agenda led the introduction of FIT and subsidies for renewables promotion (taxes), etc. It often resulted in a sharp rise in the electricity tariff (impact from FIT-related levy, etc.) or failure of the renewable scheme itself due to revenue shortfalls.

JICA Study Team has experience receiving renewable power beyond what is perceived possible and conducting demonstrations on remote islands of Japan. For example, based on the experience, JICA Study Team cannot suggest pumped-storage hydropower as the first option for an island area, knowing its long development period, high cost and risk in ensuring sufficient use. Instead, batteries for long-cycle fluctuation control are excellent in terms of cost and portability, and are becoming more suitable for general use in step with the market growth.

JICA Study Team recommends, instead of photovoltaics that will be relatively expensive, wind power as a renewable power source, since Cabo Verde has ample experience operating wind power plants, wind power offers both quality and quantity in conformity with the grid code, and output is relatively level and easy to utilize. There are techniques that are not new, such as the utilization of output control capability of diesel power and wind power as a base power source. JICA Study Team believes that it will be important in the future to focus on the operational advantages of these techniques and take approaches that reduce cost through hybrid operation of renewables and diesel power in a way to utilize their strong points (Figure 10.4-23).

10.5 Examination of Introducing Renewable Energy to Islands with Small Demand

On Maio and Brava, where demand is small, and Fogo and São Nicolau, where the capacity of new diesel power generation equipment is large in relation to demand, output suppression or power storage system is necessary to accommodate the introduction or expansion of renewables. However, because introducing small-scale renewable energy equipment and power storage equipment is more expensive than cost of diesel power generation, it is difficult to install such equipment unless it is installed as part of a demonstration experiment on a model island selected for expanding the renewable energy rate as a policy. Brava is here examined as the model island with small demand, by focusing on the consideration points for expanding renewables.

≪Expansion of Renewable Energy through Suppressing Renewable Energy Output≫

The demand for power on Brava is 170 - 600 kW and peak demand occurs between 18:00 and 22:00. There are four diesel power generators, and in the hypothetical case where a 400kW Perkins generator is used, the minimum output (assuming 50% of nominal capacity) would be 200kW. In this case, even if output suppression of wind power were implemented, the times in which power could be supplied from wind power generation would be limited. Accordingly, it will be necessary to consider the introduction of storage batteries if it is intended to expand renewable energy (Figure 10.5-1).

≪Important Points to Consider when Expanding Renewable Energy through Introducing Storage Batteries≫

When introducing storage batteries and expanding renewable energy, it is recommended that careful examination be implemented in light of demonstration testing, etc. and by considering the response to fault currents, frequency fluctuations (demand-supply imbalance) and stoppage of diesel power generation (Tables 10.5-1 to 10.5-3).

≪Examples of Introducing Systems with Expanded Renewable Energy in Consideration of PCS Characteristics≫

The PCS could stop operating and power interruptions could arise due to system faults or demand-supply fluctuations, etc. in the case where storage batteries and solar power generation, etc. are increased. To prevent such situations from occurring, system examples geared to expanding renewable energy while at the same time securing system stability are proposed below:

Case A: Construction of a micro grid system

The instability caused when introducing renewable energy is resolved by implementing short-cycle and long-cycle fluctuation compensation by means of storage batteries, controlling increase/reduction margins in diesel power generation, and carrying out voltage compensation through controlling reactive power, and so on. In order to expand the rate of renewable energy, allow the maximum power supply from wind power generation, while using diesel power for adjusting voltage and charging storage batteries. At times when the wind power generation output declines or at peak demand, power will be supplied from the diesel power generation and storage batteries. Doing this will enable the renewable energy rate to be raised to 63% in January when wind conditions are good and 47.5% throughout a year (Figure 10.5-2 and 10.5-3).

Case B: Construction of a new renewable energy system and aim for maximum introduction of renewable energy

The instability caused when introducing renewable energy is resolved through implementing short-cycle and long-cycle fluctuation compensation by means of a storage battery and motor generator (M-G) set, voltage compensation through reactive power control, and so on. Depending on the residual capacity of the storage battery, it is theoretically possible to achieve 100% renewable power supply. The feature of this system is that a storage battery-driven synchronous generator can be used instead of an existing internal combustion engine to supply power. While adopting similar operation to conventional power supply based on one existing diesel power generator, it is theoretically possible to conduct system operation that uses no fuel at all (however, in summer, since no wind power generation output can be anticipated, diesel power generation is necessary). However, since such a system has not been extensively introduced, it is necessary to gradually increase the renewable energy rate while implementing demonstration testing in small-scale systems and so on.

10.6 Proposal for Renewable Energy Expansion

JICA Study Team proposes four schemes below to promote the expansion of renewable energy and grid stabilization in the Republic of Cabo Verde (Table 10.6-1):

≪Four Schemes Based on the Study≫

(1) Wind power generation development

[Targets] Santiago/Sal/Boa Vista

- Cabo Verde has extremely high potential for wind power development. It is possible to consider project formation in Cabo Verde based on a low-interest loan if a government-financed corporation (for example, Electra) implements the project and governmental guarantees can be offered.
- Sao Vicente has many areas where the terrain slope angle is 10% or more. Such terrain is likely to pose issues to wind conditions and facility construction; thus it was determined that the development is difficult at this point (environmental assessment, etc. must be conducted again).
- For the reasonable development, studies and preparation period with the consideration of the following issues are necessary.

  - ✓ Detailed survey of terrain and wind conditions should be conducted for the review of wind power development zone
  - ✓ The grid code for renewable energies connection is still in the process of establishment
  - ✓ Scientific demand forecast with the view point of economy has not been conducted
  - ✓ In order to maintain the grid stability and enhance the energy efficiency, power flow analysis with the data of demand forecast is necessary

(2) Transmission/distribution facility construction

[Targets] Santiago/Sal/Boa Vista

- All 3 islands have issues; however, Boa Vista, where levels of deterioration and fragility are extreme, has greater need for facility development due to tourism development and expansion of renewable energy. It might be a good idea to consider combined utilization of batteries used for short-cycle fluctuation control and thus for system stabilization and NAS batteries that are used for long-cycle fluctuation control and for emergency. On Boa Vista, since the demand density is high and hotel construction will increase, there is also a need for power quality.

(3) Technical cooperation for the operation of diesel power

[Targets] Santiago/Boa Vista/Sal/Sao Vicente

- In order to expand renewables, it is necessary to increase the margin of reduction in diesel power generation (adjustment capability). To this end, the operation technique must be enhanced to establish optimum O&M including that to secure quality and to ensure efficiency in operation of both base power sources and output regulating power sources. It might be effective to offer both the visit by experts and technical training.

(4) Introduction of micro-grids to small, remote islands

[Targets] Maio/Fogo/Brava

- Solar power has been introduced to non-electrified areas with the EU assistance.
- Remote islands with small demand have little room for renewable energy integration. Fogo and Brava have topography that makes wind power development difficult. Accordingly, the introduction of solar power plants could be considered (using diesel power or batteries as a regulating power source), even though it is relatively expensive. Since profits cannot be anticipated, it will be difficult to compose loan projects.

≪Proposal for Efficient Use of Renewable Energy and Sustainable Energy Supply≫

(1) Government-led wind power introduction and operation

If the Cabo Verde Government brings in a foreign IPP for the purpose of obtaining funds for development, the foreign currency earned from wind power will flow out of the country, and the negative effect on the national accounts will be significant. Therefore, in the future direction of the wind power development, government-owned power companies like Electra should lead the development using soft loans from international organizations with a government guarantee. Furthermore, currently, Electra and Cebeolica have a contract with a take-or-pay clause, and the excess amount is suppressed since the electricity price is set too high. To improve the renewable energy utilization rate, it is necessary to lower the price of electricity that exceeds the purchase quota.

(2) Minimizing power loss and improving collection of uncollected tariffs on Santiago

For Electra, which is facing a serious financial situation, minimizing power loss and improving collection of uncollected electricity tariffs are urgent and important issues. Therefore, as the most effective action to be taken, necessary solutions for loss improvement and uncollected tariffs in Santiago should be carried out promptly. The Cabo Verde Government should support activities of Electra proactively to realize stable energy supply and stabilization of the country’s industrial base.

(3) Purpose of power storage facilities and pursuit of economic efficiency

Since Cabo Verde is a small island nation with stable wind, it is not in a situation in which large-scale pump-storage hydropower and batteries can be effective technologically or economically. Particularly with power storage, there is still room for improvement in terms of cost. Therefore, the first priority in creating a scheme is to recognize that these technologies are options for the future while pursuing economic performance (in the future, the need for batteries as a countermeasure to short-cycle fluctuation is anticipated). At this time, by just increasing the margin of reduction in diesel power (adjustment capacity) and installing wind power systems, the rate of renewable energy utilization could be increased significantly and the cost could be recovered for the most part.

10.7 Prospective Measures for More Renewable Energies

The suggestions for the measures to utilize more variable renewable energies (VRE) follows.

≪Issues to Be Concerned for the Introduction of VRE≫

Since VRE has higher fixed costs over variable costs compared with conventional energies. Thus, the composition ratio of VRE should be kept adequately so that the restriction of the output of VRE due to the restriction of minimum diesel output and/or network stability, may occur infrequently. Otherwise, the overall costs for electric power system will increase in the long run.

≪Suggested Measures for Further Renewable Energy Utilization (Technical)≫

(1) Improving accuracy of demand forecast

VRE (e.g., wind and solar power) tends to incur high fixed costs. In order to improve the capacity factor of VRE, it is necessary to predict demand, etc. accurately and minutely. For this purpose, it is essential not only to accumulate demand data over an extended period of time but to collect data at small intervals covering many items down to LV feeders. If the smart meter is introduced, it can be used to understand the demand characteristics by demand segment, forecast demand in real-time, and to help establish electricity tariff.

(2) Improving accuracy in evaluating supply capacity of VRE

It is possible to improve the accuracy of supply capacity forecast even that for VRE. The specific measures might include highly accurate forecast of solar radiation and wind condition with the use of various weather data, and thorough management of equipment efficiency. It might also be possible to estimate the accumulation of dust and sand on solar panels using the wide-area metrological data, and thereby optimize the schedule of panel washing.

(3) Introduction of demand response

The introduction of demand response that can absorb the fluctuations in renewable power supply on the demand side might be promising. For example, more flexible demand response could be realized by installing a time switch that facilitates scheduled operation of warn/cool thermal storage or desalination plant, or a small meter.

≪Suggested Measures for Further Renewable Energy Utilization (Institutional/Political)≫

(1) Extension of settlement period for wind power under Take-or-Pay scheme

In Cabo Verde, the wind condition as well as demand change by season. Therefore the effect of such changes could be mitigated if the period in which wind power must be purchased under the Take-or-Pay contract could be extended beyond one month and the settlement period extended to six month to a year.

(2) Virtual interconnection between islands

One of the measures to lessen the impact of uncertain factors related to VRE is to interconnect the islands virtually. In this interconnection, for example, if the purchase quota of wind power under Take-or-Pay is not (or is not likely to be) met on Sal, the purchaser can transfer the balance to another island and fulfilled the combined quota there.

(3) Establishing rules for prioritized dispatching

The rules entail the establishment of the order by which output is suppressed when supply including that from renewables exceeds demand. The rules could help promote the introduction of renewable energy while assuming stable power system operation and ensuring transparency and fairness.

(4) Introduction of spot market to utilize excess renewable power

There at times might be wind power output in excess of that sold under "Take-or-Pay" scheme. It might be effective to create a short-time spot market to trade such energy on a near real-time basis.

≪Comprehensive and Long-term Measures≫

(1) Warm/cold thermal storage

Resort business prospers in Cabo Verde and hotels and other facilities have high demand for hot water and cryogenic energy for air conditioning. Thus, warm/cold heat (ice thermal storage) could be prospective technology to store energies. However, please note that solar water heater may have an advantage over the combination of photovoltaic generation and electric boiler. The point is to choose the best option in consideration of overall energy supply chain without sticking to electricity.

(2) Electric car/bicycle and ecotourism

Introduction of electric car and bicycle (collectively EV) is relatively easy for Cabo Verde because no transportation for long distance or wide area over land is necessary. In Cabo Verde, the means of transportation with zero-emission may be introduced in cooperation with eco-tourism to add value to sightseeing resources. EV may be introduced as buggies on beach or shuttle buses between airport and resort areas. The country might be able to attract private investment by establishing special eco zones and by calling attention to its eco-friendly stance.

(3) Hydrogen by renewable energy and applications

There have been many attempts to utilize electrolytic hydrogen produced with renewable-based electricity in several countries. Such technologies are not for practical use currently but there is potential for a breakthrough by an innovation. Therefore, the development of the pertinent technologies should be watched closely.

(4) Exploitation of unutilized coastal energies

Cabo Verde, as a maritime country, has abundant unutilized energies in neighboring sea areas as well as on land. Such energies could be harnessed in tidal power generation, offshore wind power generation, ocean thermal energy conversion (OTEC) and wave power generation. Although these technologies are still at the stage of research, development or demonstration, it is necessary to watch future progress carefully to counterpoise against other possibilities (e.g. cost reduction of batteries, breakthrough in hydrogen related technologies) and conventional technologies to plan a flexible strategy to be adjusted to future scenarios.

CONTENTS

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1. Introduction

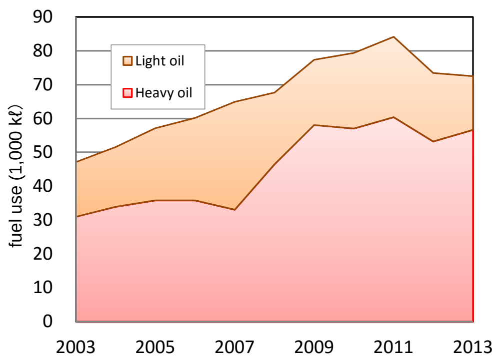
1.1 Background

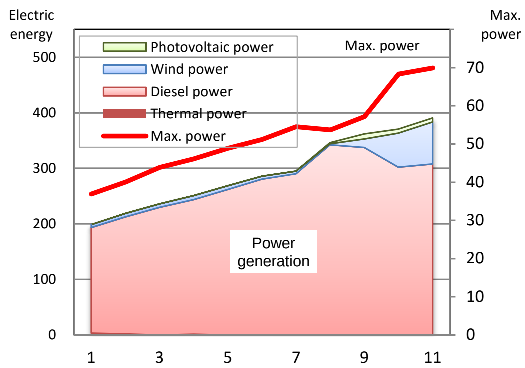
The Republic of Cabo Verde (hereafter referred to as "Cabo Verde") has limited water and energy resources as well as a geographical vulnerability as an island nation. It has to depend on import for much of its fuel and food, which results in a chronic excess of imports.

Fuel accounts for about 20% of all merchandise import, much of which light and heavy oil for power generation. The fuel import declined once in 2012; however, it still fluctuates at a high level. The average unit cost had been on the upward trend until 2013, pushing up the energy cost of Cabo Verde in terms of capacity and unit price, and greatly affecting the nation's international balance of payments.

In this light, the Cabo Verde government set a goal to raise the rate of domestically procurable renewable energy (hereafter referred to as "renewable") to 50% of the nation's power sources by 2020, and named it as one of the eight priority fields of development as stipulated in the 8th-Stage Basic Governmental Policy drawn in 2011. The government issued an ordinance in the same year to promote renewable. In 2012 Rio＋20 conference, President Fonseca of Cabo Verde gave a speech stating Cabo Verde's aim to go 100% renewable by 2020, and in 2013, "Cape Verde 100% Renewable: A Roadmap to 2020," a roadmap toward achieving the plan, was created.

According to the Ministry of Tourism, Investment and Business Development /Directrate General of Energy (hereafter referred to as MTIDE/DGE) the amount of light oil import decreased by 15% and heavy oil by 8% between 2012 and 2013, thanks to the introduction of renewable facilities especially those harnessing wind power that started in earnest around 2011. Since the total power generation increased continuously after 2011, it is likely that the increase in renewable facilities helped reduce a certain amount of fuel burned for power generation.





Source: Prepared by JICA Study Team based on information from MTIDE/DGE

Figure 1.1-1 Fuel use for generation

Figure 1.1-2 Max Demand and Generation

Cabo Verde is developing its infrastructure to achieve sustainable growth and poverty reduction based on its sound finance and using highly concessional donor support. In this Study for Cabo Verde, the Study Team will examine support measures that apply advanced technological abilities of Japan and other sources to actively promote high-quality infrastructure development. The below are Japan's recent support cases for monetary compensation.

- Power Generation, Transmission and Distribution Capacity Building Project on Santiago Island: FY2008 untied project for 4,468 million yen
- Transmission and Distribution System Development Plan: FY2012, General Untied project for 6,186 million yen
- Water Supply System Development Project in Santiago Island: FY2014 STEP project for 15,292 million yen

1.2 Purpose

The purpose of the Study is to verify basic data to determine Cabo Verde's optimal power source composition and examine support measures. Its goal is to achieve power system stabilization in Cabo Verde with an eye on renewable and battery introduction, etc.

(1) Collection and organization of basic information on the power sector

(2) Collection and analysis of information necessary for the review and examination of the roadmap for renewable facility introduction

(3) Collection and analysis of information necessary for the examination of support measures for the power sector, which will help improve energy security and utilize knowledge, experience and technology of Japan and other sources

1.2.1 Target Regions

The regions targeted by the Study are the 9 main islands in which national people are living, and regarding the selection of islands for the site surveys were determined, by the consideration of power demand and accessibility with the priority order of significance, based on the discussions with the Japan International Cooperation Agency (JICA).

1.2.2 Basic Policy of the Study

The basic policy of the Study is to "examine support measures that help enhance energy security and utilize advanced technology of Japan and other sources, on the premise of achieving fuel cost reduction accompanied by a stable power supply and sustainable implementation system." The Study is to proceed while considering the points below:

(1) Maximum use of knowledge and technology cultivated by suppling power to remote islands in Japan

Kyushu Electric Power Co., Inc. (KEPCO) in Japan has supplied power to the highest number of islands among power companies of Japan and accepted electricity from and taken measures for many renewable facilities. KEPCO will utilize its knowledge and technology gained in Japan for the Study.

(2) Proposal of realistic, allowable renewable capacity to be introduced

KEPCO has the independent grid for remote islands with different demand scales and compositions of power sources. The company verifies the well-balanced configuration of and control method for renewable facilities, diesel power and batteries connected to the grid from the short-term and long-term perspectives. It calculates realistic and allowable renewable capacity to be introduced, while satisfying the renewable promotion policy of the Japanese government to the fullest extent. Thus, when calculating the allowable renewable capacity to be introduced in Cabo Verde, a realistic proposal will be made based on the characteristics of Cabo Verde and utilizing the latest knowledge and experiences from Japan.

(3) Economic comparison regarding potential fuel use reduction in diesel power generation

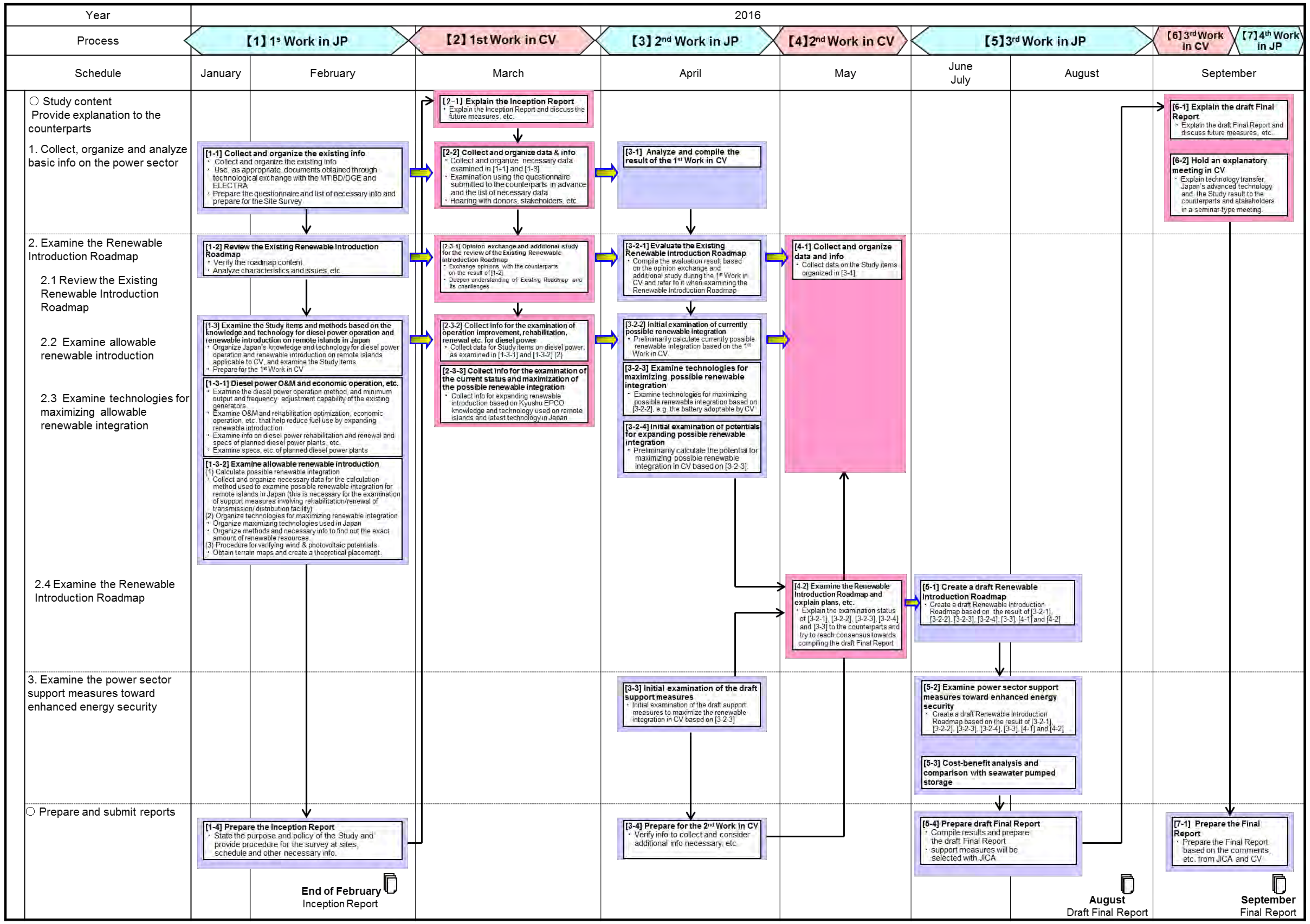
Proposals will be made on the potential fuel use reduction through the optimization of O&M for diesel power and economic operation, backed by economic rationality based on cost-effectiveness comparison with other support measures, etc.

(4) Proposals based on Japan's support policy

JICA Study Team will propose support measures that are based on Japan's policy for Cabo Verde support and high-quality infrastructure development and utilize advanced technology of Japan or other sources.

1.2.3 Study Content and Schedule

The Study is implemented by following the "1.2.2 Basic policy of the Study" in Figure 1.2-1 below.



Source: JICA Study Team

Figure 1.2-1 Overall work flow

The schedule of the Study is shown in Figure 1.2-2 below.

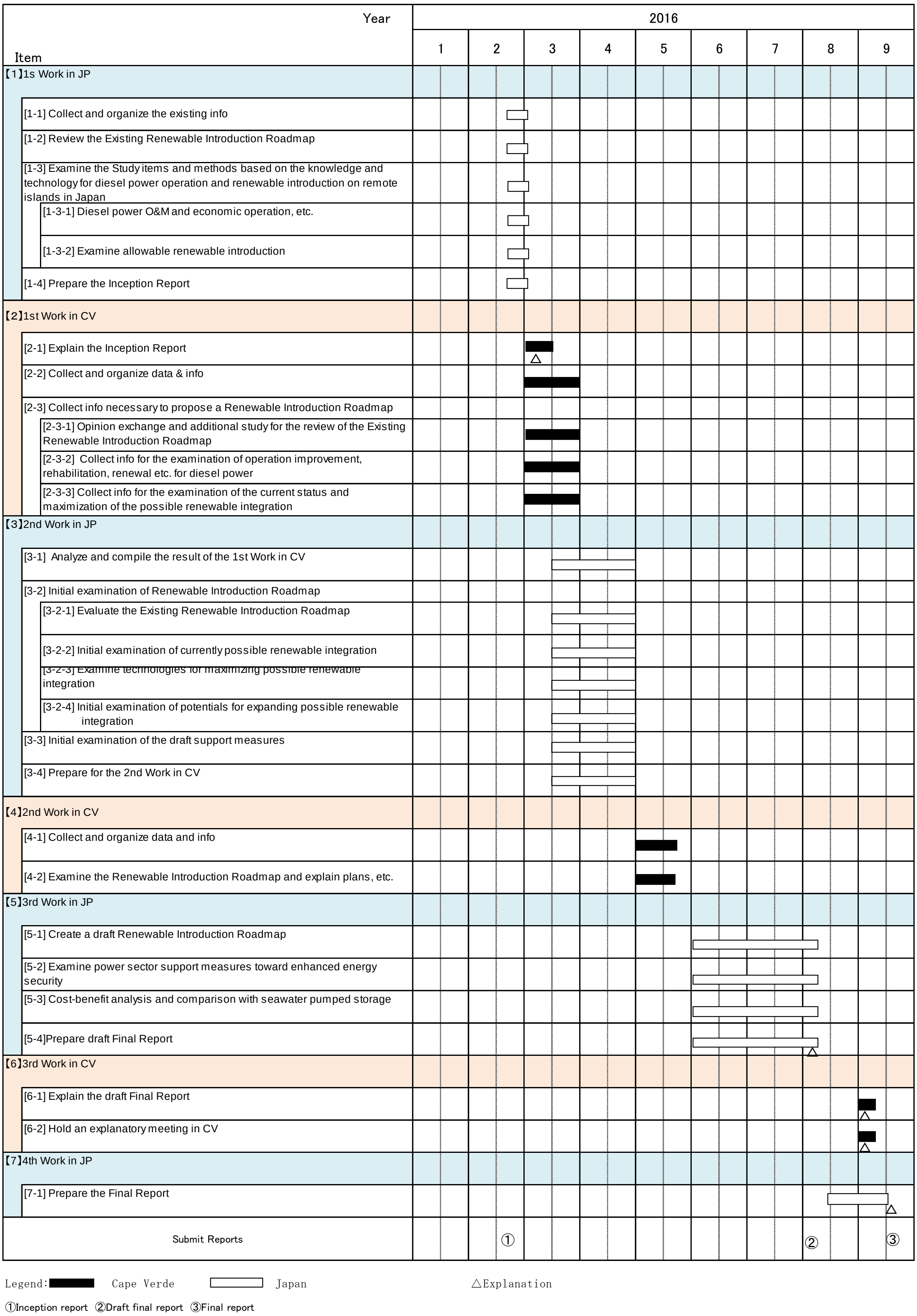


Figure 1.2-2 Study schedule

1.3 JICA Study Team Composition

The composition and work contents of the Study Team are shown in Table 1.3-1 below.

Table 1.3-1 Composition and work contents of Study Team

Name	Assignment	Contents
Hiroshi FUCHINO (KEPCO)	Leader/ Renewable Energy Interconnection	・Team leader/safety control officer ・Establish policy, content and plan of the Study ・Negotiate with local stakeholders ・Collect, organize and analyze basic info on power development, renewable introduction plan/target ・Evaluate the appropriateness of Existing Renewable Introduction Roadmap and make proposals (supervision) ・Examine the creation of a yen-loan project (STEP) based on the upper-level plans and other donor supports. ・ Examine and propose power sector support measures (supervision)
Tatsunari HAYASHI (WJEC)	Deputy leader/ Power System Operation ②	・Sub leader/assistant safety control officer ・Help establish policy, content and plan of the Study and negotiate with local stakeholders ・Collect, organize and analyze info necessary for load flow analysis ・Review Existing Renewable Introduction Roadmap & make proposals (load flow analysis) ・Collect info on power system operation②and help examine support measure, etc.
Toshiki FURUKAWA (KEPCO)	Power System Operation ①	・Collect, organize and analyze data on power source, supply & demand, transmission/distribution facility and grid operation (incl. O&M status, cost, etc.) ・Collect and analyze info on the current grid stability ・Examine the maximization of allowable renewable capacity to be introduced (power system operation) ・Review Existing Renewable Introduction Roadmap & make proposals (power system operation) ・Examine ideas for power sector support measures (rehabilitation and renewal of transmission/distribution facility)
Hironobu KIMURA (KEPCO)	Battery and System Control	・Collect, organize and analyze basic grid info necessary to examine battery and control technology introduction ・Examine the maximization of allowable renewable capacity to be introduced (battery) ・ Review Existing Renewable Introduction Roadmap & make proposals (battery) ・Compare cost of battery and seawater pumped storage power generation. ・Examine ideas for power sector support measures (battery, control facility, etc.)
Tsuyoshi SHIMADA (KEPCO)	Diesel Power Generation	・Collect, organize and analyze basic info on the existing diesel power (verify the reduction of fuel cost and fuel combustion brought on by the O&M optimization) ・ Review Existing Renewable Introduction Roadmap & make proposals (diesel operation) ・Examine ideas for power sector support measures (rehabilitation and renewal of the existing diesel power)

Name	Assignment	Contents
Masahiro SOEDA (KEPCO)	Photovoltaic Power Generation	・Collect, organize and analyze basic data on photovoltaic and other renewable (incl. O&M status, cost, etc.) ・Review Existing Renewable Introduction Roadmap& make proposals (photovoltaic, etc.) ・Examine ideas for power sector support measures (photovoltaic power)
Yasushi KAWASHIMA (WJEC)	Wind Power Generation	・Collect, organize and analyze basic info on wind power (incl. O&M status, cost, etc.) ・Review Existing Renewable Introduction Roadmap & make proposals (wind power) ・Examine ideas for power sector support measures (wind power)
Katsumi YOSHIDA (KEPCO)	Energy Policy/ Economic and Financial Analysis	・Collect, organize and analyze basic info on energy policy, legal system, structure and financial ability, etc. of the power sector-related organizations ・Examine the support status of other donors and countries ・Collect and organize info on tariff and legal system related to FIT, etc. ・Review Existing Renewable Introduction Roadmap & make proposals (economy and finance)

1.4 Overview of the Field Survey

In accordance with the Study plan such as Section 1.2.3 above, field study in Cabo Verde was conducted 3 times.

(1) The 1st works

[Period] March 5, 2016 (Sat) ～ April 3, 2016 (Sun)

[Purpose] By the inception report, presentation about the study plan to DGE as the counter part of this study. Request to the electricity sector for cooperation to this study and provision of necessary information.

[Visits]

- Santiago: MTIDE/DGE, Electra power plant (Diesel and PV), ECREEE, CERMI, Cabeolica head office and wind farm, EU delegation office in Cabo Verde
- São Vicente：Electra head office and power plant (Diesel), Cabeolica wind farm
- Boa Vista：AEB power plant (Diesel) . Cabeolica wind farm
- Sal：Electra power plant (Diesel and PV), Cabeolica wind farm, APP power plant (Diesel)
- Santo Antão：Electra power plant (Diesel and PV), Electric wind farm, Monte Trigo micro-grid facility
- Fogo：Electra power plant (Diesel)
- Brava：Electra power plant (Diesel)

(2) The 2nd works

[Period] May 14, 2016 (Sat) ～ 31 (Tue)

[Purpose] Supplemental data collection survey based on the 1st works in Cabo Verde. Confirming present situation of the current renewable energy road map

[Visits]

- Santiago: MEE/DGE, UGPE, Electra power plant (Diesel) and transmission facilities, Cabeolica head office
- São Vicente: Electra head office and power plant (Diesel)
- Boa Vista: AEB power plant (Diesel) and transmission facilities. SDTIBM
- São Nicolau: Electra power plant (Diesel), Carriçal micro-grid

(3) The 3rd works

[Period] September 2, 2016 (Fri) ～ 11 (Sun)

[Purpose] Explanation of the Draft Final Report of the study and holding workshops for the power sector in Cabo Verde

[Visits]

- Santiago: MEE/DGE
- São Vicente: Electra head office

(a) Draft final report to DGE

- JICA Study Team has explained the conclusion of the study, background, recommended schemes and political proposal to Mr. Anildo Costa, DGE Direcotr and Mr. Luis Teixeira, MEE Special Advisor who are the keyperson for the establishment of the energy sector vision, and has got their understandings.
- JICA Senegal joined to the activities implemented by the study team, and discussed with DGE, MEE Special Advisor and Electra regarding the recognition of the issues in the energy sector and future cooperation by JICA.

<Meeting with DGE > (Sep. 5 and 9, 2016 in Santiago)

Mr. Anildo Costa
Director.DGE

Mr. Luis Teixeira
MEE Special Advisor

Left : JICA Study Team Righ : DGE、MEE、JICA Senegal

(b) Workshops for power sector

- Workshops for the power sector; DGE, UGPE, Electra, ECREEE, Cabeolica have been organizsed, and JICA Study Team has explained the necessity of the recognition of the issues and exchanged opinioins related above with them.
- For example, the issues of Electra's financial improvement and the raise of utilization of unused wind potential would not be a private matter between Electra and Cabeolica, but a national issue. Additionaly, Mr. Antão Fortes, CEO of Cabeolica commented at the workshop as "Firstly, Cabeolica has to pursue a benefit for the company, and we will make efforts to find a way of benefit to Cabo Verde".

<Workshop for Electra > (Sep. 7, 2016 in São Vicente)

Diesel generation presentation

Renewable expansion simulation presentation

<Workshop for power Sector > (Sep. 8, 2016 in Santiago)

Wind power presentation

Attendees: DGE, UGPE, ECREEE, Cabeolica

2. Outline of the Energy Sector

2.1 Current Status of the Electric Power Sector

2.1.1 Overview of Electra

Electra, which was established as the state-owned water and electric power supply corporation in 1982, is responsible for power supply in Cabo Verde, except in parts of Sal and Boa Vista (Government Ordinance Decreto-lei nº 37/82). From the beginning, Electra was perennially unprofitable and struggled to secure investment for renewing equipment and so on. Accordingly, the Government of Cabo Verde in 1999 privatized Electra by selling 5% of its shares in the corporation to two Portuguese companies (EDP: Energias de Portugal, SA, ADP: Águas de Portugal, SA). It was at this time that the corporation adopted its current title as a limited liability company, i.e. Electra S.A.R.L. (Government Ordinance Decreto-Lei nº68/98).

In 2002, Electra signed a concession agreement concerning the power transmission and distribution utility for 36 years from 2000 to 2035 with the Government of Cabo Verde (with the Government of Cabo Verde holding the ownership rights to the transmission and distribution network), and equipment is today used and maintained based on this.

Following privatization, Electra attempted to conduct equipment investment and improve management efficiency, however, it continued to record a deficit due to rising fuel prices and a tariff system that made it impossible to cover costs. Accordingly, in July 2006, the two companies EDP and ADP agreed to transfer the management rights of Electra back to the Government of Cabo Verde. These two companies, which held 51% of the shares in Electra at the time, gradually transferred their shareholding to the government, until today the government holds 77.731%, the National Social Security Directorate holds 16.592%, and local governments hold 5.677%. When the Government of Cabo Verde bought the shares in Electra from EDP and ADP, the bank debts that both companies had incurred in managing the business were taken over by Electra, and this credit is now held by the Commercial Bank of Cabo Verde (Banco Comercial do Atlântico (BCA)). As of the end of fiscal 2014, the balance of credit is 4,394,025,000 CVE.

Furthermore, in July 2013, with a view to speeding up its management operations, Electra divided its operations into two branch companies covering the north and south respectively and introduced the holding company system. The following table 2.1-1 gives an outline of Electra.

Table 2.1-1 Outline of Electra

Item	Contents
Company name	Electra S.A.R.L.
Date established	April 1982
Capital	1,585,262,000 CVE
President	Dr. Carlos Miguel Sena Castro Teixeira, General Assembly Dr. Alexandre Guilherme Vieira Fontes, Board of Directors
Employees	782 (total in the 3 companies of Electra S.A.R.L., Norte, Sul) (2015)
Sales/profit this term	10,407,644,000 CVE/225,856,000 CVE (2014)
Power generating facility	222,533 kW (Diesel: 190,113 kW, Wind Power*: 26,000 kW, Solar: 6,420 kW) (2015)
Generated electrical energy	418,992,697 kWh (2015)

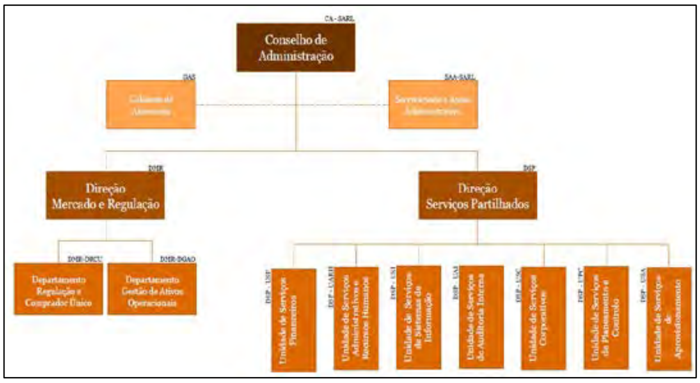
Note: The capacity of the wind power with "*" is the facility of IPP that supply electricity to Electra

Source: Prepared by Annual report and materials provided by Electra

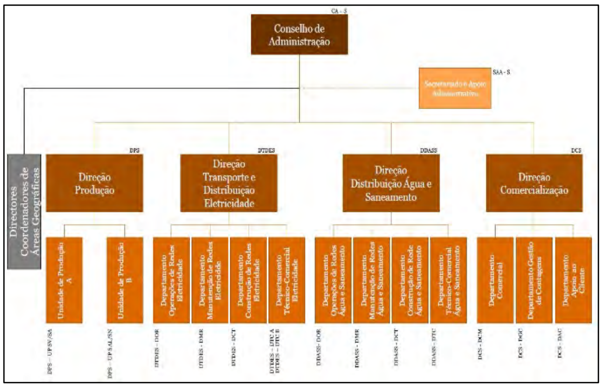
Concerning the organization, although the Government of Cabo Verde has the majority stockholding, Electra has adopted the same limited liability company system as an ordinary private sector enterprise since 1999. In Electra Head Office, the Board of Directors (Conselho de Administração) is responsible for executing affairs under the General Assembly (Assembleia Geral), and the Assets and Purchasing Department (Direcão Mercado Regulacão) and Common Services Department (Direcão Servicios Partilhados) support management, the northern business division (Electra Norte) and the southern business division (Electra Sul).

Electra Norte and Electra Sul, operating under orders from the Head Office and President, each possess departments for power generation, transmission and distribution, water supply, and marketing, and they conduct operations with jurisdiction over each area. The following figures 2.1-1 show the organization and staffing arrangement of Electra.

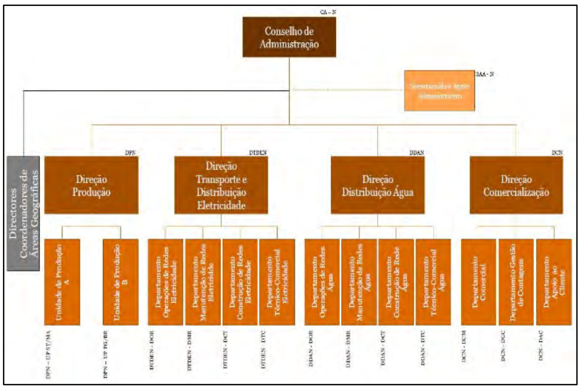
Electra Head Office



Electra Norte



Electra Sul



Source: Electra

Figure 2.1-1 Organization of Electra

Table 2.1-2 Staffing Arrangement of Electra

Electra SARL	Efectivos Permanentes	C. Prazo	Total
CA	1	0	1
UGAO	6	1	7
DRCU	2	0	2
UAI	3	0	3
UARH	19	0	19
UPC	3	0	3
USA	27	1	28
USC	1	0	1
USF	14	3	17
USI	4	1	5
GAS	3	0	3
SAA	2	0	2
ULPDC	4	4	8
Proj. Reforço Sist. Prod.	0	4	4
Total	**89**	**14**	**103**

Electra Norte	Efectivos Permanentes	C. Prazo	Total
DCN	48	8	56
DDAS	22	3	25
DPN	117	6	123
DTDE	62	6	68
SAA	8	0	8
Total	**257**	**23**	**280**

Electra Sul	Efectivos Permanentes	C. Prazo	Total
DCN	52	32	84
DDAS	42	17	59
DPN	95	22	117
DTDE	113	21	134
SAA	4	1	5
Total	**306**	**93**	**399**

Source: Electra

On comparing the organizations of Electra Norte and Electra Sul, whereas the northern region includes Sal, which has a prosperous tourism industry and relatively large-scale demand, the southern region contains the capital Praia and Santiago, which has dense population and high civil sector demand; accordingly, Electra Sul has more personnel in the transmission and distribution department (DTDE) and marketing department (DCN) than Electra Norte. The following table 2.1-3 shows the jurisdiction and diesel generator capacity of each regional company (end of 2015). Incidentally, power supply in part of Sal is conducted by a separate company (APP), while power supply in Boa Vista is conducted by AEB.

Table 2.1-3 Composition of Diesel Generator (2015)

Electra Norte	Electra Sul
Santo Antão : 10,532kW S. Vicente : 37,995kW S. Nicolau : 7,672kW Sal : 14,545kW	Maio : 2,176kW Santiago : 87,335kW Fogo : 9,304kW Brava : 1,416kW
E. Norte total: 70,744kW	E. Sul total: 100,231kW
Sal(APP) : 5,024kW	Boa Vista(AEB): 14,114kW

Source: Materials from Electra, APP and AEB

2.1.2 Financial Condition of Electra

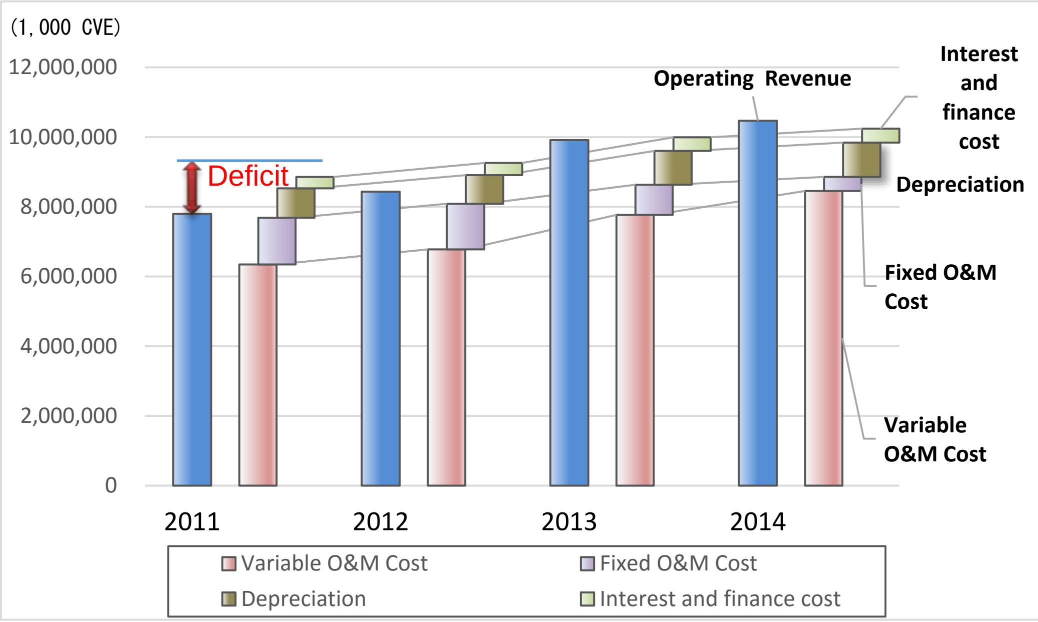
As was mentioned earlier (Section 2.1.1), the privatization of 1999 did not remedy performance, and Electra's profitability failed to improve even after the government bought back its shares in 2006.

Although sales of Electra increased by 20% (increasing at a rate of 6% per year) in line with economic growth over the three years between 2011 and 2014, except for 2014 when a minor profit for the term (225,856,000 CVE) was recorded, the company has consistently recorded a deficit ever since the management was revamped and debts were restructured in 2006.

Particularly in the period between 2011 and 2014, when international prices of crude oil were high (US$80^100 per barrel), diesel fuel costs were inflated (70-80 CVE per kg) and Electra's power generating costs increased. On the other hand, around the time when crude oil prices were at historically high levels, Cabeolica commenced its wind power generation operations in 2011 and Electra was able to financially benefit by purchasing electricity from wind power generation at a lower price than the unit price of diesel fuel. Based on the power generating performance in 2015, out of Cabo Verde's total power generation (418,992,697kWh), wind power accounted for approximately 20% (78,979,984 kWh).

However, in 2015 and 2016, with the price of crude oil dropping to less than half the peak level, Electra's guarantee to purchase wind power at a fixed price has become a financial burden for it. In other words, Electra is faced with a dilemma in that, whereas it can obtain a certain degree of benefit from purchasing wind power if the price of crude oil increases, the reverse is true when the price of crude oil drops.

Figure 2.1-2 shows movements in the revenue structure of Electra, while Table 2.1.4 shows its profit and loss statement.



Source: JICA Study Team based on Information from Electra

Figure 2.1-2 Movements in the Revenue Structure of Electra

Table 2.1-4 Electra Profit and Loss Statement

(1, 000 CVE)

	2011	2012	2013	2014
Operating Revenue	**7,797,929**	**8,435,405**	**9,913,740**	**10,468,826**
Sales and Services	7,556,626	8,292,593	9,826,800	10,407,644
Electricity Sales	6,383,997	7,132,397	8,039,506	7,876,020
Grid charge	0	0	200,020	311,929
Water and others	1,172,629	1,160,196	1,587,274	2,219,695
Subsidy	236,223	142,147	50,000	0
Revenue from subsidiaries	5,080	665	36,940	61,182
Variable O&M Cost	**-5,941,031**	**-6,368,903**	**-7,284,571**	**-8,096,063**
Combustion Cost	-5,060,263	-5,104,004	-5,877,875	-6,687,316
Power Purchase Cost	-175,000	-899,534	-1,020,145	-1,059,068
Material & Other Cost	-705,768	-365,365	-386,551	-349,679
Other Purchase and external Expenses	-404,961	-409,504	-483,681	-357,292
Gross Profit	**1,451,937**	**1,656,998**	**2,145,488**	**2,015,471**
Fixed O&M Cost				
Personnel Cost	-906,746	-868,430	-532,775	-177,929
Impairment of receivables	-411,432	-426,280	-371,633	-280,220
Other income/losses	-23,237	-14,092	39,151	53,128
EBITDA	110,522	348,196	1,280,231	1,610,451
Depreciation	-842,680	-821,070	-970,331	-984,293
Operating Profit	**-732,158**	**-472,874**	**309,900**	**626,158**
Interest and Finance Cost	**-326,783**	**-350,572**	**-390,643**	**-400,302**
Net Profit	**-1,058,941**	**-823,446**	**-80,743**	**225,856**

Source: JICA Study Team based on Information from Electra

On analyzing the features of Electra's balance sheets for the past five years, the Study Team confirmed that the finances of Electra are in a critical situation.

Table 2.1-5 Electra Balance Sheets

(1,000 CVE)

Items	2010	2011	2012	2013	2014
Assets					
Non-current Assets					
Tangible assets					
Land and natural resources	160,581	168,456	173,596	173,596	173,596
Buildings and other constructions	393,779	270,665	169,179	653,428	608,065
Base Equipment	4,385,427	3,767,249	3,308,198	5,494,376	4,797,100
Transportation equipment	53,711	52,574	42,239	53,835	42,694
Office equipment	26,483	32,005	27,029	10,127	7,904
Other fixed assets tangible	3,433	6,388	5,725	47,257	55,805
Intangible assets	2,021,582	2,026,159	1,971,565	1,886,179	1,820,192
Financial Investment by Equity method	0	10,705	11,370	64,817	126,039
Total Non-current Assets	**7,044,997**	**6,334,200**	**5,708,900**	**8,383,615**	**7,631,395**
Current Assets					
Inventories					
Materials and consumables	748,664	653,539	683,660	691,907	667,923
Customers (Net Receivable)	2,332,055	2,713,384	3,222,037	4,409,804	3,932,147
Advanced payment	282,834	219,265	226,863	21,209	11,191
Other account receivable	353,240	389,741	76,882	3,004,187	148,491
Deferrals	12,943	13,992	5,910	16,603	13,792
Cash and bank deposit	33,952	61,672	61,118	67,566	38,394
Total Current Assets	**3,763,688**	**4,051,593**	**4,276,470**	**8,211,276**	**4,811,938**
Total Assets	**10,808,684**	**10,385,793**	**9,985,370**	**16,594,890**	**12,443,333**
Equity and Liabilities					
Shareholder's Equity					
Equity in capital					
Share capital	600,000	600,000	1,585,262	1,585,262	1,585,262
Supplementary capital and other equity	1,966,740	1,966,740	213,220	263,220	263,220
Share premium			981,478	981,478	981,478
Other reserve	1,817,020	1,817,020	1,817,020	1,817,020	1,817,020
Revaluation of fixed assets	54,803	54,803	54,803	54,803	54,803
Retained earnings brought forward	-2,634,513	-3,679,338	-4,738,279	-5,708,427	-5,789,170
Retained earnings	-1,044,726	-1,058,941	-823,446	-80,743	225,856
Total Equity (before Minority Interest)	**-299,716**	**-299,716**	**-909,942**	**-1,087,387**	**-861,531**
Total Equity	**759,225**	**-299,716**	**-909,942**	**-1,087,387**	**-861,531**
Liabilities					
Non-current liabilities					
Allowances	102,866	98,324	112,414	101,479	81,509
Loans and Financing	4,855,915	3,506,778	5,416,797	9,073,726	8,962,155
Total Non-current liabilities	**4,958,781**	**3,605,102**	**5,529,211**	**9,175,205**	**9,043,664**
Current liability					
Account payable	1,983,160	2,273,103	2,657,692	982,036	940,773
State and other public entities	193,393	279,369	511,132	840,281	1,223,436
Loans and Financing	1,416,597	2,549,003	395,300	275,350	270,772
Other accounts payable	1,172,518	1,687,263	1,543,605	6,179,329	1,624,238
Deferrals	325,010	291,671	258,372	230,076	201,981
Total Current liability	**5,090,678**	**7,080,408**	**5,366,101**	**8,507,071**	**4,261,200**
Total Liabilities	**10,049,460**	**10,685,510**	**10,895,312**	**17,682,276**	**13,304,864**
Total Equity and Liabilities	**10,808,684**	**10,385,793**	**9,985,370**	**16,594,889**	**12,443,333**

Source: JICA Study Team based on Information from Electra

(1) Capital

In fiscal 2012, capital was increased threefold over the previous year to 1,582,262,000 CVE under emergency assistance to counter the financial crisis, however, the negative element in the capital section, e.g. the excess of debts over assets, is fluctuating around the 1-billion-escudo mark.

(2) Liabilities

The amount of loss carried forward was 2,634,513,000 CVE at the end of fiscal 2010. Since then the losses continued to grow and had more than doubled to 5,789,170,000 CVE at the end of fiscal 2014.

Accordingly, the amount of borrowing increased by 33% between 2010 and 2014 to 13,304,864,000 CVE. The increase in long-term borrowing has been especially marked, with the amount increasing more than twofold from 4,855,915,000 CVE in 2010 to 8,962,155,000 CVE in 2015.

The Study Team confirmed the contents and movements of long-term borrowing between fiscal 2013 and 2014 (see the following table).

Table 2.1-6 Movements in Electra's Long-term Borrowing

(1,000 CVE)

		FY 2014	FY 2013
1	Banco Angolano de Investimento	613,954	677,708
	Banco Caboverdiano de Negócios	9,308	55,460
	Total	**623,262**	**733,168**
2	EMPRÉSTIMOS OBRIGACIONISTAS (BOND)		
	Empréstimo B	1,139,698	1,139,698
	Empréstimo C	2,270,249	2,270,249
	Empréstimo D	1,196,451	1,194,633
	Total	4,606,398	4,604,581
3	EMPRÉSTIMOS DO ESTADO (LOAN)		
	Empréstimo de retro cessão - Maio de 2002	42,172	45,654
	Emprestimo de Retro cessão - Dessalinizador Acciona	322,471	322,471
	Emprestimo de Retro cessão - Extensão central Palmarejo	2,653,010	2,653,010
	Emprestimo de Retro cessão - Dessalinizador Uniha	714,843	714,843
	Total	**3,732,496**	**3,735,978**
	Long Term Loan Total	**8,962,155**	**9,073,726**

Source: JICA Study Team based on Information from Electra

Looking at the breakdown of the long-term borrowing, a slight decrease can be seen in borrowing from commercial banks (1). Capital of 781,000,000 CVE was borrowed from Banco Angolano de Investimentos in July 2012 and this is due for repayment by the end of 2022, however, even though this is a long-term loan, the annual interest rate is high at 7%.

Looking at the bonds (2) and government borrowing (3) that account for almost equal shares of the long-term borrowing, there were no repayments or redemption between 2013 and 2014.

In recent years, 1,139,698,000 CVE of 10-year bonds (Empréstimo B) are due for redemption in 2017 (interest 6.65%), however, judging from the balance sheet, Electra does not have the funds to make the necessary repayments. After that, it is due to redeem 1,196,451,000 CVE of 8-year bonds (Empréstimo D) in 2020.

Concerning borrowing, Electra owes the Government of Cabo Verde a total of 3,732,496,000 CVE as sub-loans related to borrowing of funds from the Government of Spain for construction of a water generation plant in Santiago (3,372,052 Euros) and from Japan (JICA) for installation of power generation, transmission and distribution equipment in Santiago (4,468 million yen), however, it does not have the capacity to repay these funds in its current financial condition.

Conditions regarding APP and AEB, which supply power in Sal and Boa Vista respectively, are explained later (2.1.3).

(3) Collection of uncollected tariffs (assets)

Uncollected power tariffs and other accounts receivable were approximately 5,499 million CVE on average over the three years from 2012 to 2014, however, over 70% of this comprised long-term receivables of one year or longer with high risk of non-collection.

A feature of the accounts receivable is that accounts receivable from the central and local governments, and not just private consumers, account for 30% (approximately 1,607 million CVE), and 84% of such accounts (1,345 million CVE) are long-term receivables. Thus, unpaid debts by government agencies are contributing to the financial difficulties of Electra. The following table shows a list of the accounts receivable.

Table 2.1-7 Breakdown of Electricity Tariff Accounts Receivable in Electra

(1,000 CVE)

Household, Private companies					
	2012	2013	2014	Ave. 2012-2014	
Up to 90 days	1,331,272	634,702	(5,479)	653,498	17%
Bet. 91 and 180 days	372,675	300,206	(3,750)	223,044	6%
Bet. 181 days and 1 year	201,436	90,239	(4,499)	95,725	2%
Over 1 year	2,401,338	2,817,468	3,541,983	2,920,263	**75%**
Total	4,306,721	3,842,614	3,528,255	3,892,530	100%

Local authorities, State, Public companies					
	2012	2013	2014	Ave. 2012-2014	
Up to 90 days	328,455	121,189	(2,542)	149,034	9%
Bet. 91 and 180 days	123,554	73,828	(3,078)	64,768	4%
Bet. 181 days and 1 year	108,221	34,870	(244)	47,616	3%
Over 1 year	1,131,627	1,340,405	1,565,158	1,345,730	**84%**
Total Account Receivable	1,691,857	1,570,293	1,559,294	1,607,148	100%

Total					
	2012	2013	2014	Ave. 2012-2014	
Household	3,285,963	2,933,242	2,770,707	2,996,637	54%
Private companies	1,020,757	831,678	757,548	869,994	16%
Local authorities	1,399,344	1,530,978	1,454,874	1,461,732	**27%**
State	232,668	89,598	86,544	136,270	**2%**
Public companies	59,845	27,412	17,876	35,044	**1%**
	5,998,577	5,412,907	5,087,549	5,499,678	100%

Source: JICA Study Team based on Information from Electra

Electra books 10% of these account receivable are impairment losses incapable of recovery every year. It had booked a total of 2,821,673,000 CVE as impairment loss by 2014.

Even if Electra regards approximately 5,000,000,000 CVE trade receivable for electricity supplied to consumers as revenue in each year's settlement, there is no guarantee that this will become cash income; moreover, 10% or approximately 500,000,000 CVE of this amount is treated as bad debt every year. Accordingly, Electra will always be faced with the critical financial situation unless it overcomes the problem of uncollected power tariffs.

Table 2.1-8 Booking of Accounts Receivable as Impairment Losses

(1,000 CVE)

	2012	2013	2014
Household	3,285,963	2,933,242	2,770,707
Private companies	1,020,757	831,678	757,548
Local authorities	1,399,344	1,530,978	1,454,874
State	232,668	89,598	86,544
Public companies	59,845	27,412	17,876
	5,998,577	5,412,907	5,087,549
Adjustment of payable and receivable	(607,783)	(468,922)	(456,860)
Account Balance	5,390,794	4,943,986	4,630,689
Accumulated impairment losses	(2,168,757)	(2,541,221)	(2,821,673)
Customer Related to Group North and South		2,007,040	1,890,215
Other customers (AEB, etc.)			232,915
Total Clients	3,222,037	4,409,805	3,932,147

Source: JICA Study Team based on Information from Electra

2.1.3 Private Power Companies

The only private sector water supply and electric power companies in Cabo Verde conduct operations on the two islands of Boa Vista and Sal. These islands have the most developed hotel and tourism industry in Cabo Verde; they receive a lot of foreign investment and are experiencing rapid growth of both economy and population.

Since there are numerous hotels and other large-scale consumers and the transmission efficiency of medium-voltage power is good on these islands, power sales are high and loss factors are low. They rank second and third behind Santiago, which is home to the capital city Praia, in terms of the scale of power consumption; moreover, per capita power consumption is three times higher than the average in Cabo Verde. Accordingly, also considering the viewpoint of demand density, Boa Vista and Sal represent attractive markets for electric power in Cabo Verde. The private companies supply power and water to all consumers on Boa Vista, and only a certain number of hotels on Sal. The following table shows the scale of electricity demand on the nine islands of Cabo Verde.

Table 2.1-9 Comparison of Electricity Demand on the Nine Islands of Cabo Verde

	Cabo Verde	Santo Antão	S. Vicente	S. Nicolau	Sal	Boa Vista	Maio	Santiago	Fogo	Brava
Population(1,000)	524.8	40.5	81	12.4	33.7	14.5	7	294.1	35.8	5.7
Electricty Consumption (MWh)	276,955	10,136	45,140	5,045	**57,817**	**24,019**	2,027	121,553	9,262	1,956
Consumption Per Capita (kWh)	528	250	557	407	**1,716**	**1,656**	290	413	259	343
Generation Capacity (MW)	222.5	11.00	Electra 38.0 Cabeolica 6.0	7.7	Electra 16.7 APP 5.0 Cabeolica 7.6	AEB 14.1 Cabeolica 2.6	2.2	Electra 91.6 Cabeolica 9.3	9.3	1.4

Note: Generation capacity (diesel generators) is managed entirely by Electra on 7 islands not including Sal and Boa Vista.
Source: JICA Study Team based on Information from Electra, AEB and APP

(1) APP

In Sal, Águas de Ponta Preta (APP), which is a subsidiary of the private water utility company CASSA based in Barcelona, Spain, supplies water and electricity to some of the hotel areas on the south of the island.
It supplies power from a single power station having equipment capacity of approximately 5 MW comprising HFO diesel generators made by Wartsilla (1,540 KW x 2 units). This company also possesses water making equipment with capacity of 1,000 cubic meters per day supplying water to hotel districts. Whereas the diesel generators are made by Wartsilla, it uses three gas oil and diesel generators made by Caterpillar (648 kW each) for water making, but it has plans to replace this equipment with 3,000 kW of new equipment soon in order to respond to the new demand from newly planned hotels.

APP adopts a positive approach to the renewable energy business as may be gathered from its involvement in O&M of a micro grid that has been introduced under funding from the EU, etc. in depopulated areas of Santo Antão (described later in Section 4.3.1 Monte Trigo Photovoltaic Micro-Grid), however, so far it doesn't possess any full-fledged renewable energy equipment such as wind farms and so on.

(2) AEB

On Boa Vista, based on the Government of Cabo Verde's policy of privatization, in 2008 the two Spanish private companies Bucan (water and electricity) and CASSA purchased the water and electricity company Águas e Energia da Boa Vista (AEB) in the ratios of 60% and 40% respectively, while allowing the Government of Cabo Verde the right to purchase back 60% of the company at a later date. Following that, CASSA sold its 40% shareholding to the Spanish enterprise AGBAR.

In March 2016, based on the policy to construct infrastructure for promotion of the tourism industry on Boa Vista, the Government of Cabo Verde repurchased 60% of shares via the tourism promotion organization (SDTIBM), which is financed by the central government and Boa Vista, while Bucan reduced its financing rate to 40% and became a government-owned power company. Moreover,

SDTIBM has the objective of promoting development not only on Boa Vista but also on Maio.
The Study Team held an interview with Mr. Ulisses Santos, the new president of AEB (the company name has remained the same) in May 2016 to confirm the future possibilities for development of the tourism industry. The following paragraphs describe what Mr. Santos had to say.

- ✓ The Government of Cabo Verde was aware of the tourism potential of Boa Vista even before it transferred the power utility to AEB, however, as it deemed it better from the financial and technical viewpoints to consign operations to private Spanish companies, it consigned management to the private sector for roughly eight years from 2008.
- ✓ During this period, the tourism industry of Boa Vista prospered, however, since it became necessary to also comprehensively develop not only power equipment but also environmental and infrastructure facilities related to resort hotels and access roads, it was impossible for the former AEB to do manage all these activities and the power utility by itself.
- ✓ Accordingly, the Government of Cabo Verde purchased AEB with a view to accelerating the speed of tourism promotion based on strengthening capital and negotiating capacity.

When AEB was visited in March 2016, it seemed to be struggling to secure power sources because problems in its diesel generators meant that it was having to purchase wind power even with ratio in excess of 50%, however, when it was visited again in May, it was intending to introduce new diesel generators (1,360 kVA x 4 units) in response to demand. The demand for hotels on Boa Vista fell to one third in the financial crisis following the collapse of Lehman Brothers in 2008, however, it has since recovered and the island's population is expected to increase 1.5 times in the next 15 years. Meanwhile, since wind conditions on the island are also favorable, it is anticipated that growth will be realized in terms of both economy and introduction of renewable energy from now on.

2.1.4 Cabeolica

Cabeolica is a wind power IPP operator of Cabo Verde that was established in 2008 as a public-private partnership (PPP) by the private infrastructure development fund InfraCo Africa, the Government of Cabo Verde and Electra. Investment was also made by the Africa Finance Cooperation (AFC) and an investment fund linked to the Government of Finland, while loans were secured from the European Investment Bank (EIB) and AfDB. The total amount invested was approximately US$78 million, and Cabeolica commenced operation of wind farms with total capacity of 25.5 MW (850kW x 30 units) on four islands of Cabo Verde in 2011.

Following the start of operation, the Cabeolica equipment has operated smoothly and the operator has secured stable profits while attaining its annual operating rates. The following table shows the main operating indicators that are disclosed by Cabeolica.

In 2015, the average wind speed was 9 m/s and generated electric energy was stable at 77,153 MWh (equipment utilization rate: approximately 35%). It can also be seen that revenue-related indicators have been good with the DSCR (debt service coverage ratio) at almost 2% each year. Accordingly, the Cabeolica project is a high-revenue CF structure.

Table 2.1-10 Key Indicators of Cabeolica

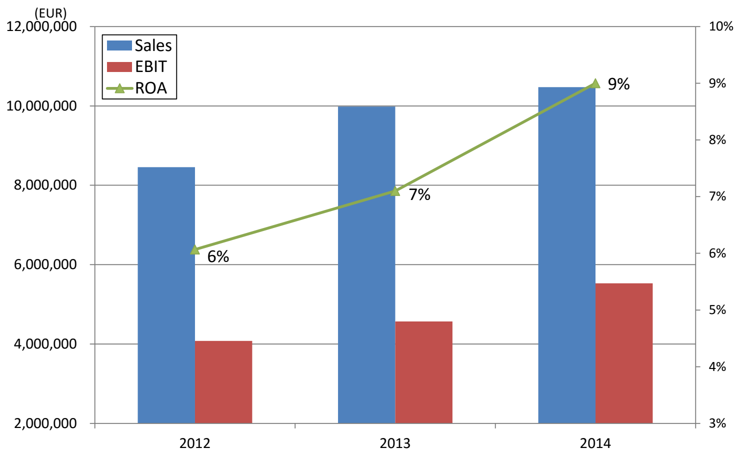
Key Indicators	2015	2014
Electricity Revenues (EUR)	10,516,731	10,474,073
EBIT (EUR)	5,970,272	5,529,729
Profit for the period (EUR)	1,385,453	636,840
Debt to Equity Ratio*	15.7	34.2
Debt Service Coverage Ratio*	1.87	1.74
Average Collection period (days)	65	73
Installed capacity (MW)	25.5	25.5
Production (MWh)	77,153	80,878
Penetration rate (Cabo Verde)	21%	24%
Average wind speed (m/s)	9.0	9.1
CO2 Equivalent avoided (tons)	52,697	54,577
Hours of training	568	428
H&S Hazards (number)	0	0

*Considering only Lenders' Loans

Source: Cabeolica Annual report (website)

Sales, EBIT (earnings before interest and tax) and ROA have increased every year for the past three years (2012-14), and the figures in 2015 also exceeded the previous year. On the other hand, debt servicing is also making good progress.

Moreover, the Cabeolica project made the news when it became the first renewable energy project by a PPP in the Sub-Saharan region to be commended by the Private Infrastructure Development Group (PIDG).



Source: JICA Study Team based on the Cabeolica annual report (website)

Figure 2.1-3 Profitability of Cabeolica

2.2 Energy-related Laws and Regulations

2.2.1 Electricity Business Law Decree (No. 14/2006)

Law Decree No. 14/2006, which partially revised Electricity Business Law Decree No. 54/99 (August 30, 1999), establishes the basic framework concerning the electricity business in Cabo Verde.

This law was enacted with the aim of conducting power supply to all consumers, promoting private sector investment, and establishing a normal degree of market competition for the electricity business, and the basic framework has remained largely unchanged since it was first enacted in 1999. Based on the concession and license systems, this law is intended to maintain a system for sustaining the necessary power supply, conducting supply at reasonable tariffs, and contributing to economic development based on normal market competition not as a government utility but rather as a private sector utility.

As of July 2012, concession operators in the electricity business are Electra, AEB and APP, while IPPs comprise the wind power generation operators of Cabeolica and Electric.
Table 2.2.-1 gives an outline of this law decree.

Table 2.2-1 Outline of Electricity Business Law Decree No. 14/2006

Item	Contents
Enforced date	February 20, 2006
Background	Partial revision of Electricity Business Law Decree No. 54/99 of August 30, 1999
Purpose	To establish the framework for the electricity business, and thereby contribute to economic and social development and environmental conservation.
Concessions	In order to enter the transmission and distribution business, it is necessary to first obtain a concession authorized by the government. (Article 10)
Power consignment	Transmission and distribution operators who have received concessions must consign power if requested by a licensed operator. The regulatory commission (ARE) stipulates the consignment costs. (Article 56)
System operation	System operation, power feed commands, and securing of system stability are conducted under the responsibility of the concession holders in the transmission and distribution systems (Article 54, Article 55) The regulatory commission (ARE) stipulates the Grid Code. (Article 56)
Tariffs	In cases of competitive tender, the outcome will be observed. If there is no competition, tariffs will be set as agreed between the operator and regulatory commission (ARE) based on costs and appropriate profit. (Article 58, Article 59, Article 60) When applying a unified tariff (low-voltage tariff: BT, streetlight tariff: IP, medium-voltage tariff: MT, special-low-voltage tariff: BTE), the regulatory commission (ARE) hold the right to decide the tariff. (Article 66)

Source: Law Decree No. 14/2006

2.2.2 Renewable Energy Law Decree (Law Decree No. 1/2011)

Following Electricity Business Law Decree No. 14/2006, the regulatory foundations for IPPs have been established with the enforcement of Law Decree No. 30/2006 (IPP license regulations), Law Decree No. 18/2006 (IPP license performance guarantee), and Law Decree No. 21/2006 (IPP license tariffs).

In 2011, the Renewable Energy Law Decree (Law Decree No. 1/2011) was issued with the aim of promoting renewable energy. An outline of this is given in Table 2.2-2.

The Renewable Energy Law Decree (Law Decree No. 1/2011) has the objective of compiling a master plan of renewable energy development in consideration of system stability on each island and constructing a renewable energy long-term plan (PESER) that identifies the locations and equipment of renewable energy installations. It is required for the renewable energy long-term plan (PESER) to be compiled based on Cabinet approval only after consent has been given by local governments, the Ministry of Environment and other related stakeholders to ensure that it does not impede the development plans of local governments, and environmental impact assessment has been finished while retaining consistency with environmental conservation policies. Based on this renewable energy long-term plan (PESER) and the renewable energy development plans (ZDER) that are compiled for each area, it is assumed that operating companies will be selected in IPP tender. Based on this, the "Cape Verde 100% Renewable: A Roadmap to 2020" (hereafter referred to as the 100% Renewable Energy Roadmap 2020) was compiled (for details see Section 3).

Table 2.2-2 Outline of Renewable Energy Law Decree (Law Decree No. 1/2011)

Item	Contents
Enforced date	January 3, 2011
Purpose	This stipulates promotion measures and license rules with the aim of promoting renewable energy power generation as an IPP enterprise. (Article 1)
License	Normally an IPP license is required, however, a registration system will be adopted for cases of private power generation of 100 kVA or less, while a basic license will be sufficient to supply to independent micro grids. (Article 4)
Renewable energy Master plan	When the need arises, the DGE will prepare a renewable energy master plan for each island on condition that approval is obtained from the minister upon holding discussions with the concession holder every 5 years. In compiling the master plans, consideration must be given to the future demand forecast, investment plans for the transmission and distribution network and system stability. (Article 9)
Long-term plan (PESER)	The DGE will compile a detailed renewable energy long-term plan (PESER) upon incorporating the opinions of local governments in each development area, the Ministry of Environment, INGRH and the regulatory commission (ARE). In the renewable energy long-term plan (PESER), it is necessary to stipulate the details of power stations, locations of transmission lines, etc. and also conduct environmental impact assessment (EIA) on major items. In the case where the renewable energy long-term plan (PESER) is approved, the EIA can be abbreviated. (Article 10, Article 11)
Tender system	Based on the quotas that are established in the master plan and renewable energy long-term plan (PESER), tenders are implemented to determine the operators every year. (Article 37)
Power purchase price	The purchase price of electricity from renewable energy, which is decided by the regulatory commission (ARE), is fixed for 15 years. (Article 16, Article 17)
Preferential tax measures	Corporation tax is exempted for the first 5 years, limited to 50% between years 6-10, and reduced by 25% between years 11-15. Import tariffs are exempted. (Article 12, Article 13, Article 14)

Source: Law Decree No. 1/2011

Based on Renewable Energy Law Decree No. 1/2011, the renewable energy long-term plan (PESER), which identified the renewable energy development zones (ZDER) for each type of renewable energy, was indicated. The energy potential assessment conducted in the renewable energy development zones (ZDER) is explained in Chapter 7 (wind power generation) and Chapter 8 (solar power generation). Since priority is given to promotion of renewable energy concerning land use in the renewable energy development zones (ZDER), environmental impact assessment (EIA) for renewable energy development is exempted, while depending on height restrictions and distance intervals for general buildings and the types of renewable energy resources involved, it is sometimes prohibited to build general building structures or install underground structures.

The government is currently considering a new IPP system aimed at expanding the share of renewable energy.

2.3 Electricity Tariffs

As was explained in section 2.2 Energy-related Laws and Regulations, the regulatory commission (ARE) determines electricity tariffs and the prices of gasoline and other fuels, i.e. energy prices, as uniform prices for all islands. Table 2.3-1 shows the latest electricity tariffs as of the start of 2016 (applied since December 2015), while Figure 2.3-1 shows movements in electricity tariffs.

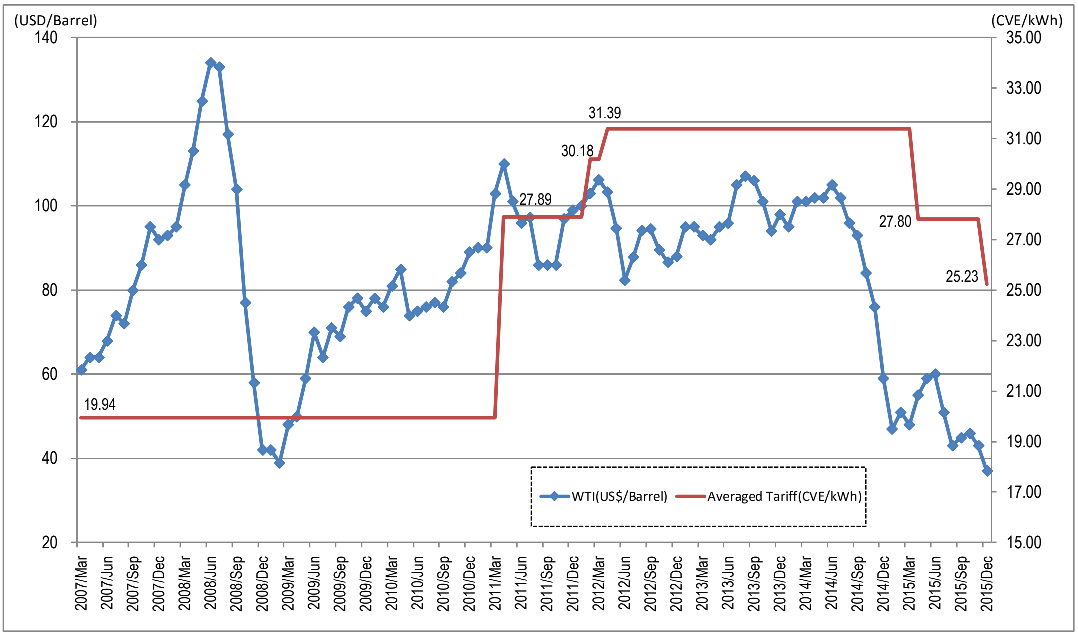
The electricity tariff increased steadily in line with inflation in the price of crude oil up until April 2015, however, it has recently declined in tandem with the falling price of crude in recent months.

Table 2.3-1 Electricity Tariffs (renewed December 10, 2015)

(Unit: CVE/kWh)

Category	Electricity tariff (excluding tax) [a]	Value Added Tax [b]	Electricity tariff (including tax) [a]+[b]
Low-voltage tariff (BT)≦ 60 kWh	23.52	3.53	27.04
Low-voltage tariff (BT)>60 kWh	30.38	4.56	34.93
Street lights (IP)	23.52	3.53	27.04
Business low-voltage (LT)	26.53	3.98	30.50
Business middle-voltage (MT)	22.21	3.33	25.54
Average unit tariff	25.23	3.78	29.02

Source: Electra



Source: JICA Study Team based on materials from Electra, WTI

Figure 2.3-1 Movements in Electricity Tariffs and Price of Crude Oil (WTI) in Cabo Verde (March 2007-December 2015)

The new administration established after the parliamentary elections in March, 2016, submitted a bill of political program “PROGRAMA DO GOVERNO IX LEGISLATURA” from the view point of the 10 years’ reform to Congress. In this bill, new government has showed an ambitious target to reduce the national electricity cost (tariff) by 25%.

According to DGE, this bill has been just approved by the parliament in the end of July, 2016, however the specific measures and action plans will be considered by the government and supervisors in near future. In addition to the tariff reduction campaign, restructuring of Electra will be also taking into account.

2.4 Donors' Support

2.4.1 Status of Support by Country and Donor

Since Cabo Verde was upgraded to a middle-income country, the countries such as the UK, Germany, Denmark and Austria that had supported Cabo Verde have disengaged from full support. The fewer nations still offer active support, including Luxembourg, Portugal, Holland, France and Spain that provides small-scape support.

Among international organizations, the World Bank (WB) is implementing a power-sector recovery & reform project planned for 2012 – 2016, offering a wide-ranged support of physical and non-physical nature, including diesel generator introduction in Santiago and policy support.

EU provided grant assistance between 2008 and 2013 for the micro-grid introduction (combination of small-scale PV and battery) in the unelectrified areas of São Nicolau and San Antão through Community Aid.

The recent support projects that were impactful due to the amount spent and scale were, (1) the Power Generation, Transmission and Distribution Capacity Building Project (2007-2010), which was carried out in Santiago in two stages, and (2) Electricity Transmission and Distribution Network Development Project implemented in Santiago and six other islands, which were made possible thanks to the co-financing by JICA, AfDB and others.

In addition, Dutch ORET worked for the (3) reinforcement of distribution of electricity and improvement of the transmission system in islands such as Santiago and Boa Vista, which was completed in 2016 The latest facility status based on the three transmission/distribution-related projects by JICA, AfDB and ORET is given in Chapter 9 (Transmission and distribution facilities).

2.4.2 Feasibility Study by EU for Renewable Energy Master Plan and Pumped-storage Hydropower

In March 2016, the Study Team interviewed the EU official residing in Cabo Verde. EU was preparing for a feasibility study (FS) which is to start in 2016 for the creation of the renewable energy master plan and the introduction of large-scale pumped-storage hydropower in Santiago (the study period is about one year and the result is to be reported in 2017). It is in an effort to support and enhance the effectiveness of the strategic plan for renewables promotion and energy efficiency improvement in Cabo Verde, which received the national approval in 2015. Reportedly, at present, European Investment Bank (EIB), AfDB and WB are interested in co-financing the seawater pumped-storage hydropower, while EU is considering participating by covering the project risk.

EU recognizes that the urgent task in improving Cabo Verde's attractiveness to the investors in the country's energy sector is to develop appropriate framework for law and for ensuring profit.

2.4.3 Deliberation of CERMI Utilization

Centro para as Energias Renováveis e Manutenção Industrial **(**Centre for Renewable Energy and Industrial Maintenance) (CERMI) was built in Santiago as a place to learn renewable technologies (electrical work, etc.) thanks to the support from Luxembourg. It is a facility exclusively for Cabo Verdean and offers a certificate recognized only in Cabo Verde.

Thus, the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) of the Economic Community of West African States (ECOWAS) is leading the deliberation to upgrade CERMI a facility that serves Cabo Verde people exclusively to the region's certification authority for renewables technologies used widely by 15 West African nations (ECOWAS). Currently, EU agrees to support the effort, and the deliberation is underway with ECOWAS/ECREEE and CERMI to expand the CERMI utilization.

Figure 2.4-1 CERMI

2.4.4 List of Support by Donor

The tables below organize the support provided by donors from various countries in recent years.

Table 2.4-1 Support provided by donors in Cabo Verde in recent years (1/2)

Donor		Project Title	Amount	Approved Year	Execution Period	Outline
JICA	1	The Power Generation, Transmission and Distribution Capacity Building Project **【Same as No.4 & 8】**	JPY 4,468 Million **[Co-financed by AfDB & EBID]**	2008 (Signing of L/A)	2007 - 2010	The purpose of the project is to construct a diesel power plant and transmission and distribution lines in Santiago Island, the most populated island with the capital city of Praia, the center of economic activities of Cape Verde. Upon completion, the project will help stabilize power supply and reinforce access to energy thereby improving the economy and living environment of Cape Verde.
	2	Electricity Transmission and Distribution Network Development Project **【Same as No.5】**	JPY 6,186 Million **[Co-financed by AfDB]**	2012 (Signing of L/A)	2012 - 2017	The project aims to stabilize power supply and improve access to electricity on 6 islands by implementing new installation, enhancements and update works on their transmission and distribution lines. The project is expected to help improve the country's living environment as well as contribute to the vitalization of its economy.
European Union	3	Energy Supply program in Tarrafal and Monte Trigo Santo Antão	EUR 11 Million	2007	2008 - 2013	The project of Manuel Lopes / Tarrafal of Monte Trigo Power Line aims to connect Tarrafal of Monte Trigo to the public grid managed by Electra SA and is a part of the SESAM-ER project (Sustainable Energy Services for isolated villages, by Renewable Energy micro-grids). This project will provide power energy 24 hours/day to the population, a greater absorption capacity of the long term energy growth demand, as well as the integration of Tarrafal of Monte Trigo on the public power grid of the Island of Santo Antão.
African Development Bank (AfDB)	4	Santiago Production Capacity and Distribution Network Strengthening Project **【Same as No.1 & 8】**	USD 8.12 Million **[Co-financed by JICA & EBID]**	2008	2007 - 2010	The purpose of the project is to construct a diesel power plant and transmission and distribution lines in Santiago Island, the most populated island with the capital city of Praia, the center of economic activities of Cape Verde. Upon completion, the project will help stabilize power supply and reinforce access to energy thereby improving the economy and living environment of Cape Verde.
	5	Cape Verde Electricity Transmission and Distribution Network Development Project **【Same as No.2】**	USD 13.48 Million **[Co-financed by JICA]**	2012	2012 - 2017	The project aims to stabilize power supply and improve access to electricity on 6 islands by implementing new installation, enhancements and update works on their transmission and distribution lines. The project is expected to help improve the country's living environment as well as contribute to the vitalization of its economy.
	6	Cape Verde Wind Farm Project - Cabeolica (28MW) **【Same as No.7】**	EUR 15 Million **[Co-financed by EIB]**	2010	2010 - 2011	The project will introduce modern wind power technology provided by Vestas to enable wind power to be established as the primary alternative to electricity produced by fuel oil or diesel. Alongside significantly reducing greenhouse gas emissions.

Source: JICA Study Team based on donor websites and published information

Table 2.4-2 Support provided by donors in Cabo Verde in recent years (2/2)

Donor	Project Title		Amount	Approved Year	Execution Period	Outline
European Investment Bank (EIB)	7	Cape Verde Wind Farm Project - Cabeolica (28MW) **【Same as No.6】**	EUR 30 Million **[Co-financed by AfDB]**	2010	2010 - 2011	The project will introduce modern wind power technology provided by Vestas to enable wind power to be established as the primary alternative to electricity produced by fuel oil or diesel. Alongside significantly reducing greenhouse gas emissions.
ECOWAS Bank for Investment and Development (EBID)	8	Reinforcement of distribution of electricity and improvement of the transmission system **【Same as No.1 & 4】**	EUR 10.6 Million **[Co-financed by JICA & AfDB]**	2008	2007 - 2011	The purpose of the project is to construct a diesel power plant and transmission and distribution lines in Santiago Island, the most populated island with the capital city of Praia, the center of economic activities of Cape Verde. Upon completion, the project will help stabilize power supply and reinforce access to energy thereby improving the economy and living environment of Cape Verde.
	9	Upgrading of production and distribution of electricity in Santo Atao, Fogo, Sao Nicolau and Boavista project in Cape Verde	USD 5.0 Million	2012	Details not confirmed	Details not confirmed
International Bank for Reconstruction and Development (IBRD) [World Bank Group]	10	Reform of the Energy Sector in Cape Verde (Recovery and Reform of the Electricity Sector Project)	EUR 40.2 Million	2012	2012 - 2016	The objectives of the project are to increase electricity generation in the Islands of Sao Vicente and Santiago and to assist ELECTRA to reduce electricity losses on Santiago Island. The investment component of the project would focus on priority investments, notably extension of Palmarejo Power Plant in Praia, extension of Lazareto Power Plant in Mindelo, additional water storage capacity in Palmarejo through the construction and installation of two water storage reservoirs and related interconnecting pipes at the Palmarejo Power Plant.
OPEC Fund for International Development (OFID)	11	Reinforcement of distribution of electricity and improvement of the transmission system **【Same as No.12】**	USD 12.5 Million **[Co-financed by ORET]**	2007	Completed	Construction of four new power plants on the island of Santo Antão, Fogo, São Nicolau and Boavista, installation of four new groups of 1.5 MW each in Santo Antão and Fogo and 1 MW in São Nicolau and Boavista. The project also includes the financing and construction of 164 km of 20 KV transmission line, of which 55 km in Santo Antão, 32 km in Fogo, 54 km in São Nicolau and 23 km Boavista.
Dutch Government (ORET Program)	12	Reinforcement of distribution of electricity and improvement of the transmission system **【Same as No.11】**	USD 12.5 Million **[Co-financed by OFID]**	2007	Completed	Construction of four new power plants on the island of Santo Antão, Fogo, São Nicolau and Boavista, installation of four new groups of 1.5 MW each in Santo Antão and Fogo and 1 MW in São Nicolau and Boavista. The project also includes the financing and construction of 164 km of 20 KV transmission line, of which 55 km in Santo Antão, 32 km in Fogo, 54 km in São Nicolau and 23 km Boavista.
						Santo Antão Diesel Power Plants (1600kW)x2 commissioning year:2015 donor: budget: 5,3 Mil l ion Euro Fogo Diesel Power Plant (1250kW)x2 commissioning year:2015 donor: budget: 5 Million Euro Sao Nicolau Diesel Power Plants (1000kW)x1 commissioning year:2015 donor: budget: 3 Million Euro

Source: JICA Study Team based on donor websites and published information

3. Cabo Verde 100% Renewable: A Roadmap to 2020

In 2011, Cabo Verde set a goal to increase the domestically procurable renewables to 50% of the nation's power sources by 2020. The same year, an ordinance was issued for the promotion of renewables. Following year in 2012 Rio＋20 conference, President Fonseca gave a speech stating the nation's aim to go 100% renewable by 2020, and in 2013, "Cape Verde 100% Renewable: A Roadmap to 2020," a roadmap toward achieving the plan, was created (hereafter "100% Renewable Roadmap 2020). The 100% Renewable Roadmap 2020 was created by Trier University of Applied Sciences, Institute for Applied Material Flow Management, Germany.

3.1 Issues of the Renewable Roadmap

For the Study, JICA Study Team organized the characteristics and issues of the existing Renewable Roadmap 2020 in the table below for reference, in order to calculate the possible renewable introduction in Cabo Verde and to examine specific promotional measures.

Care must be given to the evaluation of feasibility and cost, since it includes a future power storage technology. Caution must be practiced not to confuse the facility introduction with purpose, since the implementation cost turned out to be huge once it was summed up.

Table 3.1-1 Issues of the 100% Renewable Roadmap 2020

	Characteristics of the Existing Roadmap	Issues/response policy
Examination policy	・ Proposed the composition of renewable, battery and large-capacity power storage facilities that satisfies 100% of the demand in 2020 with renewables, and estimated cost of 1.27 billion EUR	・ The Roadmap fails to show steps to take each year. It is necessary to propose a phase-by-phase renewable facility introduction plan based on Cabo Verde's power demand forecast, power source development & grid plans.
Renewable facility	・ Examination of renewable facilities was limited to wind and PV.	・ The Study considers wind and PV as the main sources, but will not deny the possibility of other renewables.
Power storage	・ Proposed seawater pumped-storage hydro and methanation (demand expansion potential mentioned, e.g. gas for household use) for large-capacity power storage. ・ Set the battery capacity as: 50% of the island's peak load × 8-hour discharge, and seawater pumped-storage hydro and methanation capacity as: 100% of the island's peal load × 1.5-day discharge (basis for the decision unknown). ・ Planned to compensate for short-cycle fluctuation with battery charge/discharge capacity above.	・ The methanation is not in the stage of economic efficiency; thus it will be positioned as a future technology. The examination will address batteries that have successful record worldwide. Both seawater and freshwater pumped-storage will be considered. ・ The optimal capacity will be calculated to minimize the battery cost. ・ ・Short-cycle fluctuations can be absorbed by the battery capable of absorbing long-cycle fluctuations. However, the battery capacity can be reduced if controlling short-cycle fluctuations only. The optimal combination of batteries will be examined while confirming the rules for system operation.
Transmission /substation facility	・ The examination of grid reinforcement is limited to that to meet the increase in power demand.	・ Understand the current grid status and examine grid stabilization from the reinforcement perspective.
Power demand	・ Corrected the 2012 hourly load curve of the islands (for the year) to the 2020 demand forecast cross- section (forecasted by GESTO in 2011).	・ The examination will be done using the method in the left column as a rule. The latest data will be used for the daily load curve as much as possible.
Weather data	・ Used data from the existing wind farms for wind condition and those from the meteorological observation points for the insolation intensity.	・ Contrive ways such as substituting wind condition and insolation intensity data from nearby islands for islands for which measurement is not taken.
Assumption of Calculation	・ There are specs for diesel, serving as a reference when examining the renewable facility and battery. ・ Did not examine battery types.	・ Examine details and scales, etc. of the measures while paying attention to funding procurement, on the premises that the measures will contribute to the renewable facility expansion and grid stability in Cabo Verde.

Source: JICA Study Team

Table 3.1-2 Cost to implement the 100% Renewable Roadmap 2020

Islands	Max Demand (MW)	Solar Capacity (MWh)	Solar Cost (Mil.€)	Wind Capacity (MWh)	Wind Cost (Mil.€)	Battery Capacity (MWh)	Battery Cost (Mil.€)	Pump Storage Hydro Capacity (MWh)	Pump Storage Hydro Cost (Mil.€)	Capacity Total (Mil.€)	Generation Cost (€ Ct./kWh)
Santo Antão	6	12	14.4	3	5.1	3	5.4	250	11.0	35.9	15.1
São Vicente	20	64	76.8	16	27.2	10	18.0	900	38.0	160.0	14.63
São Nicolau	2	3	3.6	2	3.4	1	1.8	70	3.4	12.2	19.09
Sal	20	36	43.2	24	40.8	9	16.2	2,100	62.0	162.2	18.44
Boa Vista	18	42	50.4	28	47.6	9	16.2	1,600	50.0	164.2	16.96
Maio	3	10	12.0	3	5.1	1	1.8	280	8.6	27.5	20.78
Santiago	60	168	201.6	112	190.4	30	54.0	7,700	214.0	660.0	21.18
Fogo	4	10	12.0	7	11.9	2	3.6	550	15.0	42.5	20.86
Brava	1	2	2.4	1	1.7	1	1.8	70	2.4	8.3	21.23
Total	–	347	416.4	196	333.2	66	118.8	13,520	404.4	**1,272.8**	**18.91**

Source: prepared by the Study Team based on the "Cabo Verde 100% Renewable: A Roadmap to 2020"

After the parliamentary election on March 20, 2016, the Movimento para a Democracia (Movement for Democracy) (MpD), a right-center party, singly won the majority of seats, replacing the left-centered Partido Africano da Independência de Cabo Verde (African Party of Independence of Cabo Verde) (PAICV) and forming a stable administration. MpD's manifest lists the restoration of sound management by promoting private investment in Electra and the expansion of streetlights in the energy field. However, the manifest did not particularly mention renewables.

The 15 ministries have been consolidated into 12, and the jurisdiction over energy has been transferred to the Ministério da Economia e Emprego.

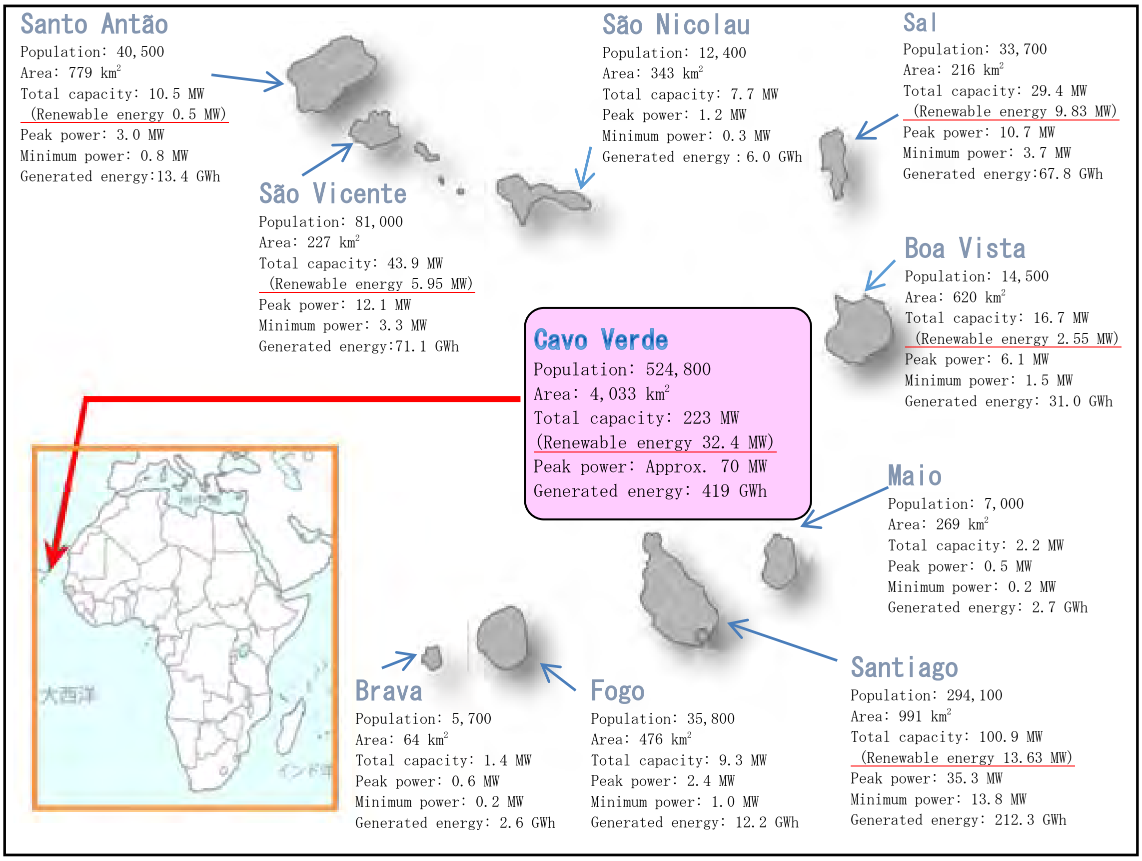
After the change of administration, it was decided to review the existing Renewable Roadmap. DGE plans to create a new Renewable Roadmap based on the renewable energy master plan that EU is preparing for and the result of the tentative calculation of renewable energy (wind and PV) potentials which will be offered to Cabo Verde as part of the findings of the Study.

According to DGE, the Cabo Verde government have declared the goal to go 100% renewable by the target year of 2020, however, after the aforementioned 2016 parliamentary election; it has been dropped and these target share and year have been started to reconsidered not to be such specific ones.

4. Power Demand and Supply Situation

4.1 Demand and Supply Situation

The demand and supply conditions for the entire country (all islands) and each island have been summarized based on the 2015 demand and supply data from Electra, AEB, APP and Cabeolica. Moreover, in Cabo Verde, power transmission and distribution equipment and power plants are being constructed to enable power supply from one power plant per island based on assistance from JICA and the Netherlands (ORET). This construction of power transmission and distribution equipment and power plants by JICA and ORET is scheduled to be completed soon, however, it should be remembered that the data and so on that were surveyed and obtained here apply to a period characterized by transition from old power stations to new power stations, power stoppages for implementation of power transmission and distribution equipment work, and advancement of interconnection between non-synchronized areas and to off-grid areas.

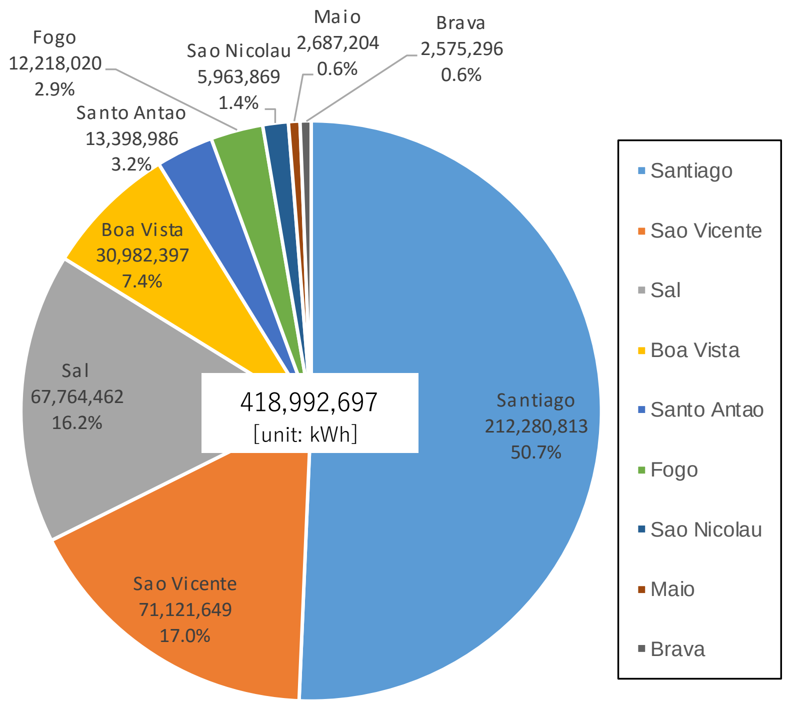


Source: JICA Study Team based on Information from Electra, AEB, INE, etc.

Figure 4.1-1 Overview of Each Island in Cabo Verde (2015)

4.1.1 All Nine Inhabited Islands of Cabo Verde

The generated energy of Cabo Verde in 2015 was 408 GWh, of which more than half was conducted in Santiago. The four islands of Santiago, São Vicente, Sal and Boa Vista accounted for 90% of the total. Figure 4.1-2 shows the generated energy of each island in Cabo Verde in 2015.



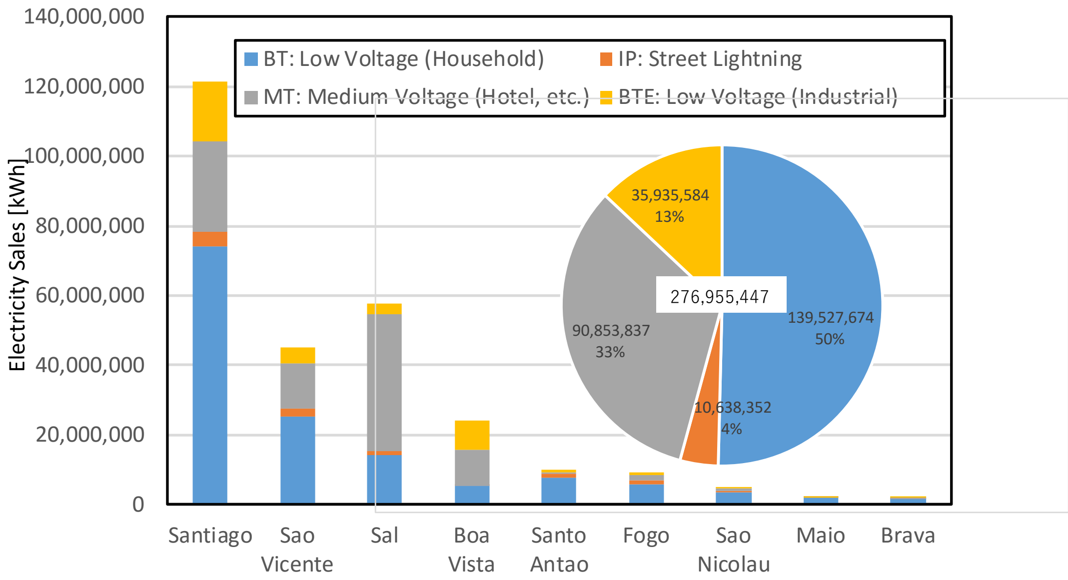
Note: Sal includes the Electra and APP generated energy.

Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-2 Island-separate Generated Energy in Cabo Verde (2015)

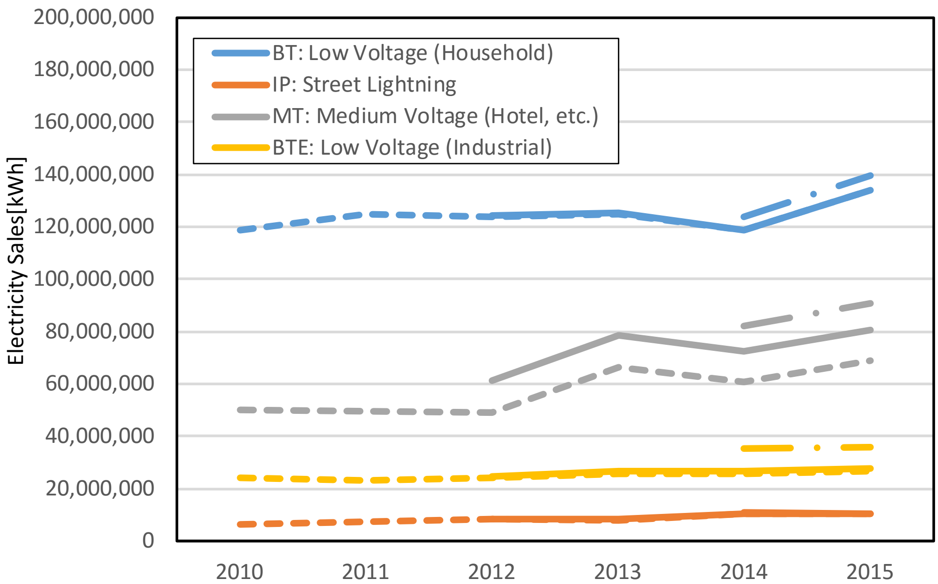
Figure 4.1-3 shows the electricity sales in Cabo Verde in 2015. Low-voltage household sales account for approximately half, while medium voltage sales to large consumers account for a large share of approximately 30% of the total on the four main island, where hotels and tourism are relatively popular. In particular, tourism is expected to grow even more on Sal and Boa Vista, so the securing of supply sources that can meet demand is also important in Cabo Verde.

These electricity sales do not include power consumed by the Electra and AEB power stations and seawater desalination systems. The power loss after deducting the 2015 Electra and AEB power consumption of 42 GWh (estimate value) is approximately 25%. Until now Electra has not measured or recorded technical losses and non-technical losses, however, in future when power transmission and distribution equipment have been constructed by JICA, ORET and so on, it will be urgently necessary to investigate and address the causes of loss.



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-3 Cabo Verde Electricity Sales (2015)



Note: Three divisions were adopted because not all data could be obtained for 2010 and after. Staggered lines indicate Electra only, while solid lines denote Electra and APP (supply of electricity to part of Sal). The lines of alternate long and short dashes denote Electra, APP and AEB (supply of electricity to Boa Vista).

Source: JICA Study Team based on Information from Electra, etc.

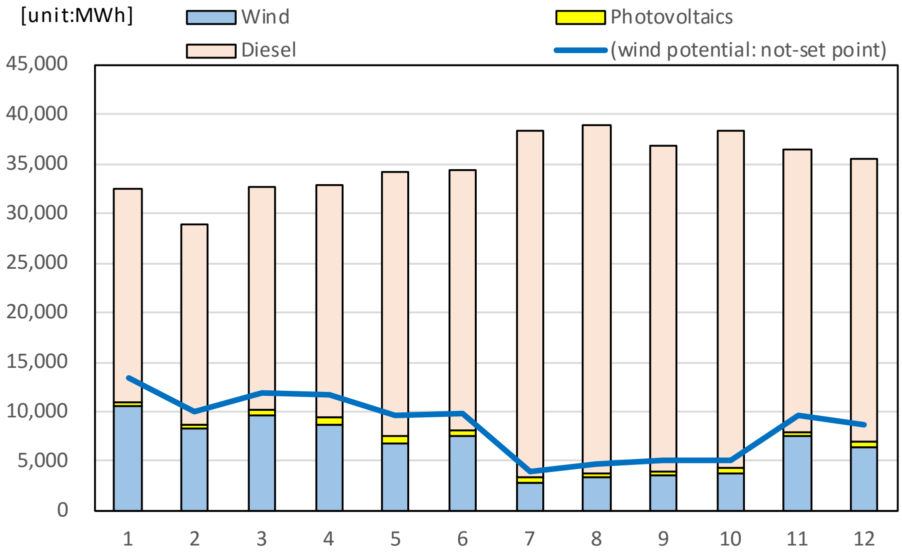
Figure 4.1-4 Movements in Electricity Sales by Type of Power Tariff in Cabo Verde

Figure 4.1-5 shows the monthly generated energy of Cabo Verde in 2015. The demand for power is large during the tourism season from July to October, while it is relatively low from January to March. Out of generated energy, the blue colored part denotes wind power. Wind power is described in detail in Chapter 7, however, wind power generation equipment of Cabeolica IPP is installed on Santiago, São Vicente, Sal and Boa Vista, while wind power generation equipment of the IPP of ELECTRIC is installed on Santo Antão.

The yellow portion indicates generated energy from the mega solar systems owned by Electra. Solar power generation is described in Chapter 8, however, mega solar systems are installed on Santiago and Sal.

The amount of generated energy from renewable energy equipment is approximately 35% during periods of favorable wind conditions, for example, January 2015. Electra implements output suppression on Cabeolica wind IPP in order to secure system stability, and utilization of this limited energy is also considered when examining ways to improve the renewable energy ratio. The solid lines in the figure show theoretical output in the case where existing wind power output is not suppressed. In January, when wind conditions are favorable, there is enough equipment capacity to meet approximately 44% of the power demand of Cabo Verde.

On the other hand, wind conditions are not so favorable between July and October when the power demand is relatively high. Since wind power supply capacity in Cabo Verde has a seasonally mismatch of supply capacity and demand, it is essential to have hybrid systems that combine wind, solar and diesel power.



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-5 Monthly Generated Energy in Cabo Verde (2015)

Table 4.1-1 Monthly Demand and Supply Situation in Cabo Verde (2015)

	Item	unit	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	2015
a	Capacity Total (b+d)	[kW]	178,623		189,663	212,431		215,775				219,119	222,533		222,533
b	Diesel [Installed capacity]	[kW]	146,203		157,243	180,011		183,355				186,699	190,113		190,113
c	Diesel [Available output]	[kW]	119,904		130,558	153,022		156,366				159,230	161,510		161,510
d'	Wind	[kW]	26,000												26,000
d''	Photovoltaics	[kW]	6,420												6,420
e	Diesel	[kWh]	21,458,248	20,113,670	22,509,778	23,503,703	26,575,896	26,337,937	34,936,698	35,096,506	32,816,580	34,074,348	28,444,803	28,555,806	334,423,973
f	Wind	[kWh]	10,533,023	8,220,964	9,581,606	8,647,241	6,827,809	7,510,676	2,850,852	3,454,855	3,661,392	3,829,507	7,523,707	6,338,352	78,979,984
g	(wind potential: not-set point)	[kWh]	(13,321,227)	(9,939,549)	(11,857,889)	(11,623,817)	(9,546,544)	(9,771,306)	(3,911,967)	(4,701,045)	(5,069,566)	(5,000,298)	(9,561,046)	(8,748,885)	(103,053,140)
h	Photovoltaics	[kWh]	460,682	492,913	659,103	731,036	768,180	541,006	534,282	276,610	282,004	415,367	411,598	547,741	6,120,522
i	sub total (e+f+h)	[kWh]	32,411,605	28,773,262	32,684,740	32,853,896	34,137,714	34,315,738	38,277,215	38,785,249	36,721,957	38,271,635	36,350,238	35,409,448	418,992,697
j	ELECTRA/AEB house-use	[kWh]	3,754,870	3,520,654	4,068,335	4,075,127	4,157,109	4,129,691	4,913,630	4,941,803	4,500,180	4,699,658	4,306,876	4,300,060	51,367,992
k	ELECTRA/AEB house-use rate (j/i)	[%]	11.6%	12.2%	12.4%	12.4%	12.2%	12.0%	12.8%	12.7%	12.3%	12.3%	11.8%	12.1%	12.3%
l	Tech and non-Tech Loss (n-i-j)	[kWh]	7,450,792	5,998,096	8,536,120	7,464,289	8,931,735	7,961,999	8,105,398	8,431,782	7,609,240	7,150,485	5,507,025	7,522,296	90,669,257
m	Tech and non-Tech Loss rate (l/i)	[%]	23.0%	20.8%	26.1%	22.7%	26.2%	23.2%	21.2%	21.7%	20.7%	18.7%	15.1%	21.2%	21.6%
n	Sales	[kWh]	21,205,943	19,254,512	20,080,285	21,314,481	21,048,871	22,224,048	25,258,187	25,411,664	24,612,537	26,421,492	26,536,338	23,587,091	276,955,447

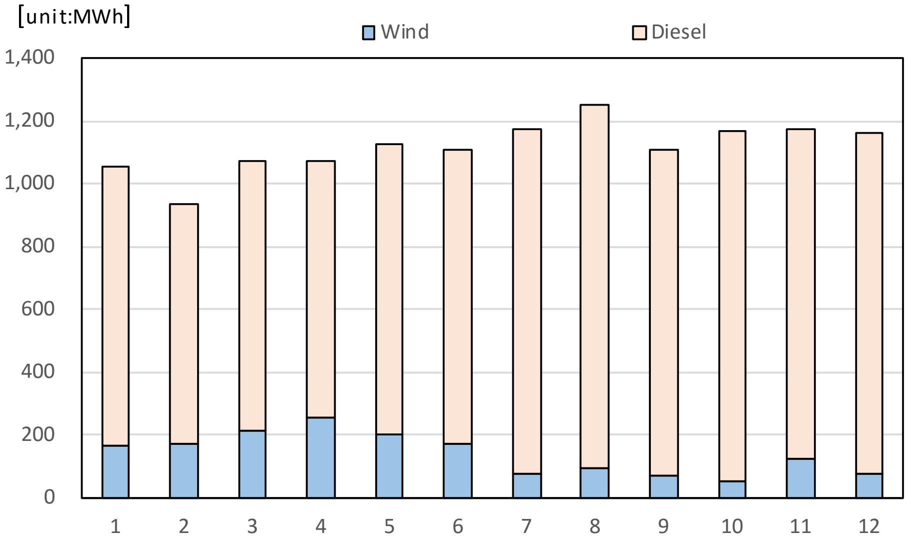
Source: JICA Study Team based on Information from Electra, AEB, APP, Cabeolica

4.1.2 Santo Antão

Santo Antão has an area of 779km^2 and a population of 40,500 as of 2015. Figure 4.1-6 shows the monthly generated energy of Santo Antão in 2015. The annual generated energy is 13 GWh, of which a wind power IPP accounts for 1.7 GWh (renewable energy ratio 12.6%). Incidentally, the wind power generation does not have any particular kind of output suppressing function for conducting network stabilization. Wind power generation is described in greater detail in Chapter 7.

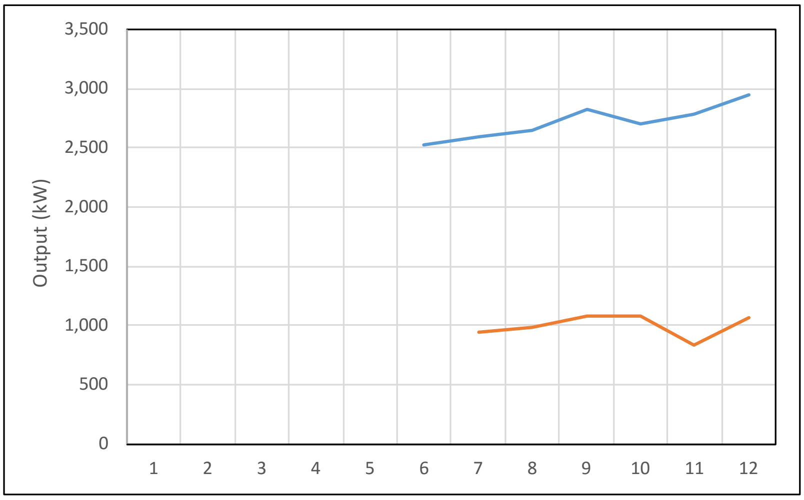
Construction of one power station per island is being advanced under a project by JICA and ORET. On Santo Antão, power supply on the island was started from the New Port Novo power station in July 2015. Now that the scale of network demand has become larger following the inter-connection of demand areas, examination is being directed towards expanding electric wind power generation.

JICA Study Team requested Electra to provide daily load curve data, however, since this was not received in time for this report, only a rough examination is conducted. Moreover, according to the monthly report of power generation performance since July when New Port Novo power station commenced operation, peak demand (annual peak approximately 3 MW) occurred at around 20:00 on December 31 while minimum demand (annual minimum approximately 1 MW) occurred around 15:00 on November 26 (see Figure 4.1-7).



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-6 Monthly Generated Energy on Santo Antão



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-7 Movements in Monthly Maximum/Minimum Demand

Table 4.1-2 Monthly Demand and Supply Situation on Santo Antão (2015)

	Item	unit	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	2015	2014	2013
a	Capacity Total (b+d)	[kW]	7,688					11,032							11,032		
b	Diesel [Installed capacity]	[kW]	7,188					10,532							10,532		
c	Diesel [Available output]	[kW]	6,924					10,268							10,268		
d	Wind	[kW]	500												500	500	500
e	Diesel	[kWh]	884,009	763,117	854,483	814,958	924,235	935,403	1,099,689	1,153,664	1,034,575	1,113,617	1,047,096	1,087,036	11,711,882	10,742,505	12,529,991
f	Wind	[kWh]	169,464	170,927	216,157	254,742	202,107	169,909	76,745	96,438	72,553	56,122	126,238	75,702	1,687,104	1,737,011	1,131,061
g	(wind potential: not-set point)	[kWh]															
h	Photovoltaics	[kWh]															
i	sub total (e+f+h)	[kWh]	1,053,473	934,044	1,070,640	1,069,700	1,126,342	1,105,312	1,176,434	1,250,102	1,107,128	1,169,739	1,173,334	1,162,738	13,398,986	12,479,516	13,661,052
j	ELECTRA house-use	[kWh]	13,134 *	11,645 *	13,348 *	13,337 *	14,043 *	13,781 *	14,667 *	15,586 *	13,803 *	14,584 *	14,629 *	14,497 *	167,055	14,402	15,655
k	ELECTRA house-use rate (j/i)	[%]	1.2% *	1.2% *	1.2% *	1.2% *	1.2% *	1.2% *	1.2% *	1.2% *	1.2% *	1.2% *	1.2% *	1.2% *	1.2%	0.1%	0.1%
l	Tech and non-Tech Loss (n-i-j)	[kWh]	164,887	123,133	318,907	235,304	280,008	264,629	310,487	324,772	243,148	261,331	306,677	262,943	3,096,224	2,241,472	3,217,981
m	Tech and non-Tech Loss rate (l/i)	[%]	15.7%	13.2%	29.8%	22.0%	24.9%	23.9%	26.4%	26.0%	22.0%	22.3%	26.1%	22.6%	23.1%	18.0%	23.6%
n	Sales	[kWh]	875,452	799,266	738,385	821,059	832,291	826,902	851,280	909,744	850,177	893,824	852,028	885,299	10,135,707	10,223,642	10,427,416
o	Pmax	[kW]						2,520	2,595	2,642	2,831	2,705	2,782	2,950	2,950		
p	date & time	–						25 20:35	23 20:45	15 20:25	17 20:35	26 20:30	15 20:00	31 20:35	31 20:35		
q	Pmin	[kW]							950	985	1,085	1,082	842	1,063	842		
r	date & time	–							5 06:20	15 07:15	6 06:15	25 03:30	26 03:30	23 04:30	26 03:30		

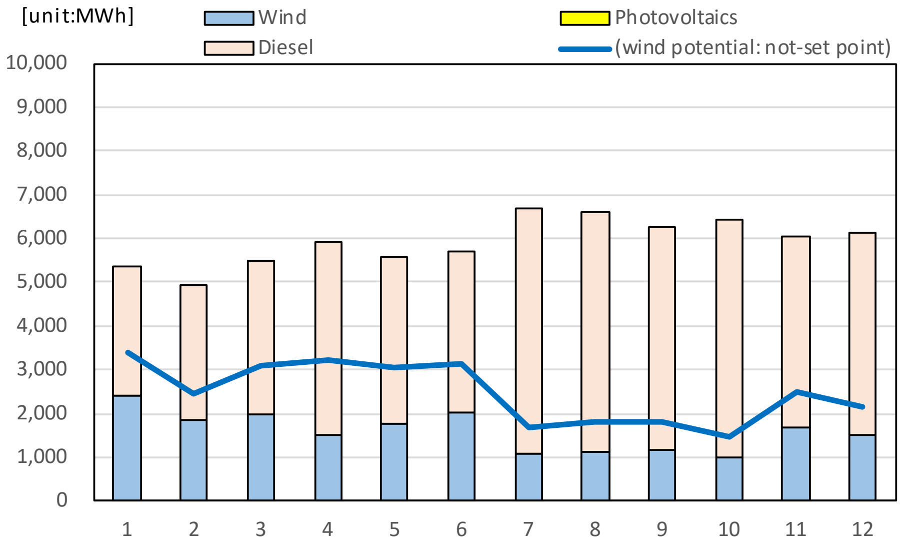
*In-station power for each month is calculated using the in-station ratios for 2015.
Source: JICA Study Team based on Information from Electra, etc.

4.1.3 São Vicente

São Vicente has an area of 227km^2, and a population of 81,000 as of 2015. Figure 4.1-8 shows the monthly generated energy of São Vicente in 2015. The annual generated energy is 71 GWh, of which Cabeolica wind power IPP accounts for 19 GWh (renewable energy ratio 26.7%). Out of the Electra in-station power consumption, 7.8 GWh is used for water manufacture and supply pumps.

The amount of generated energy from renewable energy equipment is approximately 45% during periods of favorable wind conditions, for example, January 2015. Electra implements output suppression on Cabeolica wind IPP in order to secure system stability. If no such output suppression were implemented, this IPP has the potential to provide approximately 63% of energy.

On the other hand, on São Vicente too, wind conditions tend to become weaker between July and October when the demand for power is high.



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-8 Monthly Generated Energy on São Vicente

Table 4.1-3 Monthly Demand and Supply Situation on São Vicente (2015)

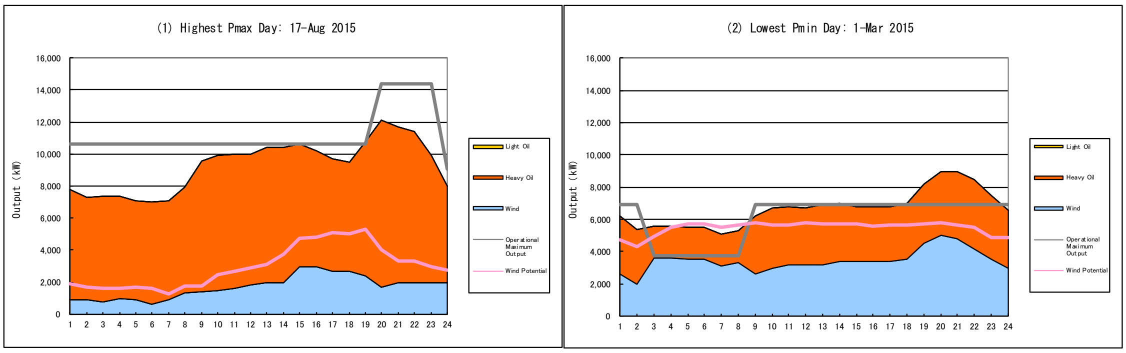
	Item	unit	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	2015	2014	2013
a	Capacity Total (b+d)	[kW]	32,905		43,945										43,945		
b	Diesel [Installed capacity]	[kW]	26,955		37,995										37,995		
c	Diesel [Available output]	[kW]	25,898		36,552										36,552		
d	Wind	[kW]	5,950												5,950		
e	Diesel	[kWh]	2,934,400	3,090,183	3,538,356	4,405,930	3,819,827	3,696,289	5,597,529	5,465,824	5,099,439	5,441,433	4,363,465	4,624,325	52,076,999	67,570,039	66,089,474
f	Wind	[kWh]	2,414,530	1,840,280	1,963,090	1,497,530	1,749,230	2,024,880	1,083,620	1,134,790	1,148,950	983,770	1,693,920	1,510,060	19,044,650		
g	(wind potential: not-set point)	[kWh]	(3,383,361)	(2,449,377)	(3,086,726)	(3,231,268)	(3,053,823)	(3,153,585)	(1,669,892)	(1,820,233)	(1,813,396)	(1,453,427)	(2,508,007)	(2,147,924)	(29,771,021)		
h	Photovoltaics	[kWh]															
i	sub total (e+f+h)	[kWh]	5,348,930	4,930,463	5,501,446	5,903,460	5,569,057	5,721,169	6,681,149	6,600,614	6,248,389	6,425,203	6,057,385	6,134,385	71,121,649	67,570,039	66,089,474
j	ELECTRA house-use	[kWh]	1,051,121 *	968,888 *	1,081,092 *	1,160,092 *	1,094,378 *	1,124,270 *	1,312,916 *	1,297,090 *	1,227,874 *	1,262,620 *	1,190,340 *	1,205,471 *	10233679	9,983,591	8,809,242
k	ELECTRA house-use rate (j/i)	[%]	19.7% *	19.7% *	19.7% *	19.7% *	19.7% *	19.7% *	19.7% *	19.7% *	19.7% *	19.7% *	19.7% *	19.7% *	19.7%	14.8%	13.3%
l	Tech and non-Tech Loss (n-i-j)	[kWh]	742,219	751,269	1,231,059	1,481,133	1,298,514	1,086,627	1,569,589	728,829	852,758	860,549	472,977	930,157	15,748,153	16,459,693	13,676,404
m	Tech and non-Tech Loss rate (l/i)	[%]	13.9%	15.2%	22.4%	25.1%	23.3%	19.0%	23.5%	11.0%	13.6%	13.4%	7.8%	15.2%	22.1%	24.4%	20.7%
n	Sales	[kWh]	3,555,590	3,210,306	3,189,295	3,262,235	3,176,165	3,510,272	3,798,644	4,574,695	4,167,756	4,302,034	4,394,068	3,998,757	45,139,817	41,126,755	43,603,828
o	Pmax	[kW]	10,400	10,600	10,500	no data	10,400	11,000	12,100	12,100	12,100	no data	11,900	11,400	12,100		
p	date & time	–	15 20:00	16 20:00	25 20:00	no data	11 20:00	5 14:00	15 21:00	17 20:00	17 20:00	no data	8 20:00	2 19:00	15 21:00		
q	Pmin	[kW]	5,100	5,400	5,100	no data	5,200	5,400	6,100	6,300	6,300	no data	6,000	5,700	5,100		
r	date & time	–	11 07:00	7 01:00	1 07:00	no data	10 07:00	2 05:00	12 06:00	30 07:00	30 04:00	no data	5 07:00	13 07:00	11 07:00		

*In-station power for each month is calculated using the in-station ratios for 2015.

Source: JICA Study Team based on Information from Electra, etc.

In 2015, peak demand on São Vicente was 12 MW (20:00 on August 17) and minimum demand was 5 MW (07:00 on March 1). Demand starts increasing from early morning and peaks around 20:00, and then it falls from late night to early next morning.

On São Vicente, wind conditions around the Cabeolica windmill are favorable, and output suppression of wind power generation is appropriately conducted as shown in the daily load curve in Figure 4.1-9. This suppressed power in 2015 was estimated to be 10.7 GWh from the data of wind conditions. It may be possible to reduce fuel costs in diesel power generation through expanding the reduction of minimum diesel power operation, revising the sale price of power in excess of the Take or Pay quota of PPA, effectively utilizing storage batteries to secure network stability and so on.



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-9 Daily Load Curve for São Vicente

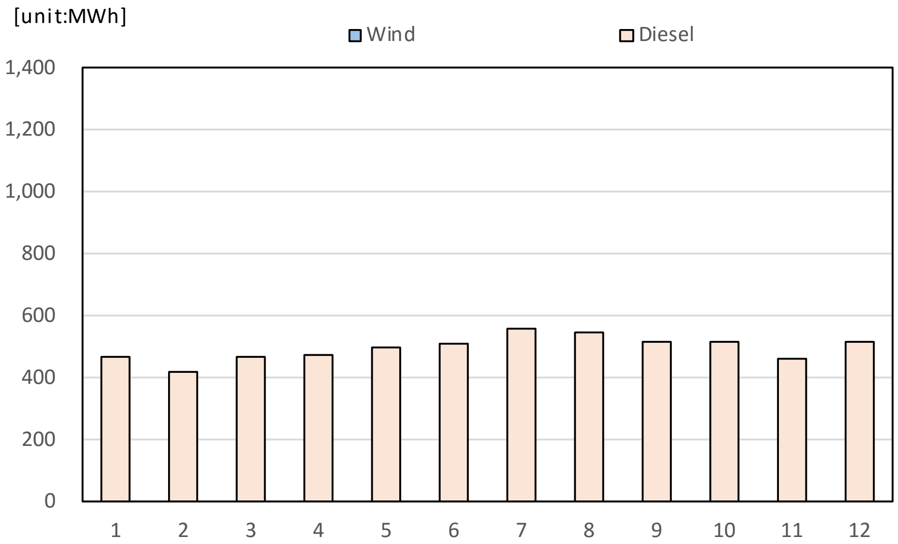
4.1.4 São Nicolau

São Nicolau has an area of 343 km^2, and a population of 12,400 as of 2015. Figure 4.1-10 shows the monthly generated energy of São Nicolau in 2015.The annual generated energy is 6 GWh. Electra does not conduct water supply business here, and the in-station power ratio is around 0.2%.

On São Nicolau, Cacimba power station newly started operation in November 2015. This power station usually operates two large-capacity diesel generators. This is because, even though reactive power is needed for voltage stabilization due to the adoption of cables on transmission and distribution lines and the small scale of demand, operating only one diesel generator leads to the possible reactive power supply capacity being exceeded. Accordingly, Electra is striving to secure system stability through cancelling the 20kV loop and isolating relatively long-distance cables from the system, and also conducting low-output operation with two generators (efficiency is worse than in rated operation) even when demand is low due to the supply of reactive power. Concerning the reactive power issue, Electra plans to take steps such as installing a shunt reactor, so operating problems are expected to be resolved.

The peak demand during the year from June 2015 to May 27, 2016 was 1,184 kW (20:00 on February

4, 2016) and the minimum demand was 392 kW (07:00 on June 1, 2015). As is shown in the daily load curve in Figure 4.1-11, demand for power increases between 19:00 and 22:00, but demand fluctuations at other times are relatively small.



Source: JICA Study Team based on Information from Electra, etc.

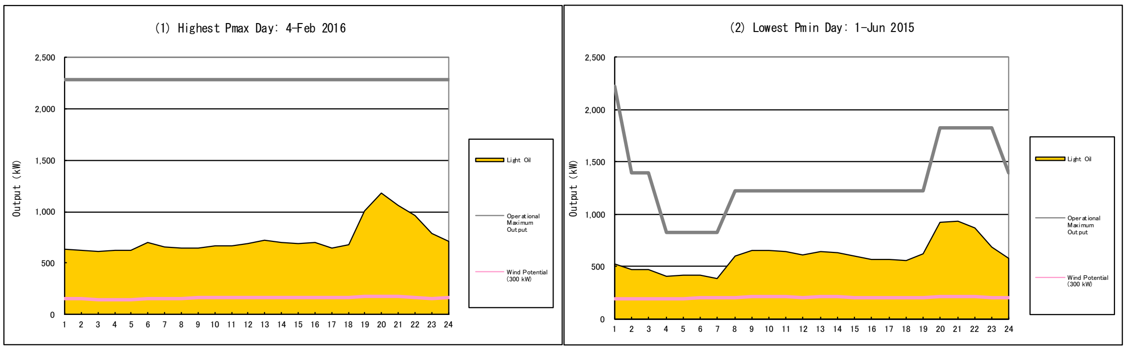
Figure 4.1-10 Monthly Generated Energy on São Nicolau

Table 4.1-4 Monthly Demand and Supply Situation on São Nicolau (2015)

	Item	unit	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	2015	2014	2013
a	Capacity Total (b+d)	[kW]	4,258										7,672				
b	Diesel [Installed capacity]	[kW]	4,258										7,672				
c	Diesel [Available output]	[kW]	3,024										5,304				
d	Wind	[kW]															
e	Diesel	[kWh]	469,613	420,547	466,272	473,887	496,963	511,206	559,981	548,277	517,579	517,805	463,673	518,066	5,963,869	5,719,557	5,522,596
f	Wind	[kWh]															
g	(wind potential: not-set point)	[kWh]															
h	Photovoltaics	[kWh]															
i	sub total (e+f+h)	[kWh]	469,613	420,547	466,272	473,887	496,963	511,206	559,981	548,277	517,579	517,805	463,673	518,066	5,963,869	5,719,557	5,522,596
j	ELECTRA house-use	[kWh]	1,923 *	1,722 *	1,909 *	1,940 *	2,034 *	2,093 *	2,292 *	2,245 *	2,119 *	2,120 *	1,898 *	2,121 *	24,415	11,893	11,945
k	ELECTRA house-use rate (j/i)	[%]	0.4% *	0.4% *	0.4% *	0.4% *	0.4% *	0.4% *	0.4% *	0.4% *	0.4% *	0.4% *	0.4% *	0.4% *	0.4%	0.2%	0.2%
l	Tech and non-Tech Loss (n-i-j)	[kWh]	49,653	55,568	110,538	76,240	65,235	86,065	59,093	72,357	117,630	55,211	26,053	120,397	894,041	943,437	925,974
m	Tech and non-Tech Loss rate (l/i)	[%]	10.6%	13.2%	23.7%	16.1%	13.1%	16.8%	10.6%	13.2%	22.7%	10.7%	5.6%	23.2%	15.0%	16.5%	16.8%
n	Sales	[kWh]	418,037	363,257	353,825	395,707	429,694	423,048	498,596	473,675	397,830	460,474	435,722	395,548	5,045,413	4,764,227	4,584,677
o	Pmax	[kW]	1,134	1,128	1,180	1,050	1,030	1,103	1,172	1,126	1,145	1070	1,051	1,094	1,180		
p	date & time	–	7-Jan 20:00	7-Feb 19:00	7-Mar 19:00	15-Apr 20:00	19-May 20:00	30-Jun 21:00	11-Jul 21:00	21-Aug 20:00	29-Sep 20:00	10-Oct 20:00	16-Nov 20:00	31-Dec 20:00	7-Mar 19:00		
q	Pmin	[kW]	256	382	300	340	326	392	485	487	454	396	423	455	256		
r	date & time	–	16-Jan 24:00	1-Feb 7:00	19-Mar 23:00	6-Apr 24:00	24-May 1:00	1-Jun 7:00	20-Jul 6:00	30-Aug 8:00	13-Sep 7:00	16-Oct 10:00	24-Nov 16:00	14-Dec 7:00	16-Jan 24:00		

*In-station power for each month is calculated using the in-station ratios for 2015.

Source: JICA Study Team based on Information from Electra, etc.



Source: JICA Study Team based on Information from Electra, etc.

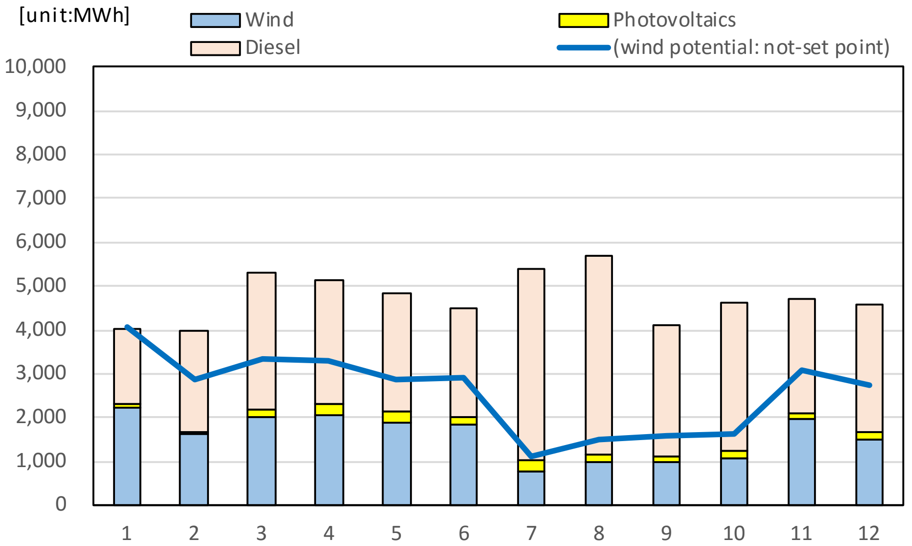
Figure 4.1-11 Daily Load Curve for São Nicolau

4.1.5 Sal

Sal has an area of 216km^2, and a population of 33,700 as of 2015. Figure 4.1-12 shows the monthly generated energy of Sal in 2015.The annual generated energy is 57 GWh, of which the Cabeolica wind power IPP accounts for 19 GWh (renewable energy ratio 33.0%). Out of the Electra in-station power consumption, approximately 6 GWh (estimate value) is used for water manufacture and supply pumps.

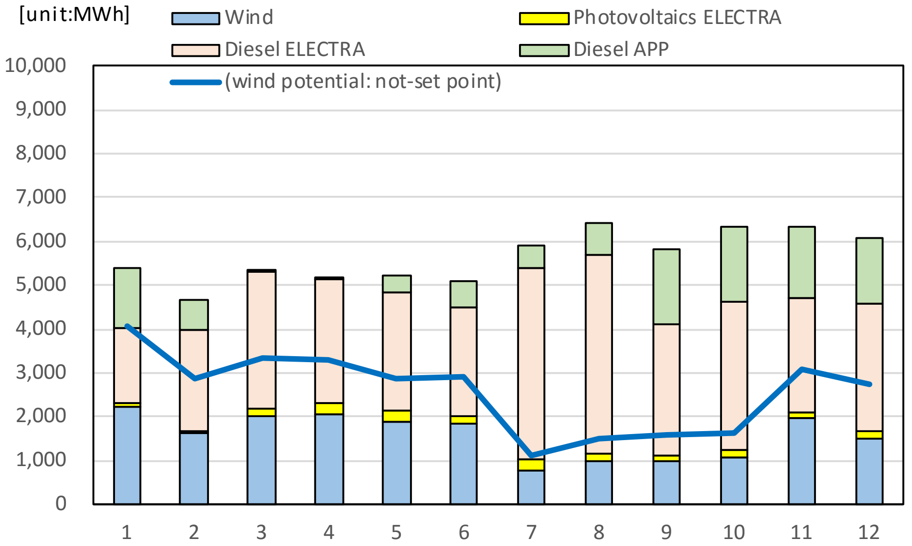
The amount of generated energy from renewable energy equipment in the Electra supply area is approximately 57% during periods of favorable wind conditions, for example, January 2015. Electra implements output suppression on the Cabeolica wind IPP in order to secure system stability. If no such output suppression were implemented, this IPP has the potential to provide more energy than the demand placed on Electra. Moreover, on Sal APPs conduct power and water supply and sewage treatment for some hotels and so on. Overall generated electric energy including that generated by APPs on Sal is 67.8 GWh, and the graph of monthly generated electric energy is shown in Figure 4.1-13.

On Sal too, wind conditions tend to become weaker and generated energy declines between July and October.



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-12 Monthly Generated Energy on Sal (Electra supply only)



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-13 Monthly Generated Energy on Sal (including APP)

Table 4.1-5 Monthly Demand and Supply Situation on Sal (2015)

	Item	unit	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	2015	2014	2013
a	Capacity Total (b'+c'+d'+d'')	[kW]	29,359												29,359		
b'	Diesel [Installed capacity]	[kW]	14,545												14,545		
b''	Diesel APP	[kW]	5,024												5,024		
c'	Diesel [Available output]	[kW]	13,540												13,540		
c''	Diesel APP	[kW]	5,024												5,024		
d'	Wind	[kW]	7,650												7,650		
d''	Photovoltaics	[kW]	2,140												2,140		
e'	Diesel ELECTRA	[kWh]	1,724,947	2,296,660	3,111,418	2,810,801	2,672,253	2,476,640	4,392,812	4,540,699	3,012,447	3,385,442	2,583,820	2,929,588	35,937,527		
e''	Diesel APP	[kWh]	1,356,065	681,084	33,002	40,819	377,181	624,149	508,483	725,854	1,690,641	1,731,690	1,616,996	1,484,574	10,870,538		
f	Wind	[kWh]	2,206,340	1,611,290	2,025,880	2,045,170	1,879,680	1,829,130	756,840	980,990	963,690	1,048,620	1,945,670	1,483,160	18,776,460		
g	(wind potential: not-set point)	[kWh]	(4,079,421)	(2,868,865)	(3,333,372)	(3,282,890)	(2,858,397)	(2,910,743)	(1,126,914)	(1,483,418)	(1,595,497)	(1,637,876)	(3,061,332)	(2,743,156)	(30,981,881)		
h'	Photovoltaics ELECTRA	[kWh]	89,376	74,352	170,262	276,656	279,698	172,946	254,439	184,215	146,409	174,214	165,820	185,088	2,173,475		
h''	Photovoltaics APP	[kWh]	0	0	0	0	0	0	0	0	0	1,010	2,633	2,819	6,462		
i'	sub total ELECTRA (e'+f+h')	[kWh]	4,020,663	3,982,302	5,307,560	5,132,627	4,831,631	4,478,716	5,404,091	5,705,904	4,122,546	4,608,276	4,695,310	4,597,836	56,887,462	51,930,042	40,056,231
i''	sub total APP (e''+h'')	[kWh]	1,356,065	681,084	33,002	40,819	377,181	624,149	508,483	725,854	1,690,641	1,732,700	1,619,629	1,487,393	10,877,000	17,412,018	17,676,646
i'''	Production total (i'+i'')	[kWh]	5,376,728	4,663,386	5,340,562	5,173,446	5,208,812	5,102,865	5,912,574	6,431,758	5,813,187	6,340,976	6,314,939	6,085,229	67,764,462	69,342,060	57,732,877
j'	ELECTRA house-use	[kWh]	334,475 *	445,332 *	603,318 *	545,027 *	518,162 *	480,231 *	851,785 *	880,461 *	584,127 *	656,452 *	501,014 *	568,060 *	11,030,727 *	8,815,765	6,628,148
k'	ELECTRA house-use rate (j'/I')	[%]	19.4% *	19.4% *	19.4% *	19.4% *	19.4% *	19.4% *	19.4% *	19.4% *	19.4% *	19.4% *	19.4% *	19.4% *	19.4%	17.0%	16.5%
j''	APP house-use	[kWh]	387,891	330,891	352,543	334,262	291,446	294,136	327,260	352,463	376,531	357,924	361,092	336,142	4,102,581	4,322,178	4,309,999
k''	APP house-use rate (j''/I'') **	[%]	28.6%	48.6%	1068.3%	818.9%	77.3%	47.1%	64.4%	48.6%	22.3%	20.7%	22.3%	22.6%	37.7%	24.8%	24.4%
l	Tech and non-Tech Loss (n'-i'-j')	[kWh]	531,582	121,573	761,088	381,247	697,161	355,925	419,197	419,745	211,427	349,225	317,510	577,648	1,081,045	1,737,798	2,978,674
m	Tech and non-Tech Loss rate (l'/i')	[%]	13.2%	3.1%	14.3%	7.4%	14.4%	7.9%	7.8%	7.4%	5.1%	7.6%	6.8%	12.6%	1.9%	3.3%	7.4%
n'	Sales ELECTRA	[kWh]	3,154,606	3,415,397	3,943,154	4,206,353	3,616,308	3,642,560	4,133,109	4,405,698	3,326,992	3,602,599	3,876,786	3,452,128	44,775,690	41,376,479	30,449,409
n''	Sales APP	[kWh]	964,090	832,233	917,890	904,915	935,336	954,047	1,165,615	1,274,798	1,313,055	1,373,228	1,256,600	1,149,253	13,041,060	13,065,844	13,305,807
n'''	Sales total (n'+n'')	[kWh]	4,118,696	4,247,630	4,861,044	5,111,268	4,551,644	4,596,607	5,298,724	5,680,496	4,640,047	4,975,827	5,133,386	4,601,381	57,816,750	54,442,323	43,755,216
o	Pmax	[kW]	7,800	9,639	9,930	9,619	8,800	9,200	10,515	10,697	8,645	8,750	8,950	9,027	10,697		
p	date & time	–	4 19:00	25 19:00	30 19:00	7 20:00	7 20:00	20 20:00	17 20:00	9 20:00	4 19:00	30 19:00	19 19:00	29 19:00	9 20:00		
q	Pmin	[kW]	3,792	3,716	5,200	4,676	4,350	4,025	4,279	5,018	4,000	4,119	4,401	4,424	3,716		
r	date & time	–	19 05:00	11 05:00	5 05:00	1 03:00	1 05:00	14 06:00	1 04:00	30 07:00	1 08:00	25 07:00	27 07:00	8 02:00	11 05:00		
o''	Pmax	[kW]	2,717	2,563	2,586	2,571	2,698	2,845	3,068	3,094	3,205	3,185	3,123	2,932	3,205		
q''	Pmin	[kW]	1,121	987	996	949	1,002	1,068	1,032	1,008	1,154	1,008	1,028	1,074	949		

* In-station power for each month is calculated using the in-station ratios for 2015.

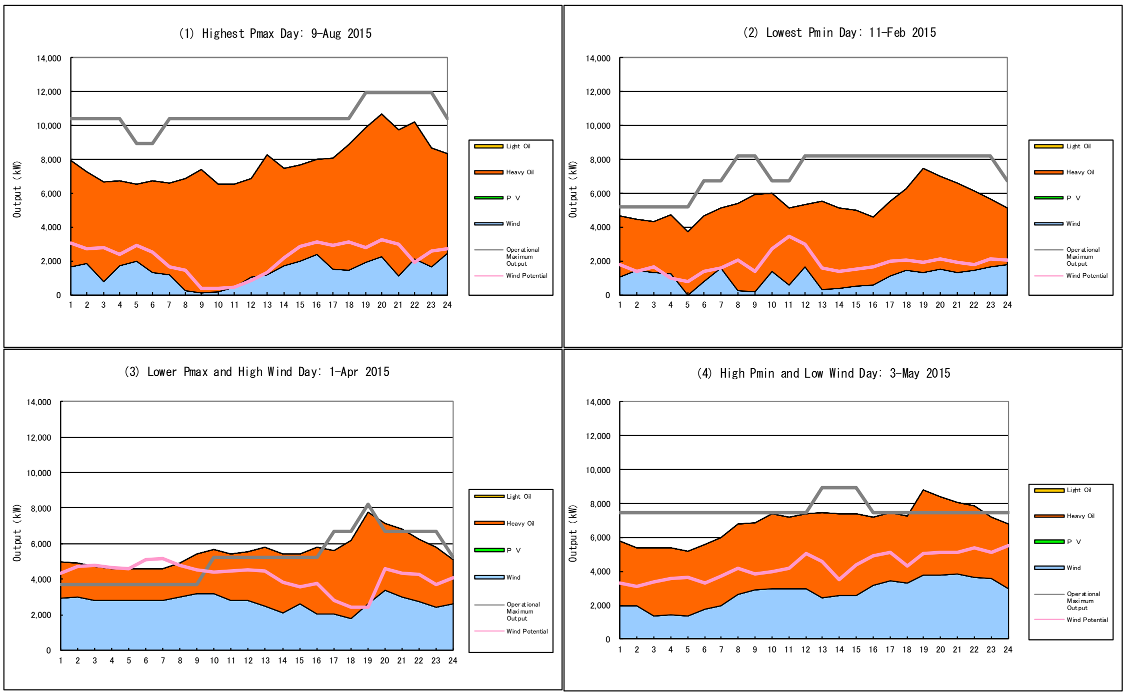
** In 2015, since APPs procured part of the electric power from Electra between February and August, the in-station power ratio is more than 100%.

Source: JICA Study Team based on Information from Electra, APP, etc.

Omitting APPs, the peak demand supplied by Electra on Sal in 2015 was 10.7 MW (20:00 on August 9) and minimum demand was 3.7 MW (05:00 on February 11). On Sal, which has a prosperous hotel and tourism industry, demand tends to increase around 10:00, 13:00 and 20:00, but according to the daily load curve in Figure 4.1-13, load over the course of a day is relatively uniform. Moreover, according to the APP monthly report, the APP supplied between 1 MW and 3.2 MW of electric energy separate from Electra to hotels and its own water manufacturing plant in 2015.

Electra makes it a basic point to secure spare capacity of more than half the wind power output in order to deal with sudden output fluctuations in the Cabeolica wind power IPP, however, it lets each power plant operate as it sees fit in light of demand and wind conditions. On Sal, except in cases where wind power generation output has stability equivalent to the base power supply due to load suppression, etc., enough spare capacity to satisfy demand is secured in readiness for interruptions to wind power supply.

On Sal, output suppression of wind power generation is conducted from the viewpoint of securing network stability at times when wind conditions are favorable. This suppressed power in 2015 is estimated to be 12.2 GWh from the data of wind conditions. It may be possible to reduce fuel costs in diesel power generation through expanding the reduction of minimum diesel power operation, revising the sale price of power in excess of the Take or Pay quota of PPA, effectively utilizing storage batteries to secure network stability and so on.



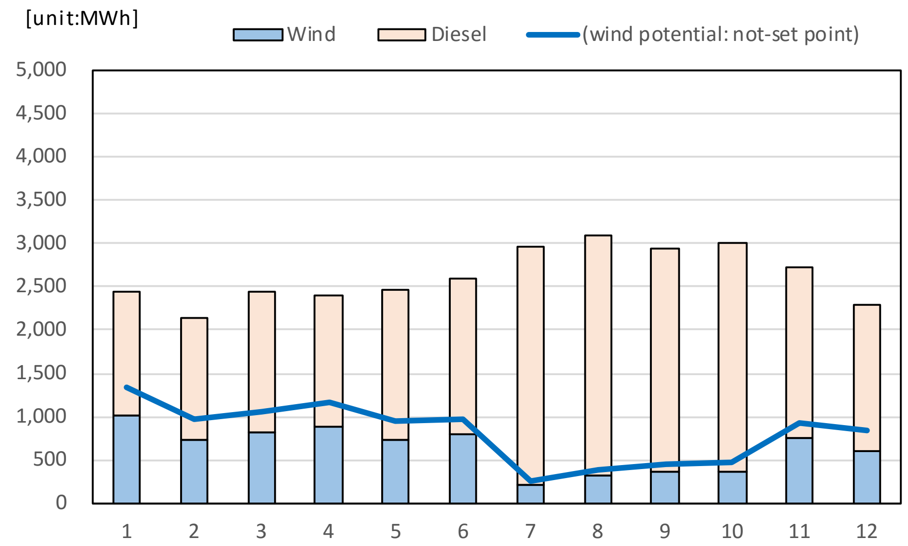
* There is a mega solar system with capacity of 2.5 MW, but solar power generation output is not included here because the data collection device is broken.

Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-14 Daily Load Curve for Sal (2015)

4.1.6 Boa Vista

Boa Vista has an area of 620 km^2, and a population of 14,500 as of 2015. Figure 4.1-15 shows the monthly generated energy of Boa Vista in 2015.The annual generated energy is 30 GWh, of which the Cabeolica wind power IPP accounts for 7.6 GWh (renewable energy ratio 33.0%). On Boa Vista, AEB conducts power and water supply and sewerage services, and 3.9 GWh of in-station power consumption is used for water manufacture, sewage treatment and supply pumps.



Source: JICA Study Team based on Information from AEB.

Figure 4.1-15 Monthly Generated Energy on Boa Vista (2015)

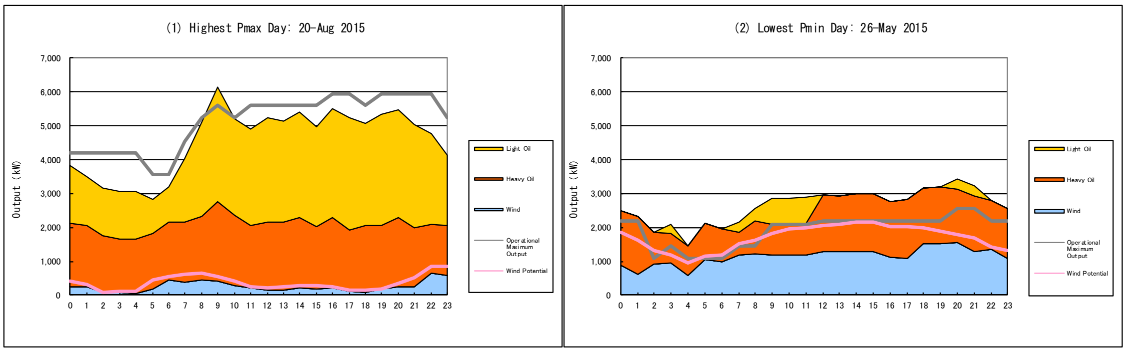
Table 4.1-6 Monthly Demand and Supply Situation on Boa Vista (2015)

	Item	unit	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	2015
a	Capacity Total (b+d)	[kW]	16,664												16,664
b	Diesel [Installed capacity]	[kW]	14,114												14,114
c	Diesel [Available output]	[kW]	9,550												9,550
d	Wind	[kW]	2,550												2,550
e	Diesel	[kWh]	1,441,597	1,402,286	1,626,948	1,505,142	1,732,309	1,793,574	2,733,765	2,780,349	2,593,696	2,637,586	1,972,109	1,682,960	23,902,321
f	Wind	[kWh]	1,009,445	737,024	811,735	889,585	730,343	802,044	220,846	314,222	358,579	369,574	762,460	606,001	7,611,858
g	(wind potential: not-set point)	[kWh]	(1,339,570)	(964,803)	(1,058,428)	(1,170,121)	(941,352)	(965,096)	(265,498)	(393,211)	(451,594)	(471,972)	(935,201)	(851,787)	(9,808,633)
h	Photovoltaics	[kWh]													
i	sub total (e+f+h)	[kWh]	2,410,694	2,085,025	2,372,936	2,366,643	2,428,481	2,521,737	2,909,994	3,051,849	2,914,256	2,959,573	2,704,699	2,256,510	30,982,397
j	AEB house-use	[kWh]	332,935	297,479	321,440	312,818	322,361	302,935	327,988	357,853	363,490	375,726	342,748	320,215	3,977,987
k	AEB house-use rate (j/i)	[%]	13.8%	14.3%	13.5%	13.2%	13.3%	12.0%	11.3%	11.7%	12.5%	12.7%	12.7%	14.2%	12.8%
l	Tech and non-Tech Loss (n-i-j)	[kWh]	249,531	115,446	225,267	250,237	164,888	261,368	381,101	303,729	283,007	258,597	270,606	221,151	2,984,929
m	Tech and non-Tech Loss rate (l/i)	[%]	10.4%	5.5%	9.5%	10.6%	6.8%	10.4%	13.1%	10.0%	9.7%	8.7%	10.0%	9.8%	9.6%
n	Sales	[kWh]	1,828,228	1,672,100	1,826,229	1,803,588	1,941,232	1,957,434	2,200,905	2,390,267	2,267,759	2,325,250	2,091,345	1,715,144	24,019,481
o	Pmax	[kW]	4,848	4,472	4,530	4,698	4,878	4,715	5,396	6,136	5,453	5,515	5,559	4,885	6,136
p	date & time	–	20 19:00	18 18:00	24 19:00	2 19:00	19 19:00	10 19:00	31 21:00	20 09:00	30 16:00	15 13:00	9 08:00	29 18:00	20 09:00
q	Pmin	[kW]	2,122	2,058	1,936	2,014	1,455	2,129	2,493	2,058	2,414	2,663	2,392	1,719	1,455
r	date & time	–	8 5:00	20 04:00	5 05:00	29 06:00	26 04:00	22 02:00	3 05:00	13 03:00	9 05:00	15 5:00	13 05:00	8 03:00	26 04:00

Source: JICA Study Team based on Information from AEB.

In 2015, peak demand on Boa Vista was 6.1MW (21:00 on August 20) and minimum demand was 1.5 MW (04:00 on May 26). On Boa Vista, which has a prosperous hotel and tourism industry, demand tends to increase around 10:00, 13:00 and 20:00 as is shown in the daily load curve in Figure 4.1-16. Moreover, the difference in power demand between the tourism high season and low season can be recognized.

AEB incorporates wind power as a base power source to a certain extent during periods when wind conditions are favorable. In January, when wind conditions are favorable, renewable energy equipment supplies around 42% of the generated energy. Similar to Electra, AEB also implements output suppression on the Cabeolica wind IPP in order to secure system stability. The excess power that results from such output suppression is around 2.2 GWh. Accordingly, through expanding the reduction of minimum diesel power operation, revising the sale price of power in excess of the Take or Pay quota of PPA, effectively utilizing storage batteries, it may be possible to make use of the excess power from wind power output suppression and increase output from renewable energy.
However, diesel power generation is still essential at times when wind conditions tend to become weaker between July and October.

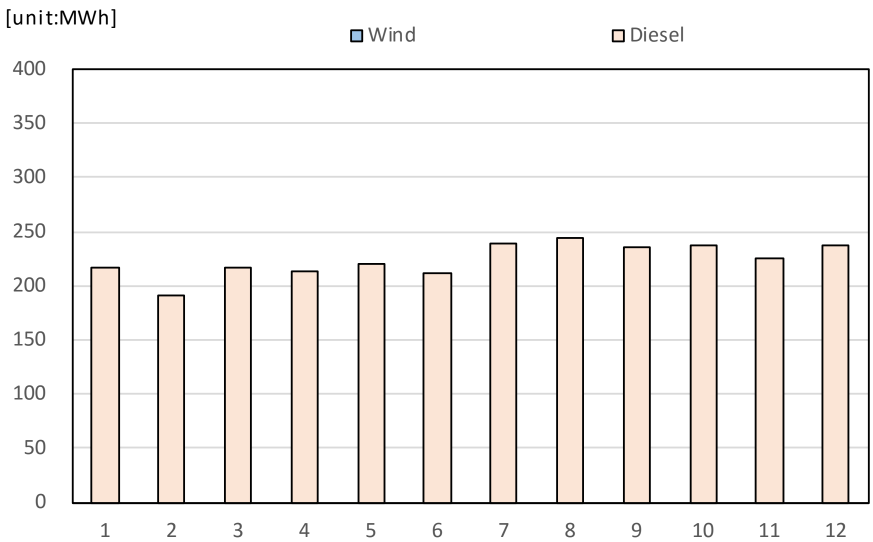


Source: JICA Study Team based on Information from AEB.

Figure 4.1-16 Daily Load Curve for Boa Vista (2015)

4.1.7 Maio

Maio has an area of 269 km^2, and a population of 7,000 as of 2015. Figure 4.1-17 shows the monthly generated energy of Maio in 2015. The annual generated energy is 2.6 GWh.



Source: JICA Study Team based on Information from Electra, etc.

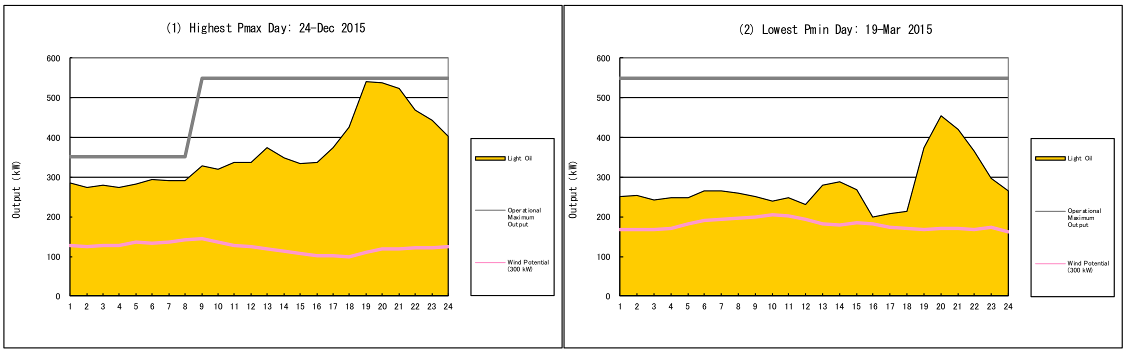
Figure 4.1-17 Monthly Generated Energy on Maio (2015)

Table 4.1-7 Monthly Demand and Supply Situation on Maio (2015)

	Item	unit	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	2015	2014	2013
a	Capacity Total (b+d)	[kW]	2,176												2,176		
b	Diesel [Installed capacity]	[kW]	2,176												2,176		
c	Diesel [Available output]	[kW]	900												900		
d	Wind	[kWh]															
e	Diesel	[kWh]	217,565	190,447	216,233	212,818	219,830	212,017	238,266	244,732	235,969	237,555	224,569	237,203	2,687,204	2,607,729	2,733,453
f	Wind	[kWh]															
g	(wind potential: not-set point)	[kWh]															
h	Photovoltaics	[kWh]															
i	sub total (e+f+h)	[kWh]	217,565	190,447	216,233	212,818	219,830	212,017	238,266	244,732	235,969	237,555	224,569	237,203	2,687,204	2,607,729	2,733,453
j	ELECTRA house-use	[kWh]	1,202 *	1,052 *	1,195 *	1,176 *	1,214 *	1,171 *	1,316 *	1,352 *	1,304 *	1,312 *	1,241 *	1,310 *	14,846	14,241	10,813
k	ELECTRA house-use rate (j/i)	[%]	0.6% *	0.6% *	0.6% *	0.6% *	0.6% *	0.6% *	0.6% *	0.6% *	0.6% *	0.6% *	0.6% *	0.6% *	0.6%	0.5%	0.4%
l	Tech and non-Tech Loss (n-i-j)	[kWh]	35,068	30,322	79,091	35,032	53,209	65,160	88,042	65,570	48,650	40,242	49,695	54,954	645,034	663,799	720,151
m	Tech and non-Tech Loss rate (l/i)	[%]	16.1%	15.9%	36.6%	16.5%	24.2%	30.7%	37.0%	26.8%	20.6%	16.9%	22.1%	23.2%	24.0%	25.5%	26.3%
n	Sales	[kWh]	181,295	159,073	135,947	176,610	165,407	145,686	148,908	177,810	186,015	196,001	173,633	180,939	2,027,324	1,929,689	2,002,489
o	Pmax	[kW]	509	500	492	498	494	485	499	538	518	480	487	542	542		
p	date & time	–	6 19:00	19 20:00	5 20:00	29 20:00	4 20:00	11 20:00	29 20:00	11 20:00	5 21:00	30 20:00	8 19:00	24 19:00	24 19:00		
q	Pmin	[kW]	200	202	200	208	207	210	206	223	206	227	220	212	200		
r	date & time	–	11 08:00	8 07:00	19 16:00	15 09:00	8 24:00	20 07:00	23 08:00	1 07:00	12 17:00	25 07:00	27 24:00	15 06:00	11 08:00		

*In-station power for each month is calculated using the in-station ratios for 2015.
Source: JICA Study Team based on Information from Electra, etc.

In 2015, peak demand on Maio was 542 kW (19:00 on December 24) and minimum demand was 200 kW (16:00 on March 19). As is shown in the daily load curve in Figure 4.1-18, demand tends to increase between 19:00 and 22:00, but fluctuations are relatively small at other times.



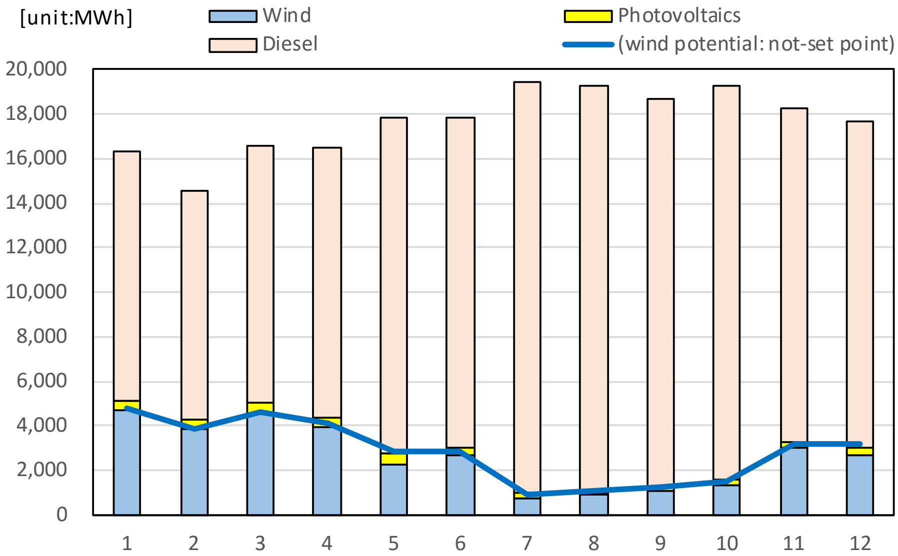
Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-18 Daily Load Curve for Maio (2015)

4.1.8 Santiago

Santiago has an area of 991 km^2, and a population of 29,400 as of 2015. Figure 4.1-19 shows the monthly generated energy of Santiago in 2015. The annual generated energy is 212 GWh, of which the Cabeolica wind power IPP accounts for 31.9 GWh (renewable energy ratio 15.0%). On Santiago, Electra conducts power and water supply and sewerage services, and approximately 15 GWh (estimate value) of in-station power consumption is used for water manufacture, sewage treatment and supply pumps.

In 2015, at times of favorable wind conditions, the said renewable energy equipment supplied around 30% of the monthly generated energy. According to hearings with Electra, due to the decline in fuel prices, in 2016 output suppression of wind power generation is conducted on Santiago too when the PPA minimum guaranteed purchase quantity is exceeded, however, because not enough diesel power output is secured relative to wind power output in order to secure network stability, it was confirmed that output suppression of wind power generation was not implemented in 2015 due to consideration of network stability.



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-19 Monthly Generated Energy on Santiago (2015)

Table 4.1-8 Monthly Demand and Supply Situation on Santiago (2015)

	Item	unit	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	2015	2014	2013
a	Capacity Total (b+d)	[kW]	100,965												100,965		
b	Diesel [Installed capacity]	[kW]	64,567			87,335									87,335		
c	Diesel [Available output]	[kW]	50,084			72,548									72,548		
d'	Wind	[kW]	9,350												9,350		
d''	Photovoltaics	[kW]	4,280												4,280		
e	Diesel	[kWh]	11,234,969	10,237,055	11,498,711	12,095,919	15,082,787	14,784,185	18,445,068	18,292,411	17,420,208	17,700,908	15,011,753	14,676,342	176,480,316		
f	Wind	[kWh]	4,733,244	3,861,443	4,564,744	3,960,214	2,266,449	2,684,713	712,801	928,415	1,117,620	1,371,421	2,995,419	2,663,429	31,859,912		
g	(wind potential: not-set point)	[kWh]	(4,518,876)	(3,656,503)	(4,379,363)	(3,939,537)	(2,692,972)	(2,741,883)	(849,663)	(1,004,183)	(1,209,079)	(1,437,024)	(3,056,505)	(3,006,018)	(32,491,605)	205,854,419	187,343,755
h	Photovoltaics	[kWh]	371,306	418,561	488,841	454,380	488,482	368,060	279,843	92,395	135,595	240,143	243,145	359,834	3,940,585		
i	sub total (e+f+h)	[kWh]	16,339,519	14,517,059	16,552,296	16,510,513	17,837,718	17,836,958	19,437,712	19,313,221	18,673,423	19,312,472	18,250,317	17,699,605	212,280,813		
j	ELECTRA house-use	[kWh]	2,011,159 *	1,786,841 *	2,037,349 *	2,032,206 *	2,195,566 *	2,195,472 *	2,392,502 *	2,377,179 *	2,298,429 *	2,377,087 *	2,246,351 *	2,178,566 *	21,722,181 *	20,737,119	14,390,590
k	ELECTRA house-use rate (j/i)	[%]	12.3% *	12.3% *	12.3% *	12.3% *	12.3% *	12.3% *	12.3% *	12.3% *	12.3% *	12.3% *	12.3% *	12.3% *	12.3%	10.1%	7.7%
l	Tech and non-Tech Loss (n-i-j)	[kWh]	5,083,910	4,714,385	6,323,675	5,601,027	6,549,541	5,728,545	5,528,193	6,701,007	5,234,029	4,817,439	3,529,037	4,787,856	69,005,170	76,796,896	69,250,095
m	Tech and non-Tech Loss rate (l/i)	[%]	31.1%	32.5%	38.2%	33.9%	36.7%	32.1%	28.4%	34.7%	28.0%	24.9%	19.3%	27.1%	32.5%	37.3%	37.0%
n	Sales	[kWh]	9,244,450	8,015,834	8,191,272	8,877,280	9,092,611	9,912,941	11,517,017	10,235,035	11,140,965	12,117,946	12,474,930	10,733,183	121,553,462	108,320,404	103,703,070
o	Pmax	[kW]	31,971	31,149	32,289	32,828	33,616	33,985	34,321	34,624	35,282	34,515	34,951	33,704	35,282		
p	date & time	–	7 20:00	4 19:00	30 20:00	22 20:00	5 20:00	3 20:00	29 20:00	5 20:00	15 20:00	29 19:00	10 19:00	15 19:00	15 20:00		
q	Pmin	[kW]	13,768	14,270	14,246	15,555	17,217	17,399	18,916	18,435	18,205	17,145	17,044	16,844	13,768		
r	date & time	–	24 04:00	24 03:00	28 03:00	23 04:00	8 03:00	5 24:00	7 04:00	25 04:00	2 05:00	28 05:00	30 04:00	11 04:00	24 04:00		

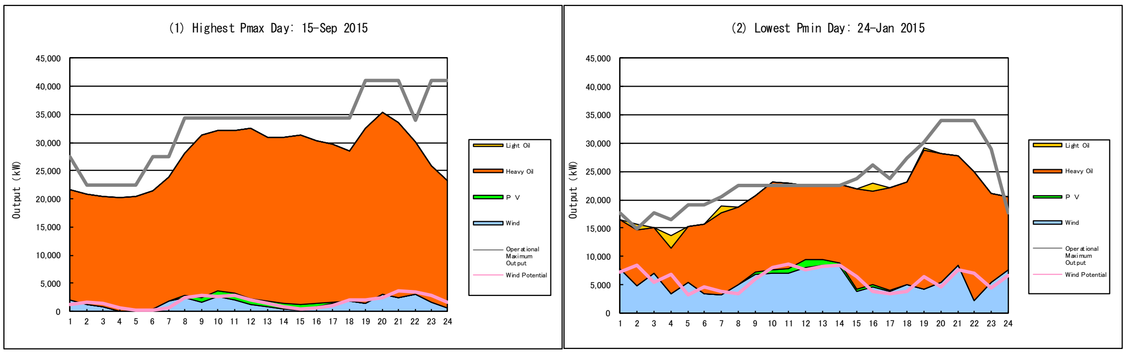
*In-station power for each month is calculated using the in-station ratios for 2015.
Source: JICA Study Team based on Information from Electra, etc.

On Santiago too, wind conditions tend to become weaker between July and October when the demand for power is high, leading to a mismatch of supply capacity and demand.

In 2015, peak demand on Santiago was 35 MW (21:00 on September 15) and minimum demand was 14MW (04:00 on January 24). Demand tends to start increasing from early morning and reaches a peak around 20:00 in the evening, and then it falls from late night to early next morning.

As is shown in the daily load curve in Figure 4.1-20, on Santiago, operation is conducted with network stability without output suppression of wind power generation even during January and February, when wind conditions are favorable. According to data from 2015, even though there is no output suppression of wind power generation for network stabilization, according to the calculation of potential renewable energy introduction, the current demand and amount of wind power introduced to existing diesel power generation are at appropriate levels. In order to further increase renewable energy, it will be necessary to examine the output suppression of renewable energy, expansion of diesel power generation reduction, introduction of storage batteries and so on.

However, diesel power generation is still essential at times when wind conditions tend to become weaker between July and October.

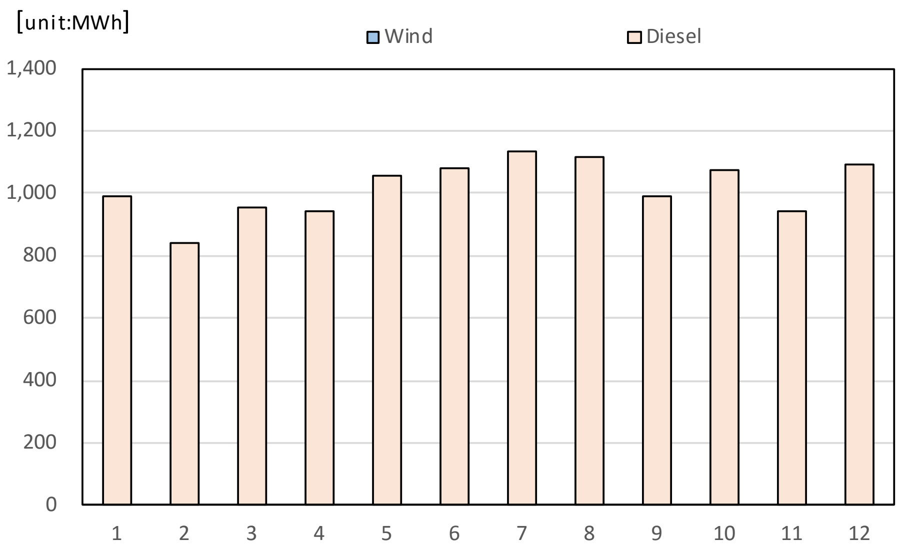


Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-20 Daily Load Curve for Santiago (2015)

4.1.9 Fogo

Fogo has an area of 476 km^2, and a population of 35,800 as of 2015. Figure 4.1-21 shows the monthly generated energy of Fogo in 2015. The annual generated energy is 13.4 GWh.



Source: JICA Study Team based on Information from Electra, etc.

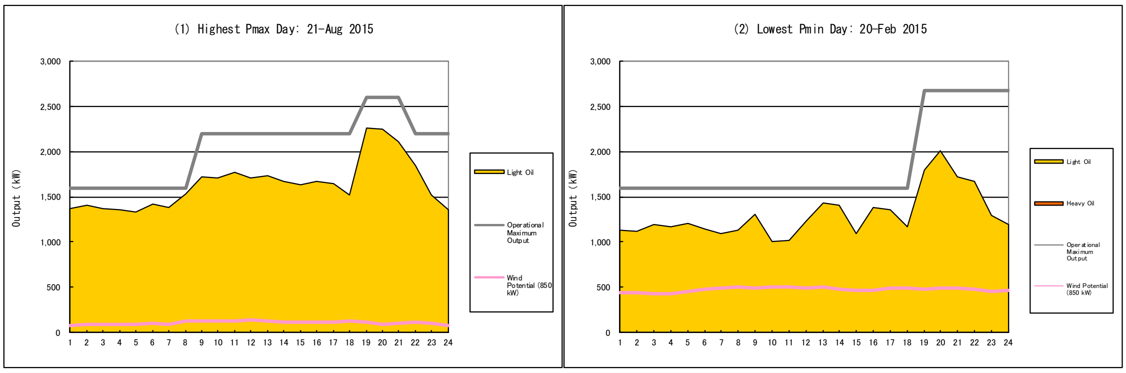
Figure 4.1-21 Monthly Generated Energy on Fogo (2015)

Table 4.1-9 Monthly Demand and Supply Situation on Fogo (2015)

	Item	unit	Jan-2015	Feb-2015	Mar-2015	Apr-2015	May-2015	Jun-2015	Jul-2015	Aug-2015	Sep-2015	Oct-2015	Nov-2015	Dec-2015	2015	2014	2013
a	Capacity Total (b+d)	[kW]	5,960									9,304			9,304		
b	Diesel [Installed capacity]	[kW]	5,960									9,304			9,304		
c	Diesel [Available output]	[kW]	3,870									6,734			6,734		
d	Wind	[kW]															
e	Diesel	[kWh]	992,748	841,976	956,637	943,561	1,058,062	1,082,872	1,131,637	1,114,241	988,125	1,073,612	944,700	1,089,849	12,218,020	11,927,773	12,085,345
f	Wind	[kWh]															
g	(wind potential: not-set point)	[kWh]															
h	Photovoltaics	[kWh]															
i	sub total (e+f+h)	[kWh]	992,748	841,976	956,637	943,561	1,058,062	1,082,872	1,131,637	1,114,241	988,125	1,073,612	944,700	1,089,849	12,218,020	11,927,773	12,085,345
j	ELECTRA house-use	[kWh]	7,537 *	6,392 *	7,262 *	7,163 *	8,032 *	8,221 *	8,591 *	8,459 *	7,501 *	8,150 *	7,172 *	8,274 *	92,754	22,276	29,730
k	ELECTRA house-use rate (j/i)	[%]	0.8% *	0.8% *	0.8% *	0.8% *	0.8% *	0.8% *	0.8% *	0.8% *	0.8% *	0.8% *	0.8% *	0.8% *	0.8%	0.2%	0.2%
l	Tech and non-Tech Loss (n-i-j)	[kWh]	173,949	180,462	291,844	307,012	290,797	369,258	367,332	281,519	253,606	27,849	135,185	184,416	2,863,229	3,380,458	3,371,245
m	Tech and non-Tech Loss rate (l/i)	[%]	17.5%	21.4%	30.5%	32.5%	27.5%	34.1%	32.5%	25.3%	25.7%	2.6%	14.3%	16.9%	23.4%	28.3%	27.9%
n	Sales	[kWh]	811,262	655,122	657,531	629,386	759,233	705,393	755,714	824,263	727,018	1,037,613	802,343	897,159	9,262,037	8,525,039	8,684,370
o	Pmax	[kW]	2,222	2,210	2,175	2,277	2,356	2,244	2,351	2,420	2,320	2,440	2,203	2,340	2,440		
p	date & time	–	17 20:00	10 19:00	15 20:00	22 21:00	4 20:00	23 20:00	22 20:00	8 20:00	22 20:00	21 20:00	9 20:00	31 20:00	21 20:00		
q	Pmin	[kW]	1,004	1,000	1,015	1,016	1,080	1,005	1,002	1,007	970	1,053	1,017	1,025	970		
r	date & time	–	7 05:00	7 10:00	13 05:00	28 04:00	16 24:00	16 17:00	8 21:00	11 10:00	8 04:00	10 08:00	14 04:00	29 05:00	8 04:00		

*In-station power for each month is calculated using the in-station ratios for 2015.
Source: JICA Study Team based on Information from Electra, etc.

In 2015, peak demand on Fogo was approximately 2.4 MW (20:00 on October 21) and minimum demand was approximately 1 MW (04:00 on September 8). As is shown in the daily load curve in Figure 4.1-21, demand tends to increase from 19:00 to 22:00, and it remains more or less static at all other times.

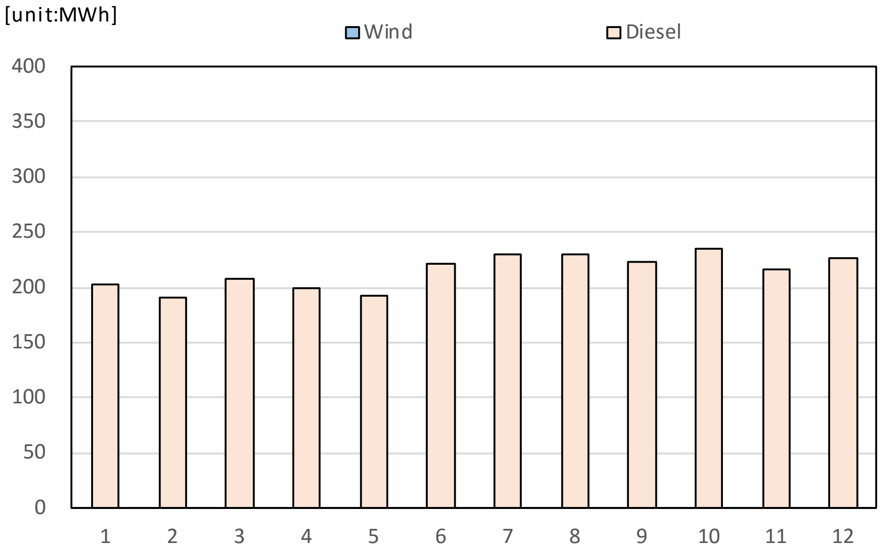


Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-22 Daily Load Curve for Fogo (2015)

4.1.10 Brava

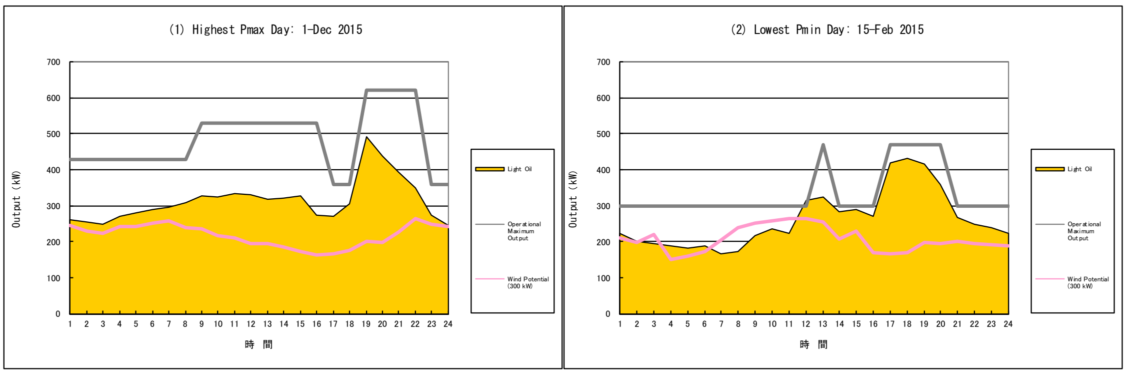
Brava has an area of 64 km^2, and a population of 5,700 as of 2015. Figure 4.1-23 shows the monthly generated energy of Brava in 2015. The annual generated energy is 2.6 GWh.



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-23 Monthly Generated Energy on Brava (2015)

In 2015, peak demand on Brava was approximately 600 kW (19:00 on December 31) and minimum demand was approximately 170 kW (07:00 on February 15). As is shown in the daily load curve in Figure 4.1-24, demand tends to increase between 19:00 and 22:00, and it remains more or less static at all other times. The pink line shows the theoretical output in the case where a 300 kW wind power generation unit is installed. A 150 kW wind power generation unit was installed on Brava in the past (it is currently out of commission). Moreover, considering the renewal period based on the scale of demand and deterioration of power plants, transmission equipment, etc., there is potential to implement demonstration testing geared to the phased raising of the renewable energy ratio based on a comprehensive system of storage batteries.



Source: JICA Study Team based on Information from Electra, etc.

Figure 4.1-24 Daily Load Curve for Brava (2015)

4.2 Power Supply/Demand Loss

4.2.1 Status of Power Supply/Demand Loss

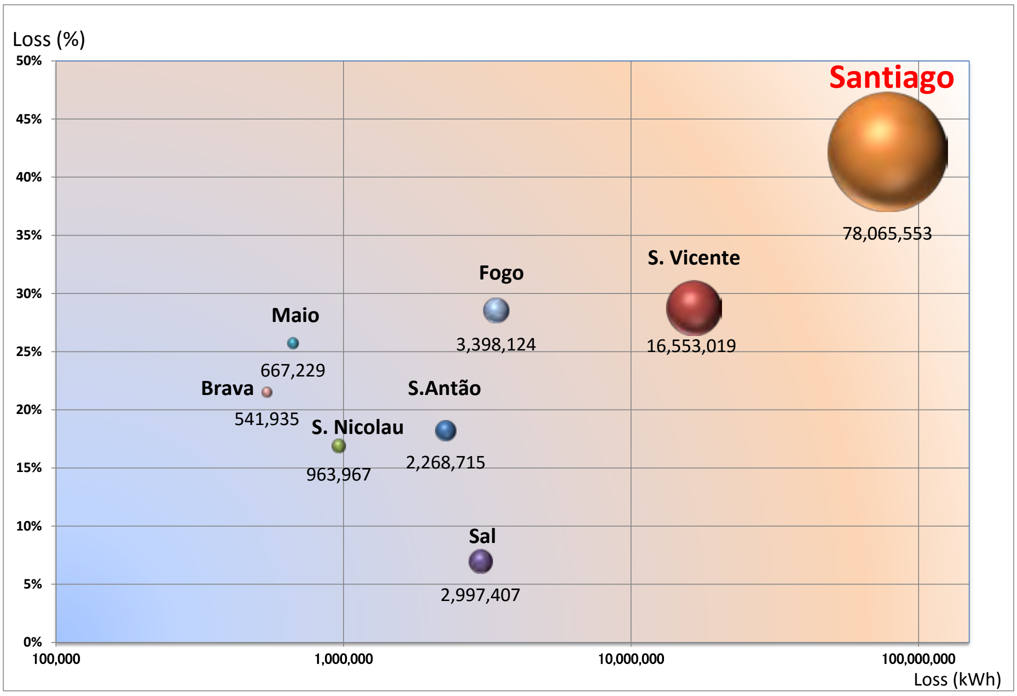
The supply/demand loss in Cabo Verde is a grave matter. In Cabo Verde, there is demand for desalination. Electra produces and sells water, and if the desalinating is included in the auxiliary power, the loss at transmission-end is calculated to be over 10% in Santiago, Sal and São Vicente. The total loss factor (power loss factor obtained by dividing the electricity sales (kWh) by the transmission-end power excluding auxiliary power) is extremely high at 33% for the eight islands served by Electra (Boa Vista served by AEB and some hotels on Sal by APP), causing significant economic loss. Table 4.2-1 below shows the loss factors in Electra's supply areas.

Table 4.2-1 Electra's loss factor by island (2014)

Island	Generation	Desalination	Internal use	Pumping	Internal use Total	Trasnmission	Consumption	Loss	
Ilha	Produção (kWh)	Dessalinização	Consumo Interno	Consumo Bombagem água produzida	Total dos consumos da produção	Produção Entregue a Rede A	(kWh) B	(kWh) C(=A - B)	(%) D(=C/A)
Santo Antão	12,479,516	0	14,402	0	14,402	12,465,114	10,196,399	2,268,715	18%
São Vicente	67,570,039	7,253,962	2,206,010	523,619	9,983,591	57,586,448	41,033,429	16,553,019	29%
São Nicolau	5,719,557	0	11,893	0	11,893	5,707,664	4,743,697	963,967	17%
Sal	51,930,042	5,934,040	2,543,325	338,400	8,815,765	43,114,277	40,116,870	2,997,407	7%
Maio	2,607,729	0	14,241	0	14,241	2,593,488	1,926,259	667,229	26%
Santiago	205,854,419	13,415,747	5,763,920	1,557,452	20,737,119	185,117,300	107,051,747	78,065,553	42%
Fogo	11,927,773	0	22,276	0	22,276	11,905,497	8,507,373	3,398,124	29%
Brava	2,534,582	0	15,723	0	15,723	2,518,859	1,976,924	541,935	22%
Total Electra	360,623,657	26,603,749	10,591,789	2,419,471	39,615,010	321,008,647	215,552,698	105,455,949	33%

Source: Electra

The systems on the islands are simple and have short transmission distance; thus, the technical loss is rarely over 10%. Electra's loss factor varies from less than 10% to over 20% depending on the island, which suggests that much of the loss comes from commercial reasons such as theft and illegal use of power. The loss factor is less than 20% on Sal and Boa Vista (served by AEB), which have high hotel demand and are served by MV transmission. Fig. 4.2-1 illustrates the scale of loss and impact on the management by showing the loss factor (%) on the vertical axis, the loss (kWh) on the horizontal axis.



Source: JICA Study Team based on the information from Electra

Figure 4.2-1 Electra's power loss by island

The figure above on the power loss reveals that the power loss and loss factor are much higher in Santiago that houses the capitol Praia and large population, which calls for urgent measures above all else. Once improvements are made in the area, the success should impart a great impact on the management, and by employing the same methods on other islands, the company should be able to achieve the result from the measures in an efficient manner.

4.2.2 Loss Improvement Approach

The reasons behind the illegal use of electricity might involve issues deeply rooted in the society such as organized crime (stealing and selling power) and poverty. Also, considering the business being in the red and no progress collecting uncollected receivables as explained earlier, the resource available to Electra staff is probably very limited.

Thus, the continuation of the past measures might just allow the vicious circle to repeat, promoting illegal activities without solving any fundamental issues. The Study Team believes it is effective, for the fundamental resolution of the loss factor issue, to implement multiple measures such as those listed below together with the Cabo Verdean government by referring to the actions and measures taken in other nations and Japan.

- Increase staff for electric bill collection and facility patrol
- Prioritized installation of prepaid meters in areas with illegal power use and low collection rate

- Cooperation with the Cabo Verdean government (see examples below)

  "Strengthening of laws, regulation and penalties," "safety net such as the provision of the prepaid cards to needy households," and "education in school and area of poverty to prevent illegal use of electricity and other public services"

The issue of power loss is not a problem of any single power company such as Electra. An effort must be made towards solving the issue with the understanding that the government of Cabo Verde is as much a responsible party as Electra.

Whether it is the uncollected receivables or illegal power use, unsolved issues can collapse Electra's revenue base and push it toward critical financial situation if left unattended. If such situation occurs, the country of Cabo Verde will likewise end up with a non-performing asset (Electra) as a shareholder and the risk of taking over the debt. Therefore, the issue of power loss must be addressed as a national problem.

4.3 Local Electrification

The Study Team has conducted the site visit to off grid facilities that supply electricity by 100% renewable energy, in Monte Trigo on March 23, 2016 and in Carriçal village on May 27, 2016.

The result of the visits is explained in the following items of 4.3.1 and 4.3.2. Additionally, regarding the general policy about the electrification for other small villages that are confirmed by the interview to DGE are explained in the 4.3.3.

4.3.1 Monte Trigo Photovoltaic Micro-grid

(1) Monte Trigo village

Monte Trigo village is a frontier village located in the coast of southwest in Santo Antão island. People can generally access to Monte Trigo village by about 1-hour small boat trip from Tarrafal village. The population of Monte Trigo village is about 230 and main industry is fishing and trading with villages in neighborhood (Refer Figure 4.3-1).

The configuration of the power demand is as follows, 75 households (total number of the household in island is approx. 100), 20 public lightings, an elementary school, a kindergarten, an ice factory, a guesthouse and several small restaurants. The total length of low-tension distribution line is about 1 km. (Refer Figure 4.3-2)

Now, one multipurpose building is being constructed and the town administrative office has a plan to introduce several PCs in a library of the facility.

Source:www.sesam-er.no.comunidades.net

Figure 4.3-1 Place of Monte Trigo

Figure 4.3-2 Landscape of Monte Trigo

(2) The main outline of micro grid

Monte Trigo Photovoltaic micro-grid (PVMG) was commenced in February 2012 as a project of SESAM-ER by the co-financing of the EU and local administration (EU: 75% and city: 25%). Constructors are APP and GRUP SOLER (Spain) and the owner is the city. The operation and maintenance services for PVMG is provided by APP.

The outline of system configuration and main specification of PVMG are shown in figure 4.3-3 and table 4.3-1. Two units of PV and battery component are installed with the monitoring and control system, and the control system provides instructions for optimal use of batteries with the combination of two inverters depending on the situation. Additionally, one diesel generator (20kV) for back up use is introduced in the system.

PV panels are set up on the roof of a school and central building with the angle of 15 degrees toward the direction of the south, and solar radiation meters and thermometers are installed at 4 points for each. In 2014, after two years of the operation commencement, PV panels (12 kW) were added due to the power demand increase, and future expansion plan of PV panels (approx. 20 kW) has been considered.

The installed batteries are the open type lead storage battery. The storage capacity of the batteries was originally designed to satisfy the power demand for at least 3 days, however, because the actual power demand has been increased a lot more than expectation, current capacity to cover the demand becomes about 2 days.

The surplus power of the batteries is supplied to the ice factory with two unit of ice producing machines. When the batteries of the No.2 unit are charged 100%, electricity will be supplied automatically to the ice production machine, or the charged level are reduced less than 90 %, power supply will be stopped automatically. Produced ice is sold to fishermen, and its profit has been used for the PVMG operation cost.

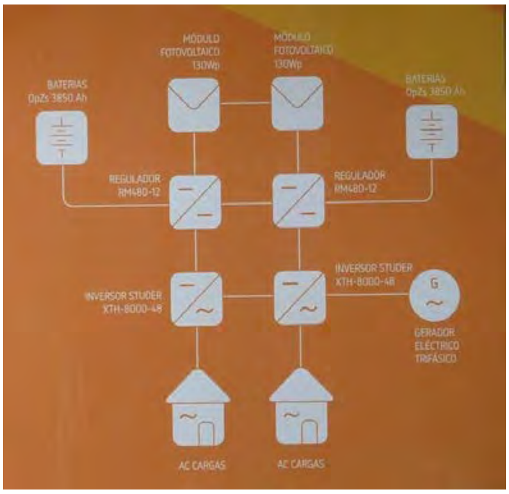
According to APP, averaged cost of generating electricity (facility construction and O&M) by this PVMG is around 30-35 CVE/kW including facility replacement cost.

Payment method of electricity tariff is a prepaid payment card system (RFID) with the tariff escalation in five stages.

The historical change of power producing and consumption from 2012 to 2015 are shown in figure 4.3-4, yearly electricity demand tends to be increased and the increase ratio of last year in 2015 has been reached 15 %

The total amount of electricity generation by pure renewable energy in last 3 years until December 2015 was 127,972kWh. Thanks to the renewable introduction, the fuel use of 37,039 liters for diesel generation and related 111 tons of CO_2 emission have been suppressed.

Details of the emission data above are referred from the SESAM-ER project website. (Table 4.3-2)



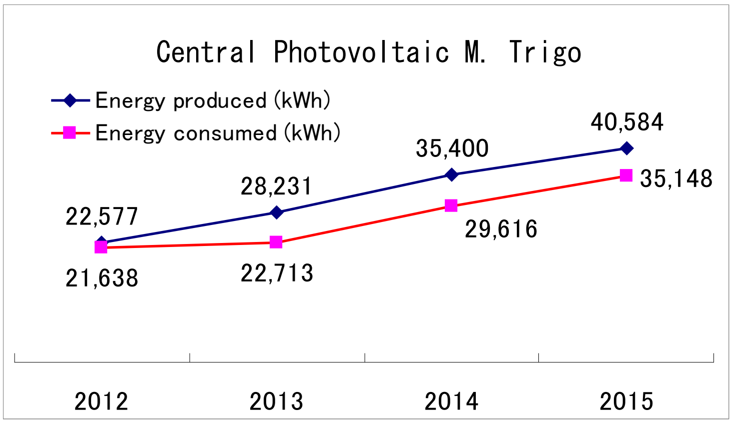
Source: APP

Figure 4.3-3 System configuration

Table 4.3-1 Main specification of system

PV GENERATOR(ATERSA/made in Spain)	
Photovoltaic Capacity Number of modules Module Type	39kWp (210×130Wp＋80×150Wp) ATERSA 130 WSTC
BATTERY (CLASSIC SOLAR/made in France)	
Number of cells Model Total capacity (C100) Autonomy	48(2×24) OPzS Solar 3850Ah 370kWh 3 days
Regulator	
Model Total capacity	RM-480 24kW (2×6×2kW)
INVERTER (XTtender/Switzerland)	
Model Total capacity	STUDER XTH 8000-48 14kW(2×7kW)
Back up Diesel generator (CIRCUTOR/Spain)	
Total capacity	20kVA

Source: JICA Study Team based on Information from APP



Source: APP

Figure 4.3-4 Annual trend chart of Energy production and consumption

Table 4.3-2 Annual historical data list of Monte Trigo Photovoltaic Micro-Grid

Item		2012	2013	2014	2015	Total
Energy production	kWh	22,577	28,231	35,400	40,584	126,792
	Ratio (%)	—	25%	25%	15%	—
Energy consumption	kWh	21,638	22,713	29,616	35,148	109,115
	Ratio (%)	—	5%	30%	19%	—
Reduction of diesel fuel	ℓ	6,640	8,303	10,393	11,703	37,039
	Ratio (%)	—	25%	25%	13%	—
Suppression CO2 emission	t	20	25	31	35	111
	Ratio (%)	—	25%	24%	12%	—

Note: Ratio(%) is previous year increase ratio
Source: APP、www.sesam-er.no.comunidades.net

(3) Operation of PVMG

The charge-discharge operation of batteries is controlled by the threshold value of charging batteries between 35% and 100% under the internal operation rule. For example, when the remaining value of batteries become less than 35 %, following procedure will be implemented.

1) For load suppression of the batteries, public lights will be turned off
2) The batteries will be charged by PV
3) The batteries will be charged by diesel power generation as the final option

The batteries are inspected their specific gravity and voltage by monthly maintenance. The storage room for battery is cooled by natural air and the inverter and monitoring room are controlled temperature by air conditioners (When the Study Team visited the site, the temperature was 19 degrees centigrade).

A local contractor of 2 staff hired by APP provides O&M services to PVMG by two staff (working hour: 8:00-17:00). The staff with mop sponge clean PV panels in 2 days monthly. According to the staff, water for cleaning are supplied from water storage tank of elementary school, and due to the periodical cleaning, efficiency of PV generation is improved as 5 %.

APP`s engineers had been originally dispatched to the site once a month, however, currently the frequency of dispatch is reduced until once a 2 or 3 months due to the enhancement of the ability of the contractor. The data collection and verification of the site could be possible by the remote terminal of the PCs, however, in case of bad climate and/or weather, data access by the radio will be stacked.

(4) Proposal based on the site visit (note)

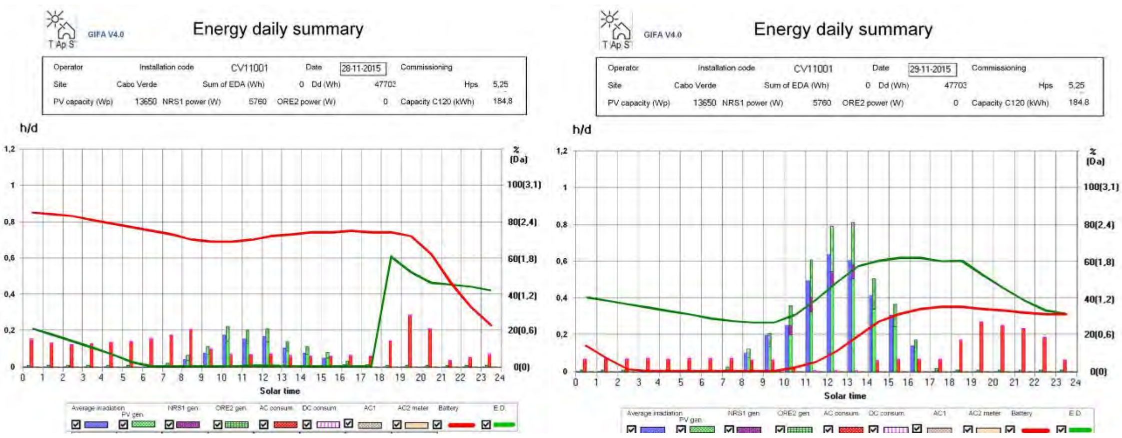
1) Batteries

At the time of our site visit, some sediment was found at the bottom of the pole of No.1 unit of batteries. Therefore, corrosion of electrode plate and phenomenon of sulfating (white lead sulfate-inaction) etc. are supposed to have occurred. Though the failure part of the batteries will be replaced in the future, firstly, to clarify the cause of failure should be conducted (Figure 4.3-6 and Figure 4.3-7).

According to the internal rule, batteries should be controlled by the threshold value of charging batteries between 35% and 100%, however, it was found that the remaining value of batteries had been reached empty sometimes due to the record at the site (from July, 2015 to March 16, 2016). In the historical chart of remaining value of No.1 unit batteries (November 28, 2015 and the 29th) as figure 4.3-5, during about 8 hours (from 3:00 to around 10 o'clock), their charging value became zero indicated as the red line in the chart. Similar cases are also found from the date in August and November, 2015, and the times of operation under 35 % of remaining value in this period was eight. Frequency of empty use of batteries was about once a month, and the timing in the day of these use was from midnight to the next morning.

These empty-operation are supposed to be a cause of degradation and short-term change of batteries. Currently, these batteries are being used within five years, however, degradation and reduction of life expectancy must be accelerated by fully discharge.

As a future countermeasure, in order to avoid excess load of batteries, review of operation plan for batteries and related improved operation should be taken. It seems necessary to consider the future maintenance issues, such as timing of replacement and securing spare parts.



Note: Blue bar: Solar radiation yield [h/day], Green bar: PV yield [h/day], Red bar: Power consumption yield, Red line: remaining battery charge [%] [days]

Source: APP

Figure 4.3-5 Energy daily summary of micro-grid (29 days from November 28, 2015)

Figure 4.3-6 Storage Battery

Figure 4.3-7 Storage Battery electrode

2) Diesel generator for emergency use

The need to tighten joints and replace packing, etc. was communicated to the local contractor since an oil leak was found in the fuel injection nozzle of the diesel generator engine. It will be necessary to check for similar occurrences in other parts during periodic maintenance, etc. in the future (see Figure 4.3-8).

3) Other

An investigation and repair of the faulty section seem necessary, because the lamp indication of No. 1 user information interface is not functioning (see Figure 4.3-9).

Although the team did not look into the measurement of voltage and frequency at the time of the site visit, it also seems necessary to follow items such as voltage, frequency etc. from the viewpoint of ensuring the power quality.

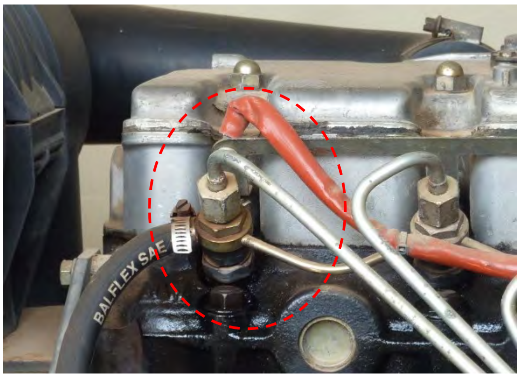


Figure 4.3-8 Fuel injection nozzle of DG

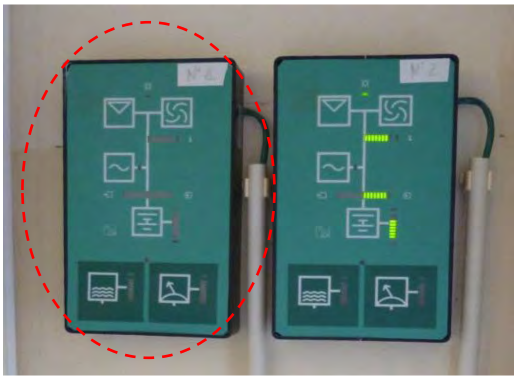


Figure 4.3-9 User information interface

4.3.2 Carriçal Photovoltaic Micro-grid

(1) Carriçal village

Carriçal is a fishing village located on the southeastern coast of the island of São Nicolau and has a population of about 200. Being about 38km away from the urban area of the island (Vila da Riberira Bra), it takes about 60 minutes by car to access the area. Main customers are 53 households (the number of total households is 56), streetlight and an elementary school. Further, the people use well water for drinking and other purposes, and for the most part, the village is not equipped with toilet. There was a fish-canning factory before, but it is closed now, and the part of building on the site is being remodeled as a fishing gear shop for fishermen.

(2) The main outline of micro-grid

The Carriçal Photovoltaic micro-grid started operation in December 2015. This project was implemented under PPP (Public Private Partnership) and APP is responsible for the construction, operation and maintenance of the micro-grid. The city is the owner of the micro grid itself.

The main specifications of the system are given in Table 4.3-3. The PV panels are installed on the roof of the school and Central at a 16-degree angle facing west, with a solar radiation meter and thermocouple at each location. Reportedly, they gave up south-facing arrangement due to space limitations. The battery used is the gel lead battery of the sealed type. The maximum demand is about 12 kW, and the electric bill collection with the use of the prepaid card (RFID system) is planned for after June 2016.

Figure 4.3-10 Carriçal Photovoltaic (PV panel)

Table 4.3-3 Main specification of system

PV GENERATOR (S-energy/made in Korea)	
Photovoltaic Capacity Module Type	22kWp(88×250Wp) SM-250PC8
BATTERY (SONNENSCHEIN/made in Germany)	
Number of cells Model	48(2×24) 2V A600 SOLAR A602/1965Ah
Power Condition System（SMA/made in Germany）	
Model	SUNNY TRIPOVER
Back up Diesel generator（made in China）	
Model Rated power Date	24GF-LDE 30kVA/24kW 2008.10

Source: JICA Study Team based on Information from APP

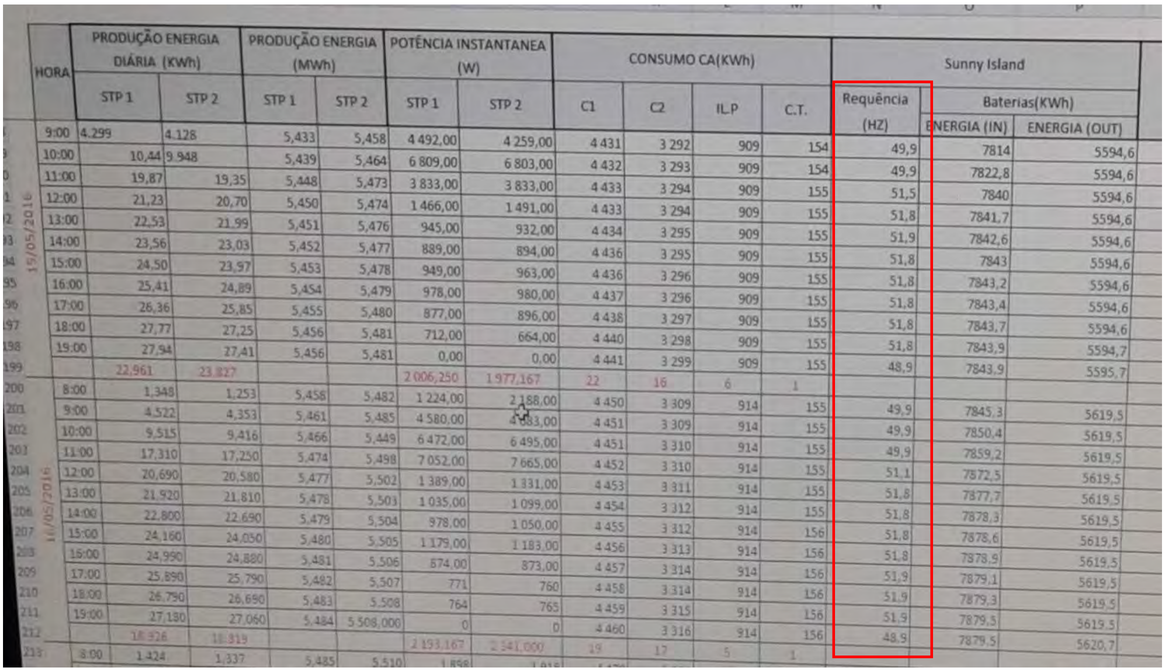
(3) Operation of PVMG

Two local contractors employed by APP operate and maintain the facility in the area (work hours: 8:00-19:00). According to the local contractors, they clean the PV panels twice a month at the interval of 15 days (the 1st and 15th of the month) using a mop sponge, and PV power generation improves by up to 3kW after the panel cleaning.

As for the measurement data, the figures indicated on the PC used for monitoring and measurement are transcribed on paper every hour. The data thus transcribed are entered and managed in the EXCEL table in the PC. APP staff is to visit the site once every 6 months; however, since the micro-grid has not been in operation for 6 months, APP staff has not come to the site.

Figure 4.3-11 PV cable connector

Figure 4.3-12 Storage battery



	HORA	PRODUÇÃO ENERGIA DIÁRIA (KWh)		PRODUÇÃO ENERGIA (MWh)		POTÊNCIA INSTANTANEA (W)		CONSUMO CA(KWh)				Sunny Island		
		STP 1	STP 2	STP 1	STP 2	STP 1	STP 2	C1	C2	ILP	C.T.	Requência (HZ)	Baterias(KWh) ENERGIA (IN)	ENERGIA (OUT)
15/05/2016	9:00	4.299	4.128	5,433	5,458	4 492,00	4 259,00	4 431	3 292	909	154	49,9	7814	5594,6
	10:00	10,44	9.948	5,439	5,464	6 809,00	6 803,00	4 432	3 293	909	154	49,9	7822,8	5594,6
	11:00	19,87	19,35	5,448	5,473	3 833,00	3 833,00	4 433	3 294	909	155	51,5	7840	5594,6
	12:00	21,23	20,70	5,450	5,474	1 466,00	1 491,00	4 433	3 294	909	155	51,8	7841,7	5594,6
	13:00	22,53	21,99	5,451	5,476	945,00	932,00	4 434	3 295	909	155	51,9	7842,6	5594,6
	14:00	23,56	23,03	5,452	5,477	889,00	894,00	4 436	3 295	909	155	51,8	7843	5594,6
	15:00	24,50	23,97	5,453	5,478	949,00	963,00	4 436	3 296	909	155	51,8	7843,2	5594,6
	16:00	25,41	24,89	5,454	5,479	978,00	980,00	4 437	3 296	909	155	51,8	7843,4	5594,6
	17:00	26,36	25,85	5,455	5,480	877,00	896,00	4 438	3 297	909	155	51,8	7843,7	5594,6
	18:00	27,77	27,25	5,456	5,481	712,00	664,00	4 440	3 298	909	155	51,8	7843,9	5594,7
	19:00	27,94	27,41	5,456	5,481	0,00	0,00	4 441	3 299	909	155	48,9	7843,9	5595,7
		22,961	23,827			2 006,250	1 977,167	22	16	6	1			
16/05/2016	8:00	1,348	1,253	5,458	5,482	1 224,00	2 188,00	4 450	3 309	914	155	49,9	7845,3	5619,5
	9:00	4,522	4,353	5,461	5,485	4 580,00	4 [illegible]83,00	4 451	3 309	914	155	49,9	7850,4	5619,5
	10:00	9,515	9,416	5,466	5,449	6 472,00	6 495,00	4 451	3 310	914	155	49,9	7859,2	5619,5
	11:00	17,310	17,250	5,474	5,498	7 052,00	7 665,00	4 452	3 310	914	155	51,1	7872,5	5619,5
	12:00	20,690	20,580	5,477	5,502	1 389,00	1 331,00	4 453	3 311	914	155	51,8	7877,7	5619,5
	13:00	21,920	21,810	5,478	5,503	1 035,00	1 099,00	4 454	3 312	914	155	51,8	7878,3	5619,5
	14:00	22,800	22,690	5,479	5,504	978,00	1 050,00	4 455	3 312	914	156	51,8	7878,6	5619,5
	15:00	24,160	24,050	5,480	5,505	1 179,00	1 183,00	4 456	3 313	914	156	51,8	7878,9	5619,5
	16:00	24,990	24,880	5,481	5,506	874,00	873,00	4 457	3 314	914	156	51,9	7879,1	5619,5
	17:00	25,890	25,790	5,482	5,507	771	760	4 458	3 314	914	156	51,9	7879,3	5619,5
	18:00	26,790	26,690	5,483	5,508	764	765	4 459	3 315	914	156	51,9	7879,5	5619,5
	19:00	27,180	27,060	5,484	5,508,000	0	0	4 460	3 316	914	156	48,9	7879,5	5620,7
		18,926	18,319			2 193,167	2 141,000	19	17	5	1			
	8:00	1,424	1,337	5,485	5,510	1 898	[illegible]	[illegible]						

Figure 4.3-13 List of measurement input data（16 days from May 15,2016）

(4) Proposal after a local inspection (important notices)

1) PV panels

The amount of dust on the surface of the PV panels seemed relatively small as of May 27, but dust was seen on the cable connectors on the underside of the panels. Cleaning of the cable connectors might be necessary where possible, since the panels could suffer damage caused by salt, etc. since the coast is nearby.

2) Batteries

Reportedly, no equipment to measure battery voltage has been delivered to the site. Assistance is recommended including technical guidance to local contractors on the maintenance of batteries among other items.

3) Generator for emergency use

The diesel generator of power supply for emergency use was in the state of non-connection to grid, and temporary putting was done. To connect to a grid through a switch beforehand seems also necessary in order to drive immediately for backup power supplies of micro-grid.

4) Fluctuation of a frequency

Based on the recorded data from May 4 to May 26, 2015 obtained at the site, the team observed a possibility of frequency deviating from the stipulated value (50±2Hz). Figure 4.3-13 shows an example from the screen for inputting measured data every hour (May 15 – May 16, 2016). The input values indicate that the frequency fluctuated between 48.9Hz and 51.9Hz. The measures for frequency fluctuation control might have to be considered for the future.

4.3.3 Electrification of Other Small Villages.

(1) XaXa village (information obtained through a hearing with DGE)

XaXa village is a mountain village with about 10 households located in the northern part of Santiago. The demand scale is about 10kW, which is covered by 10kVA of wind and photovoltaic power generation. Batteries are also installed. The village received electricity for free and is likely to be abandoned 10 years from now.

Further aging and population decline are expected for villages such as this, located far away from cities, which will result in more deserted villages. One example given was that young people tend to move to the city where there are many opportunities for education and employment, and send for their parents.

(2) Other small villages

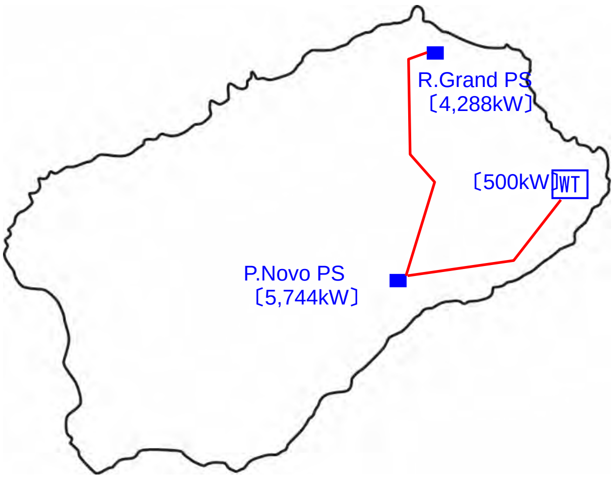
The government's policy on the electrification of small villages such as those described in the preceding section is to promote a micro-grid with small-scale PV and battery, instead of extending the distribution line. The government is also searching for ways to ensure cost reduction and self-sustenance of the contractors through lump-contracts covering the micro-grid operation and maintenance. When creating an off-grid micro-grid, movable PV and battery systems are selected to avoid the investment risk, so that more facilities can be added when the village's electricity demand increases and if there is no longer any demand, they can be moved and utilized again in other locations.

The plan for Santo Antão includes the villages near and around the Agua River (Ribeira da Agua), Alta River (Ribeira Alta) and Figueiral River (Ribeira do igueiral).

5. Power Sources and Facilities

5.1 Santo Antão

Santo Antão has a power demand of about 3,000kW. The electricity is supplied from two diesel PSs and a wind power plant, both operated and managed by Electric. The total output is 10,532kW. Fig. 5.1-1 shows the power supply facilities of Santo Antão.

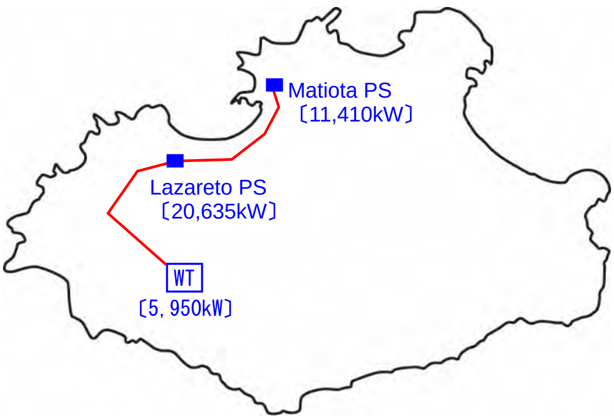


Source: prepared by the Study Team

Figure 5.1-1 Power supply facilities of Santo Antão

5.2 São Vicente

São Vicente has an electricity demand of about 12,100kW. Electricity is supplied to the island by two diesel PSs operated and managed by Electra and a wind power plant run and managed by Cabeolica. The total output is 39,646kW. Fig. 5.2-1 shows the power supply facilities of São Vicente.

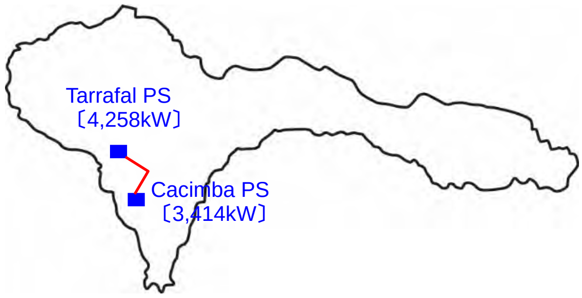


Source: prepared by the Study Team

Figure 5.2-1 Power supply facilities of São Vicente

5.3 São Nicolau

São Nicolau's demand for electricity is about 1,200kW. Two diesel PSs with a total output of 7,672kW operated and managed by Electra supply power to the island. Fig. 5.3-1 shows the power supply facilities of São Nicolau.

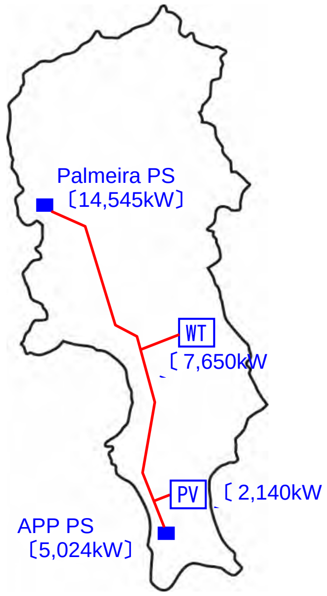


Source: prepared by the Study Team

Figure 5.3-1 Power supply facilities of São Nicolau

5.4 Sal

APP supplies power to the hotels on Sal while Electra and Cabeolica serve the rest of the island. The general demand excluding that of hotels is about 9,800kW. The island's power is supplied by a diesel PS operated and managed by APP, one diesel PS and one photovoltaic power plant run by Electra, and a wind power plant of Cabeolica. Their total output is 29,359kW. Fig. 5.4-1 shows the power supply facilities of Sal.

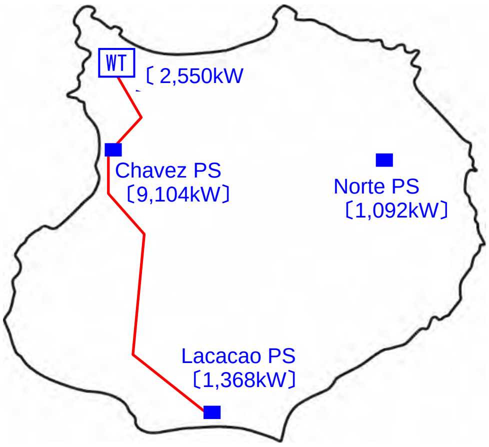


Source: prepared by the Study Team

Figure 5.4-1 Power supply facilities of Sal

5.5 Boa Vista

Boa Vista has a power demand of about 6,100kW, which is served by three diesel PSs operated and managed by AEB and a wind power plant run by Cabeolica. Their total output is 14,114kW. Currently, Norte PS supplies power through an independent system but is slated for connection to the system of Chavez PS in a month or two. Fig. 5.5-1 shows the power supply facilities of Boa Vista.

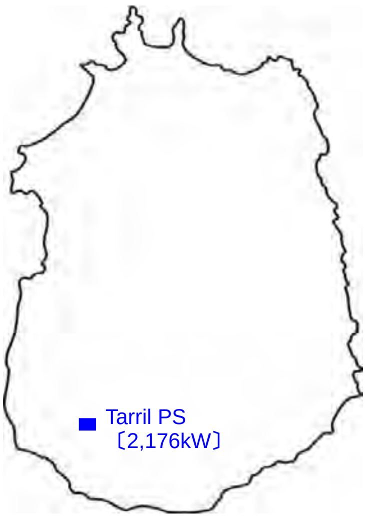


Source: prepared by the Study Team

Figure 5.5-1 Power supply facilities of Boa Vista

5.6 Maio

The electricity demand of Maio is around 500kW. Power is supplied to the island by a diesel PS with a total output of 2,176kW run and managed by Electra. Fig. 5.6-1 shows the power supply facilities of Maio.

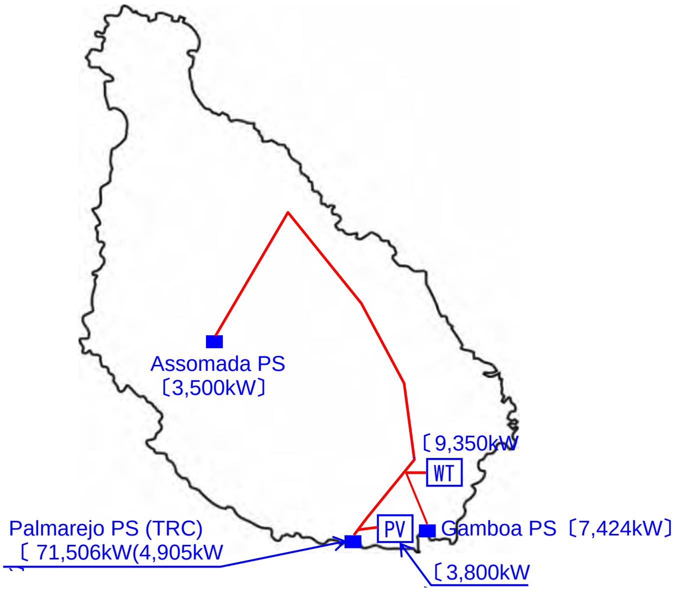


Source: prepared by the Study Team

Figure 5.6-1 Power supply facilities of Maio

5.7 Santiago

Santiago's demand for electricity is about 35,300kW. Power is supplied by four diesel PSs and a photovoltaic power plant operated and managed by Electra, and a wind power plant run by Cabeolica. The total output is 100,965kW. Fig. 5.7-1 shows the power supply facilities of Santiago.

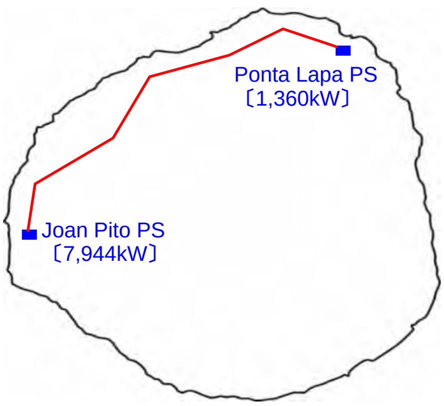


Source: prepared by the Study Team

Figure 5.7-1 Power supply facilities of Santiago

5.8 Fogo

Fogo has an electricity demand of about 2,400kW. Two diesel PSs having a total output of 9,304kW run and managed by Electra supply power to the island. Fig. 5.8-1 shows the power supply facilities of Fogo.

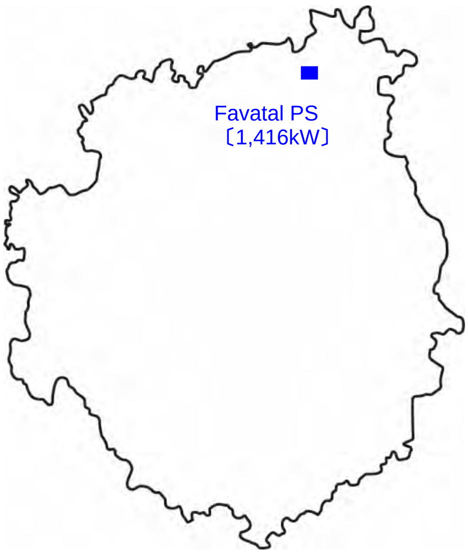


Source: prepared by the Study Team

Figure 5.8-1 Power supply facilities of Fogo

5.9 Brava

The island of Brava has an electricity demand of around 600kW. A diesel PS with a total output of 1,416kW run by Electra provides power to the island. Fig. 5.9-1 shows the power supply facilities of Brava.



Source: prepared by the Study Team

Figure 5.9-1 Power supply facilities of Brava

6. Diesel Power Generation

On a remote island where demand for electricity is not very large, steam-power generation using steam turbines would be expensive since economies of scale would not apply.
For this reason, diesel power is generally adopted to power a remote island, drawing upon its strengths including quick startup and shutdown, excellent load-following capability, ability to meet ever-changing demand, and advantage in terms of cost. Thanks to such features suitable for a remote island, diesel power is adopted by KEPCO that is responsible for supplying electricity to the highest number of remote islands among all utility companies of Japan, as well as in Cabo Verde.
Below is a brief explanation of diesel power generation, followed by the description of the diesel power facility and operation status of Cabo Verde.
Diesel power generation refers to electricity production driven by a diesel engine. The diesel engine burns fuel in its combustion chamber and converts the resultant thermal energy to mechanical work.
External-combustion engines represented by steam turbine, etc. are utilized in large-scale power generation to take advantage of the economies of scale while diesel power is often adopted for power generation of relatively small scale since it has a simple system and can be reduced in size.
With its high thermal efficiency, diesel power boasts excellent economic performance. It is adopted widely for power generation as it can be fueled by heavy oil which is easy to use. Table 6-1 shows the thermal efficiency of various engines and turbines.

Table 6-1 Thermal efficiency of engines and turbines

Type	Diesel engine	Gas turbine	Steam turbine (subcritical)	Gasoline engine
Fuel used	Gasoil, heavy oil	Heavy oil, city gas, natural gas	—	Gasoline
Thermal efficiency (%)	30 - 42	16 - 30	18 - 35	20 - 26

Source: Institute of Electrical Engineers of Japan

(1) Characteristics of diesel power

Diesel power boasts advantages below:
1) With many models developed, optimal models can be chosen to suit the power demand.
2) With short construction period, additions can be built in stages.
3) High thermal efficiency leads to excellent economic performance.
4) Many types of easy-to-use fuel can be utilized.
5) The power facility structure is simple and needs no ignition or fuel gasification devices, etc.

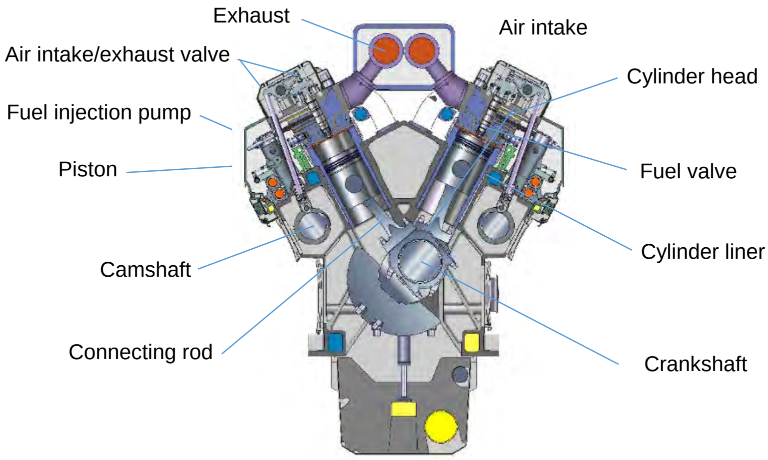
6) Simple and reliable facility can be operated by a small number of staff.
7) Startup and shutdown are quick and load following capability is excellent.

There are however shortcomings as listed below:
1) With limited unit capacity, the price per output is high.
2) With somewhat complex structure, expertise is needed for optimal maintenance.
3) Vibration and noise are likely since it is a reciprocating engine
4) black smoke is emitted during startups and low-output operation.

(2) Diesel engine structure (V type)

Fig. 6.1-1 shows a cross-section example of a diesel engine. The piston compresses the air in the cylinder to high temperature and pressure. The fuel is then injected into the air to create ignition explosion and push the piston downward. The reciprocation of the piston is conveyed to the crankshaft as rotation via the connecting rod, and electricity is produced by driving the generator connected to the crankshaft. The cylinder structure is straight-lined (L-type) in small diesel engines, and generally double-lined and referred to as V type due to the cross-section shape of med- to large-sized engines of 3,000kW or more. Fig. 6-1 shows a cross section of a diesel engine (V-type).

Since the diesel engine adopts compression ignition, it has no electric ignition system and is equipped with a fuel injection system. In the system, the stroke of the roller and the fuel cam on the camshaft that is connected to the crankshaft via a gear operate the fuel injection pump. Fuel is pressurized then atomized and sprayed into the cylinder at the fuel valve.



Source: WARTSILA

Figure 6-1 Diesel engine (V type) cross section

(3) Operation and maintenance

During the operation, the temperature of exhaust, bearing, etc., temperature and pressure of lubricant and cooling water, and tank levels are monitored, and abnormal noise and odor are checked.

The facilities are kept in sound condition, by periodically carrying out performance confirmation tests, measurement of specific fuel consumption and lubricant consumption, lubricant analysis, and exhaust gas measurement, in addition to daily monitoring.

The engine overhaul, cleaning and maintenance, and component replacement must also be done at certain intervals in order to prevent faults, maintain sound operational status and prolong service life of machines. The content and timing of inspection and maintenance might vary somewhat depending on the equipment type, usage and fuel used. One example of the endeavor is given below:

1) Daily inspection
Operation status, e.g. temperature and pressure, and visual inspection by patrol

2) Monthly inspection
Performance confirmation tests for temperature, pressure and specific fuel consumption, as well as greasing of auxiliary equipment, etc.

3) Regular inspection
Overhaul, inspection and maintenance by establishing frequency of inspection by item

(4) Characteristics of diesel engine

The diesel engine adopts natural ignition in which only air is drawn into the cylinder and the atomized fuel is sprayed into the cylinder that has reached high temperature & pressure during the compression process, whereas the gasoline engine, also a reciprocating engine, uses electrical spark for ignition by drawing mixed gas of fuel and air into the cylinder. The diesel engine thus has the following characteristics:

① Low combustion temperature;

② Combustion state is affected greatly by the larger fuel droplets.

Especially in the low-output range, the combustion state tends to worsen due to low scavenging action in addition to decline in temperature inside the cylinder and fuel spray quality.

6.1 Diesel Power Facilities and Operation Status

6.1.1 Santo Antão

Santo Antão has two diesel PPs operated and managed by Electra (P. Novo PP and R. Grand PP), of which P. Novo PP is a state-of-the-art PP newly constructed in June 2015.

Both PPs are solely fueled by gasoil, which is transported from the oil terminal on the island by tank truck. Fig. 6.1-1 shows the diesel power facilities of Santo Antão.

MAN1 and MAN2 of P. Novo PP are capable of utilizing HFO with low unit cost; however, they currently use gasoil since the island has no HFO storage facility. Although there is a plan to build an HFO storage facility by the oil distributor, the construction time is undecided.

P.Nova PP

Fuel tank

MAN 8L21/31(1,672kW)

Obsolete generator

Figure 6.1-1 Diesel power facilities of Santo Antão

(1) Generator operation method

MAN1 and MAN2 (both rated 1,672kW) of P. Novo PP serve as baseload units and others are used as peak-cut units. Table 6.1-1 lists the power facilities of Santo Antão.

(2) Control method

The control method boasts quick response to short-term load fluctuations since the isochronous control is adopted for the governors of the baseload units and the electrical governors with load-sharing functions are used.

On Santo Antão, two 250kW wind power units operated and managed by Electric are interconnected. On the day of the survey, the wind power output fluctuated between 490 and 550kW and the frequency fluctuation at 49.95 - 50.04Hz had almost no impact.

Table 6.1-1 Power facilities of Santo Antão

Station Name	Unit	Installed Capacity (kW)	Engine Maker	Engine Type	Fuel Type	Start of Operation	Status
P. Novo	CAT	1,200	Caterpillar	3512B	Gasoil	2010	Pico/UR
	Cummins	1,200	Cummins	KTA50G8CPL2354	Gasoil	2008	Pico/UR
	MAN1	1,672	MAN	8L21/31	Gasoil	2015	Base
	MAN2	1,672	MAN	8L21/31	Gasoil	2015	Base
R.Grand	Mercedes	400	Mercedes	OM444LAMTU12V183TB	Gasoil	1994	Pico/UR
	Cummins	800	Cummins	KTA50G3CPL2227	Gasoil	1995	Pico/UR
	CAT1	1,088	Caterpillar	3512B	Gasoil	2008	Pico/UR
	CAT2	1,200	Caterpillar	3512B	Gasoil	2000	AV
	Perkins	800	Perkins	4008TAG2	Gasoil	2000	AV
Wind	WT	500	Micon	M530-250	—	2008	
TOTAL	—	10,532	—	—	—	—	—

Base: Base Load, Pico/UR: Peak and Emergency, FS: Out of service, AV: Damaged

Source: Prepared by Study Group based on data and material obtained from Electra and Electric

6.1.2 São Vicente

São Vicente has two diesel PPs operated and managed by Electra (Lazareto PP and Matiota PP). Two most-advanced units manufactured by Wartsilla were added to Lazareto PP in 2015. Fig. 6.1-2 shows the diesel PP facilities on São Vicente.
At both PPs, the baseload units are fueled by HFO with low unit price, which is transported from the oil terminal on the island by tank truck.

(1) Generator operation method

War1 and War2 (both rated 5,520kW) of Lazareto PP and Mak5 and Mak6 (both rated 3,300kW) of Matiota PP serve as baseload units and others are used as peak-cut units. Table 6.1-2 lists the power facilities of São Vicente.

(2) Control method

The control method boasts quick response to short-term load fluctuations since the isochronous control is adopted for the governors of the baseload units and the electrical governors with load-sharing functions are used.

Lazareto PP

Control room

CAT 8CM32C (3,840kW)

Wartsilla W12V32(5,520kW)

Figure 6.1-2 Diesel power facilities of São Vicente

Table 6.1-2 Power facilities of São Vicente

Station Name	Unit	Installed Capacity (kW)	Engine Maker	Engine Type	Fuel Type	Start of Operation	Status
Lazareto	Cummins	1,915	Cummins	QSK60-G4 CPL2888	gasoil	2014	Pico/UR
	CAT1	3,840	Caterpillar	8CM32C	HFO	2014	Pico/UR
	CAT2	3,840	Caterpillar	8CM32C	HFO	2002	Pico/UR
	War3	5,520	Wartsilla	W12V32	HFO	2015	Base
	War4	5,520	Wartsilla	W12V32	HFO	2015	Base
Matiota	Deu3	2,340	Deutz	BV8M540	Gasoil	1975	Pico/UR
	Deu4	2,470	Deutz	BV8M540	Gasoil	1983	Pico/UR
	Mak5	3,300	Mak	9M453C	HFO	1994	Base
	Mak6	3,300	Mak	9M453C	HFO	1994	Base
Wind	WT	5,950	Vestas	V52-850kW	—	2011	—
TOTAL	—	39,645	—	—	—	—	—

Base: Base Load, Pico/UR: Peak and Emergency, FS: Out of service, AV: Damaged

Source: prepared by Study Group based on data and material obtained from Electra and Cabeolica

(3) Past and planned constructions and refurbishments

The damaged crankshaft was replaced at CAT1 (3,840kW) of Lazareto PP in 2014 and CAT2 (3,840kW) was moved to the island of Sal. This CAT2 (3,840kW) is slated for an upgrade to install a new engine.

6.1.3 São Nicolau

São Nicolau has two diesel PPs operated and managed by Electra (Cacimba PP and Tarrafal PP). Cacimba PP is an advanced PP built in November 2015. Two out of four units at older Tarrafal PP are out of order and slated for dismantlement in the near future.
Both PPs are solely fueled by gasoil, which is transported from the oil terminal on the island by tank truck. Fig. 6.1-3 shows the diesel power facilities of São Nicolau.


Cacimba PP


Perkins (1,707kW) of Cacimba PP

Tarrafal PP


Cammins (1,150kW) of Tarrafal PP

Figure 6.1-3 Diesel power facilities of São Nicolau

(1) Generator operation method

Per1 and Per2 (both rated 1,707kW) of Cacimba PP serve as baseload units and others are used as peak-cut units. Table 6.1-3 lists the power facilities of São Nicolau.

The demand is about 1,100kW at the maximum, which can be covered solely by Per (1,707kW). However, both Per1 and Per2 are operated to control reactive power. This forces the units to operate at extremely low output (20 – 30% of the rated output). Reportedly, reactive power measures are being examined at the ELECTORA head office.

(2) Control method

The control method boasts quick response to short-term load fluctuations since the isochronous control is adopted for the governors of the baseload units and the electrical governors with load-sharing functions are utilized.

(3) Past and planned constructions and refurbishments

1) The plan is to dismantle Tarrafal PP in the near future and move Cum5 (1,150kW) to Cacimba PP. There is also a plan to relocate a unit from P.Novo PP on the island of Santo Antão to Cacimba PP.

Table 6.1-3 Power facilities of São Nicolau

Station Name	Unit	Installed Capacity (kW)	Engine Maker	Engine Type	Fuel Type	Start of Operation	Status
Cacimba	Per1	1,707	Perkins	4012-46TAG3A	Gasoil	2015	Base
	Per2	1,707	Perkins	4012-46TAG3A	Gasoil	2015	Base
Tarrafal	Cum3	1,227	Cummins	KTA50G3CPL6229	Gasoil	1998	AV
	Cum4	731	Cummins	KTA38G8CPL1541	Gasoil	1990	Pico/UR
	Cum5	1,150	Cummins	KTA50G3CPL2227	Gasoil	2008	Pico/UR
	Cum6	1,150	Cummins	KTA50G3CPL1528	Gasoil	1990	AV
TOTAL	—	7,672	—	—	—	—	—

Base: Base Load, Pico/UR: Peak and Emergency, FS: Out of service, AV: Damaged

Source: prepared by Study Group based on data and material obtained from Electra

6.1.4 Sal

Sal has a diesel PP operated and managed by Electra (Palmeira PP) and that run by APP. APP's PP supplies power to hotels in the neighboring areas.

The units serving as baseload units at both PPs are fueled by HFO with low unit cost, which is transported from the oil terminal on the island by tank truck. Fig. 6.1-4 shows the diesel power facilities of Sal.

(1) Generator operation method

CAT1 and CAT2 (both rated 3,840kW) of Palmeira PP serve as baseload units and others are used as peak-cut units. APP' PP supplies power to hotels, and its War4 and War5 (both rated 1,540kW) are operated as baseload units. Table 6.1-4 lists the power facilities of Sal.

Palmeira PP

Control room

MAN 8L21/31(1,630kW)

CAT 8CM32C (3,840kW)

Cammins (1,975kW)

CAT (3,840kW) moved from São Vicente

[unutilized]

APP PP

Wartsilla (1,540kW)

Figure 6.1-4 Diesel power facilities of Sal

(2) Control method

The control method boasts quick response to short-term load fluctuations since the isochronous control is adopted for the governors of the baseload units and electrical governors with load-sharing functions are used at both Palmeira PP and APP PP.

(3) Past and planned constructions and refurbishments

1) In Palmeira power plants, in order to cope with increased demand centered on the tourism industry, financed by the AFD (French Development Agency), it is planning to introduce the HFO diesel of 6MW (1.5MW × 4 units) in 2016 year.
2) Three CAT (648kW) units at APP PP are to be replaced to 3,000kW units in the near future.

Table 6.1-4 Power facilities of Sal

Station Name	Unit	Installed Capacity (kW)	Engine Maker	Engine Type	Fuel Type	Start of Operation	Status
Palmeira	CAT1	3,840	Caterpillar	8CM32C	HFO	2002	Base
	CAT2	3,840	Caterpillar	8CM32C	HFO	2002	Base
	MAN1	1,630	MAN	8L21/31	HFO	2010	Pico/UR
	MAN2	1,630	MAN	8L21/31	HFO	2010	Pico/UR
	MAN3	1,630	MAN	8L21/31	HFO	2010	Pico/UR
	Cummins	1,975	Cummins	QSK60-G4	Gasoil	2014	Pico/UR
APP	CAT1	648	Caterpillar		Gasoil	2001	Pico/UR
	CAT2	648	Caterpillar		Gasoil	2001	Pico/UR
	CAT3	648	Caterpillar		Gasoil	2001	Pico/UR
	War4	1,540	Wartsilla		HFO	2006	Base
	War5	1,540	Wartsilla		HFO	2006	Base
Solar	PV	2,140			—	—	—
Wind	WT	7,650	Vestas	V52-850kW	—	—	—
TOTAL	—	29,359	—	—	—	—	—

Base: Base Load, Pico/UR:Peak and Emergency, FS: Out of service, AV: Damage

Source: prepared by Study Group based on data and material obtained from Electra, APP and Cabeolica

6.1.5 Boa Vista

Boa Vista has three diesel PPs operated and managed by AEB (Chavez PP, Lacacao PP and Norte PP). The northern area has an independent system and receives power from Norte PP. There is a plan to connect it to Chavez PP system in a month or two as ORET project. Fig. 6.1-5 shows the diesel power facilities of Boa Vista. The units serving as baseload units use HFO with low unit cost as fuel, which is transported from the oil terminal on the island by tank truck.

(1) Generator operation method

War1 and War2 (both rated 1,620kW) of Chavez PP serve as baseload units and others are used as peak-cut units. Table 6.1-5 lists the power facilities of Boa Vista.


Chavez PP


Wartsilla (1,620kW)


Lacacao PP


CAT (648kW & 720kW)


Norte PP


CAT (364kW)

Figure 6.1-5 Diesel power facilities of Boa Vista

(2) Control method

The control method boasts quick response to short-term load fluctuations since the isochronous control is adopted for the governors of the baseload units and the electrical governors with load-sharing functions are used at Chavez PP.

(3) Past and planned constructions and refurbishments

1) There is a plan to add two 1,000kVA units by Perkins at Chavez PP in June 2016, and further add one 4,000kVA unit in August – September 2016.

Table 6.1-5 Power facilities of Boa Vista

Station Name	Unit	Installed Capacity (kW)	Engine Maker	Engine Type	Fuel Type	Start of Operation	Status
Chavez	War1	1,620	Wartsilla	W9L20	HFO	2009	Base
	War2	1,620	Wartsilla	W9L20	HFO	2014	Base
	Mitsubishi	1,600	Mitsubishi	S16R	Gasoil	2014	Pico/UR
	CAT2000	1,600	Caterpillar		Gasoil	2008	Pico/UR
	CAT3412	648	Caterpillar		Gasoil	2008	Pico/UR
	CAT3412	648	Caterpillar		Gasoil	2008	FS
	CAT3412	648	Caterpillar		Gasoil	2008	FS
	CAT3412	720	Caterpillar		Gasoil	2009	FS
Lacacao	CAT3412	648	Caterpillar		Gasoil	2008	Pico/UR
	CAT3412	720	Caterpillar		Gasoil	2009	FS
Norte	CAT3456	364	Caterpillar		Gasoil	2012	Base
	CAT3456	364	Caterpillar		Gasoil	2011	FS
	CAT3456	364	Caterpillar		Gasoil	2011	FS
Wind	WT	2,550	Vestas	V52-850kW	—	—	—
TOTAL	—	14,114	—	—	—	—	—

Base: Base Load, Pico/UR: Peak and Emergency, FS: Out of service, AV: Damage

Source: prepared by Study Group based on data and material obtained from AEB and Cabeolica

6.1.6 Maio

Although Maio was not covered by the Site Survey, it has a diesel PP operated and managed by Electra (Tomil PP) fueled solely by gasoil, according to data obtained from Electra.

(1) Generator operation method

Cum1 (rated 688kW) and CAT3 (rated 600kW) of Tomil PP serve as baseload units while other two units (CAT2 with 200kW and Cum3 with 688kW) are out of order. Table 6.1-6 lists the power facilities of Maio.

Table 6.1-6 Power facilities of Maio

Station Name	Unit	Installed Capacity (kW)	Engine Maker	Engine Type	Fuel Type	Start of Operation	Status
Tomil	Cum1	688	Cummins		Gasoil	2008	Base
	CAT2	200	Caterpillar	3412	Gasoil	1999	AV
	Cum3	688	Cummins		Gasoil	2008	FS
	CAT3	600	Caterpillar	3412	Gasoil	2001	Base
TOTAL	—	2,176	—	—	—	—	—

Base: Base Load, Pico/UR: Peak and Emergency, FS: Out of service, AV: Damaged
Source: prepared by Study Group based on data and material obtained from Electra

(2) Control method

The control method is unknown since this Site Survey did not cover the item.

6.1.7 Santiago

Santiago has four diesel PPs operated and managed by Electra (Palmarejo PP, TRC PP, Gamboa PP and Assomada PP). Palmarejo PP expanded two state-of-the-art units by Wartsilla in 2012 and two in 2015. Figs. 6.1-6 and 6.1-7 show the diesel power facilities of Santiago. The units serving as baseload units are fueled by HFO which has low unit cost and is transported from the oil terminal on the island by tank truck.

(1) Generator operation method

Wartsilla and CAT of Palmarejo PP serve as baseload units while others are used as peak-cut units. Table 6.1-7 lists the power facilities of Santiago.

Palmarejo PP

Control room

Figure 6.1-6 Diesel power facilities of Santiago

MAN (5,582kW)

Wartsilla (11,384kW)

Fuel purification facility

Cooling water facility

Figure 6.1-7 Diesel power facilities of Santiago

(2) Control method

The control method boasts quick response to short-term load fluctuations since the isochronous control is adopted for the governors of the baseload units and electrical governors with load-sharing functions are used at Palmarejo PP.

On Santiago, eleven 850kW wind power units operated and managed by Cabeolica are interconnected, and on the day of the survey, the frequency fluctuation was 49.09 - 50.08Hz which fell within the operational target value (49.0 - 51.0Hz) of Cabo Verde.

(3) Past and planned constructions and refurbishments

1) Gamboa PP and TRC PP are to be scrapped before long; however, the decision will be made when the units suffer major failure, thus the actual time for scrapping is uncertain.
2) Assomada PP is to be left as backup since it is located in an inland area.
3) There is a plan to move the facilities of TRC PP to Sal.

Table 6.1-7 Power facilities of Santiago

Station Name	Unit	Installed Capacity (kW)	Engine Maker	Engine Type	Fuel Type	Start of Operation	Status
Palmarejo	CAT1	5,582	Caterpillar	12CM32	HFO	2002	Base
	CAT2	5,582	Caterpillar	12CM32	HFO	2002	FS
	CAT3	7,437	Caterpillar	16CM32	HFO	2008	Base
	CAT4	7,437	Caterpillar	16CM32	HFO	2008	Pico/UR
	War5	11,350	Wartsilla	W12V46	HFO	2012	Base
	War6	11,350	Wartsilla	W12V46	HFO	2012	Base
	War7	11,384	Wartsilla	W12V46	HFO	2015	Base
	War8	11,384	Wartsilla	W12V46	HFO	2015	Base
TRC	MAN1	1,635	MAN	8L21/31	HFO	2011	Pico/UR
	MAN2	1,635	MAN	8L21/31	HFO	2011	Pico/UR
	MAN3	1,635	MAN	8L21/31	HFO	2011	Pico/UR
Gamboa	Deu5	2,360	Deutz		Gasoil	1987	Pico/UR
	Mak6	2,532	Mak		Gasoil	1991	Pico/UR
	Mak7	2,532	Mak		Gasoil	1992	FS
Assomada	CAT1	1,050	Caterpillar	3512B	Gasoil	2009	Pico/UR
	CAT2	1,050	Caterpillar	3512B	Gasoil	2009	Pico/UR
	Perkins	600	Perkins		Gasoil	1999	Pico/UR
	Cummins	800	Cummins		Gasoil	1999	Pico/UR
Solar	PV	4,200					
Wind	WT	9,350	Vestas	V52-850kW	—	—	—
TOTAL	—	100,965	—	—	—	—	—

Base: Base Load, Pico/UR: Peak and Emergency, FS: Out of service, AV: Damage

Source: prepared by Study Group based on data and material obtained from Electra and Cabeolica

6.1.8 Fogo

Fogo has two diesel PPs operated and managed by Electra (Joan Pinto PP and Ponta Lapa PP). Joan Pinto PP welcomed two most advanced units by MAN in 2015. Fig. 6.1-8 shows the diesel power facilities of Fogo. Both PPs only use gasoil as fuel which is transported from the oil terminal of the island by tank truck. MAN1 and MAN2 of Joan Pinto PP are capable of utilizing HFO with low unit cost; however, they currently use gasoil since the island has no HFO storage facility. There is a plan to receive HFO directly from a tanker.

Joan Pinto PP

Fuel tank

MAN (1,672kW)

Fuel purification facility

Diesel power monitoring & control

System monitoring & control

Figure 6.1-8 Diesel power facilities of Fogo

(1) Generator operation method

MAN1 and MAN2 (both rated 1,672kW) of Joan Pinto PP serve as baseload units and others are used as peak-cut units. Table 6.1-8 lists the power facilities of Fogo.

(2) Control method

The control method boasts quick response to short-term load fluctuations since the isochronous control is adopted for the governors of the baseload units and the electrical governors with load-sharing functions are used at Joan Pinto PP.

Table 6.1-8 Power facilities of Fogo

Station Name	Unit	Installed Capacity (kW)	Engine Maker	Engine Type	Fuel Type	Start of Operation	Status
Joan Pinto	Cum1	1,000	Cummins	KTA50-G8	Gasoil	2008	Base
	Cum2	1,000	Cummins	KTA50-G8	Gasoil	1999	Base
	Cum3	840	Cummins	KTA50-G8	Gasoil	2014	Base
	CAT1	1,200	Caterpillar	3512B	Gasoil	2010	Base
	CAT2	560	Caterpillar	C18	Gasoil	2012	FS
	MAN1	1,672	MAN	8L21/31	Gasoil	2015	Base
	MAN2	1,672	MAN	8L21/31	Gasoil	2015	Base
Ponta Lapa	VOL1	200	Volvo		Gasoil	1997	FS
	VOL2	200	Volvo		Gasoil	1997	FS
	CAT	560	Caterpillar	C18	Gasoil	2005	FS
	Mercedes	400	Mercedes	MTU12V-183TB32	Gasoil	1994	Pico/UR
TOTAL	—	9,304	—	—	—	—	—

Base: Base Load, Pico/UR: Peak and Emergency, FS: Out of service, AV: Damage

Source: prepared by Study Group based on data and material obtained from Electra

6.1.9 Brava

Brava has a diesel PP operated and managed by Electra (Favatal PP). Its only fuel is gasoil, transported by truck in oil drums. Fig. 6.1-9 shows the diesel power facilities of Brava.

Favatal PP

Diesel power generation

Fuel tank

Transformer

Figure 6.1-9 Diesel power facilities of Brava

(1) Generator operation method

The generators are operated based on demand, except for Per2 which is out of order. Table 6.2-9 lists the power facilities of Brava.

Table 6.1-9 Power facilities of Brava

Station Name	Unit	Installed Capacity (kW)	Engine Maker	Engine Type	Fuel Type	Start of Operation	Status
Favatal	CAT	256	Caterpillar	3406C	Gasoil	1998	Base
	Per1	400	Perkins	2806A-E18TAG2	Gasoil	2006	Base
	Per2	400	Perkins	2806A-E18TAG2	Gasoil	2006	AV
	Cummins	360	Cummins	VT-1710-G	Gasoil	2006	Base
TOTAL	—	1,416	—	—	—	—	—

Base: Base Load, Pico/UR: Peak and Emergency, FS: Out of service, AV: Damaged
Source: Prepared by Study Group based on data and material obtained from Electra

(2) Control method

The control method boasts quick response to short-term load fluctuations since the isochronous control is adopted for the governors of the baseload units and the electrical governors with load-sharing functions are used.

6.1.10 Power Generation Cost by Island

The group tentatively calculated the fuel cost, which makes up a large portion of power generation cost, based on the fuel price, fuel consumption and generated energy obtained from DGE, Electra, etc. The result revealed the 2015 fuel cost for the entire Cabo Verde to be 13.56CVE/kWh. As for the fuel cost by island, that of four islands (Santiago, São Vicente, Boa Vista and Sal) that use HFO with relatively high demand and low unit price was relatively small at 11.70 - 17.19CVE/kWh while that of the remaining five islands that use gasoil with smaller demand and higher unit price was high at 19CVE/kWh or more. Table 6.1-10 shows the fuel cost of the islands (2015), Fig. 6.1-10 the change in fuel price and Fig. 6.1-11 fuel consumption by oil type (2015).

Table 6.1-10 Fuel cost by island (2015)

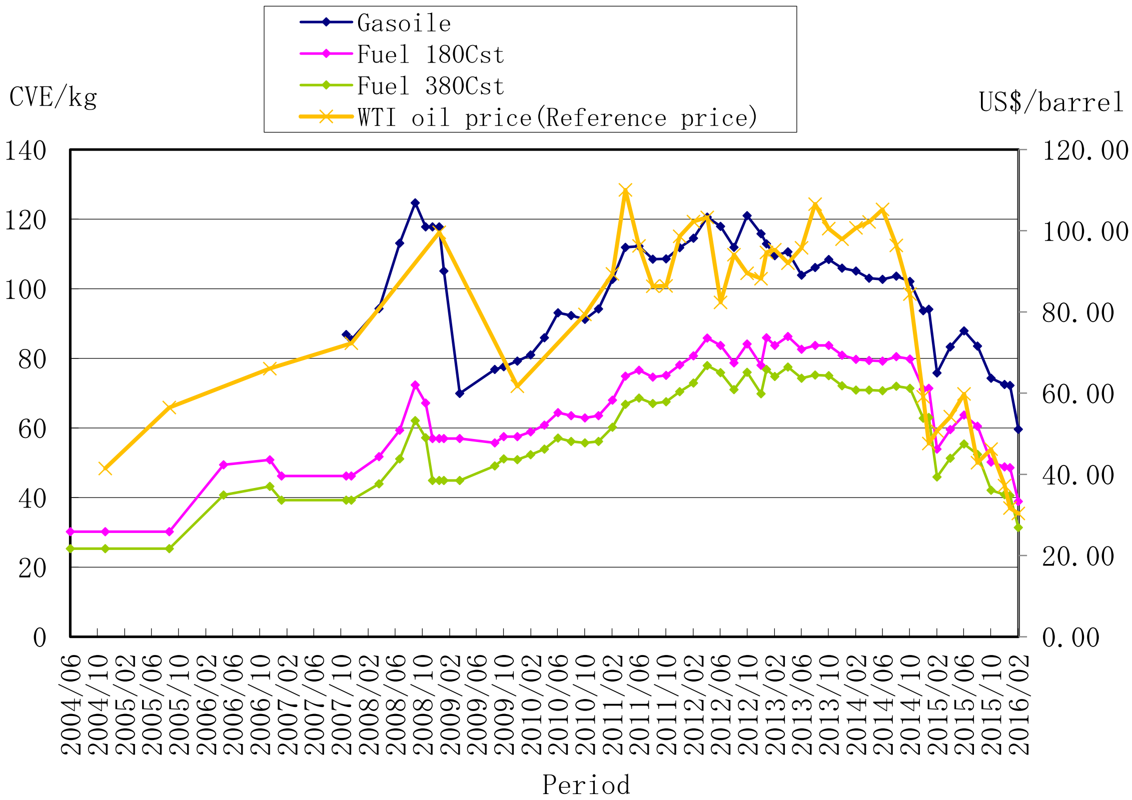
（CVE/kWh）

S.Antão	S.Vicente	S.Nicolau	Sal *1	B.Vista	Maio	Santiago	Fogo	Brava	TOTAL
19.32	11.70	19.78	14.20	17.19	21.04	12.24	19.46	19.42	13.56

*1 Sal (ELECTORA): 13.94CVE/kWh, Sal (APP): 15.06CVE/kWh

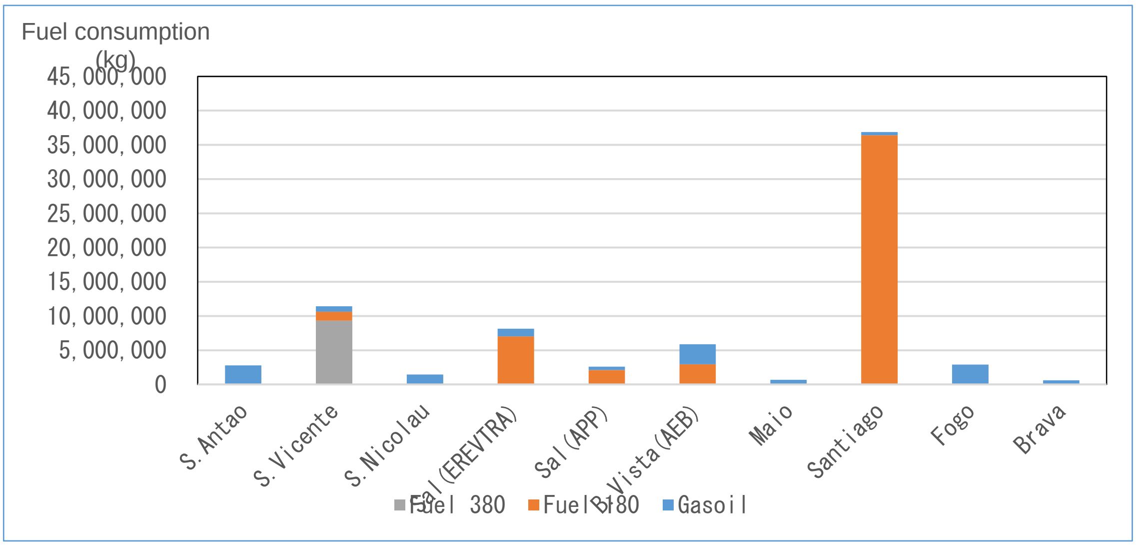
Source: prepared by Study Group based on data obtained from DGE, Electra, etc.

The fluctuation of fuel price is similar to that of crude oil price. It is the same throughout the islands due to Cabo Verde's regulation.



Source: prepared by Study Group based on data obtained from DGE

Figure 6.1-10 Change in fuel price



Source: prepared by Study Group based on data obtained from Electra, etc.

Figure 6.1-11 Fuel consumption by oil type

Table 6.1-11 shows the typical characteristics of HFO (Fuel 180) used by the baseload units. The main characteristics are very similar to those of C heavy oil that Kyushu Electric uses, and with C.C.A.I (calculated carbon aromaticity index) indicating the ignition quality being 860 or less, there should be no problem with combustion.

However, it contains Aluminum plus silicon which is extremely hard and could cause abnormal wear on the fuel injection pump, piston ring, cylinder, etc.; thus the centrifugal oil purifier, pretreatment system and filter must be maintained and managed properly.

Table 6.1-11 Typical characteristics of HFO (Fuel180)

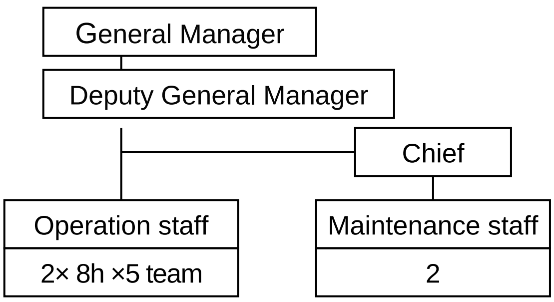
Characteristics	Test method	ENACOL Fuel(*)	Limit	ISO Specs RME 180	ISO Specs RMF180	Reference Kyushu Electric
Density at 15°C, kg/l	ISO 3675	0,9850	max.	0,9910	0,9910	<098
Kinematic viscosity at 50°C	ISO 3104	180,0	max.	180	180	50～180
Flash point, °C	ISO 2719	92	min.	60	60	70<
Pour point, °C	ISO 3016	−3	max.	30	30	<20
Carbon residue, % (m/m)	ISO 10370	13,1	max.	15	20	<13
Ash, % (m/m)	ISO 6245	0,04	max.	0,1	0,15	<0.1
Water, % (V/V)	ISO 3733	0,19	max.	0,5	0,5	<0.5
Sulfur, % (m/m)	ISO 8754	3,35	max.	4,5	4,5	<2.0
Vanadium, mg/kg	IP 288	55	max.	200	500	−
Aluminium plus silicon, mg/kg	IP 377	22	max.	80	80	N.D
Total sediment, potential, % (m/m)	IP 390 + IP 375	<0,01	max.	0,10	0,10	−
Specific energy (net) MJ/kg	Calculated Value	40,12	min.	−	−	−
C.C.A.I.(Calc. Carbon Aromat. Index)	Calculated Value	854	max	−	−	<860
C.I.I.(Calculated Ignition Index)	Calculated Value	34	min.	−	−	−
Spot test stability	ASTM D 4740	−	max.	−	−	−

Source: prepared by Study Group based on data obtained from Electra

6.1.11 Operation and Maintenance of Diesel Power facilities

(1) System of operation and maintenance

Fig. 6.1-12 shows the operation and maintenance system of major PSs of Cabo Verde. This system is very similar to that used by KEPCO and it would be hard to further improve efficiency while ensuring a stable operation and the passing down of skills.



Source: prepared by the Study Team based on hearing with Electra

Figure 6.1-12 System of operation and maintenance for major PSs

(2) Operation method

Efficient units are used for baseload operation. The operation method seems appropriate as the majority of the PSs are engaged in operation with an awareness of the adverse effect of low-output operation.

However, the performance is not checked on a regular basis. The study team recommends the periodical implementation of the performance confirmation test, measurement of specific fuel consumption and lubricant consumption, etc. in addition to daily monitoring for the stable operation and performance retention of the diesel power facility as described at the beginning of the chapter.

(3) Maintenance

The diesel power facility is generally inspected and maintained at intervals and for items as recommended by the manufacturer. Since the inspection and maintenance work for the diesel power facility could vary depending on the environment and service condition, KEPCO has created optimal maintenance criteria based on the analysis and evaluation of past inspection records, thereby ensuring stable operation and cost reduction. It is desirable for Cabo Verde to adopt the same practice by analyzing and evaluating the record of past inspections and creating criteria for optimal maintenance.

6.2 Future Challenges for Diesel Power

6.2.1 Key Points and Challenges towards Renewables Expansion

In order to increase the allowable renewable capacity to be introduced, it is important to properly operate, maintain and manage diesel power plants which serve as a base power source and regulated power source to balance the output from renewable facilities that fluctuates with the weather. It is also critical to ensure frequency regulation capability and margin for output reduction (minimum output).

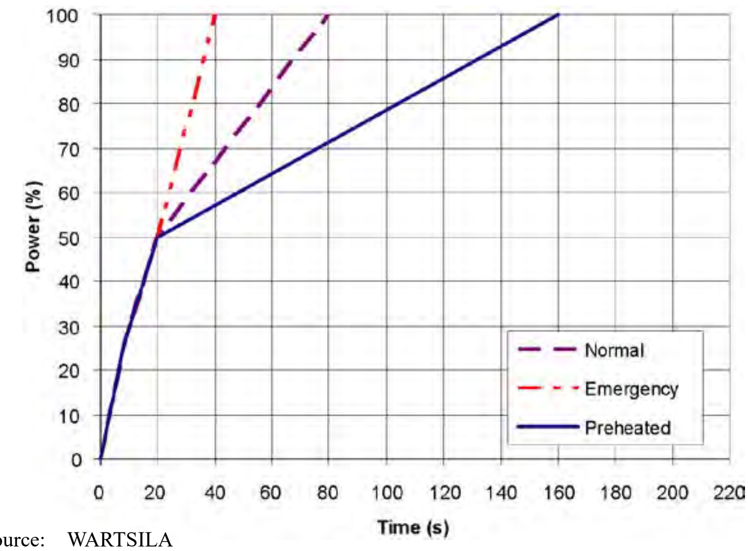
1) Frequency adjustment control (aspect of short term adjustment)

Diesel generators can control output from maximum to minimum and vice versa in short time with superior load-following capability. The governor of a diesel generator turns up and down the input of the engine in order to keep the rotating speed of the generator constant. The operation of governor without restriction so that the governor can fully respond to the fluctuation of frequency, is regarded as governor-free operation. In governor-free operation, the output of the generator automatically increases if the frequency decreases (i.e., the rotation of the generator decreases) and vice versa to stabilize the frequency of electric power system. The generators with governor-free operation capability can absorb and stabilize the fluctuating frequency and output in so-called short term (within minutes). During site survey and with collected documentations such as the specifications of the facilities, the Study Team confirmed that the diesel generators installed in Cabo Verde are capable of governor-free operation.

Thus, the Study Team assumes that the fluctuation of wind power generation can be absorbed and managed by the operation of diesel generators, in consideration of stable wind state of Cabo Verde.

However, since frequent rise and fall of diesel generator output negatively affects the durability, it is essential to study and take necessary actions based on the research on the fluctuations of wind power output before implementing abovementioned operation.

Fig. 6.2-1 shows the rate of load increase of Wartsila 32 diesel engine installed in Lazareto Power Station, São Vincente according to the recommendation by the manufacturer. The rate of load decrease is similar.



Source: WARTSILA

Figure 6.2-1 Load increase rate recommended by Wartsila 32 manufacturer

(2) Minimum output

As described in “6 Outline of diesel power generation,” the diesel engine adopts natural ignition in which only air is drawn into the cylinder and the atomized fuel is sprayed into the cylinder that reached high temperature & pressure during the compression process, unlike the gasoline engine, also a reciprocating engine, that uses electrical sparks to ignite the mixed gas of fuel and air drawn into the cylinder. Due to this reason, the diesel engine has a tendency to produce unburned carbon in the low-output range, more specifically:

[Temperature drop inside the cylinder]

Since the diesel engine uses natural ignition in which atomized fuel is sprayed into the cylinder that reached high temperature and pressure during the compression process, the low output causes the drop in combustion temperature and thus the temperature inside the cylinder, leading to a deterioration of the combustion state.

[Drop in the scavenging efficiency inside the cylinder]

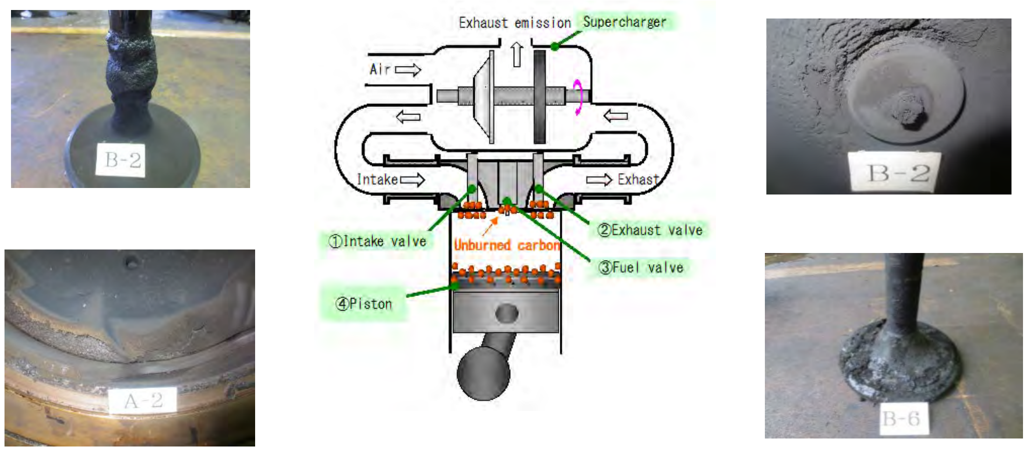
In the diesel engine with supercharger, both the exhaust valve and air intake valve are opened (overlap) when moving from the exhaust stroke to air intake stroke, and the combustion gas is pushed out with the air intake. However, under low output, a decrease in the gas volume slows the supercharger rotation and causes the scavenging action to worsen. It results in combustion gas remaining in the cylinder.

[Worsening of fuel spray quality]

In the diesel engine, fuel pressurized by the fuel injection pump is sprayed directly into the cylinder through the fuel valve. When output drops, the spray pressure goes down. It causes the atomized fuel droplets to become large and harder to burn.

[Adverse effect of low-output operation]

If low-output operation continues for a prolonged period, it causes a drop in temperature and scavenging action inside the cylinder, which worsens the fuel spray quality. It leads to poor combustion and resultant unburned carbon adhering to the cylinder and piston, resulting in damage in the air intake/exhaust valves and piston. Fig. 6.2-2 shows troubles that Kyushu Electric experienced under low-output operation.



Source: prepared by Study Group

Figure 6.2-2 Troubles suffered by Kyushu Electric Power under low-output operation

3) Available Minimum Load Operation (aspect of long term adjustment)

Air sufficient for combustion and adequately fine fuel spray is essential for stable operation of diesel generators. The minimum load to achieve the conditions is generally around 50% of the rated output. However, with adjustable suction valve timing and suction preheating system, a diesel generator can operate at around 30% of the rated output. In fact, Kyushu Electric Power, the leading company holding 315MW, six-tenth of the diesel generation facilities in Japan, has been introducing the diesel generator with such function in order to maximize the capacity for the penetration of renewable energies, when generation facilities are introduced or expanded.

The Study Team reviewed the specifications of the diesel generators recently introduced in Cabo Verde. As the result, it is confirmed that the diesel generators manufactured by Wartsila installed in Lazareto Power Station, São Vicente and Palmarejo Power Station, Santiago, can operate at as low as around 30% of the rated output.

Therefore, even though the specific fuel consumption may worsen more or less, there is plenty room for further introduction of renewable energy, by governor-free operation described previously and full utilization of the potential to depress minimum load. Furthermore, the economic effect by decreased diesel fuel consumption outweighs the degeneracy of specific fuel consumption.

Table 6.2-1 and Table 6.2-2 shows the minimum loads of Wartsila diesel generators recently installed in Lazareto Power Station, São Vincente and Palmarejo Power Station, Santiago.

Fig. 6.2-3 shows the specific fuel consumption of the major units of Kyushu Electric Power for reference

Table 6.2-1 Minimum output of Wartsila W32

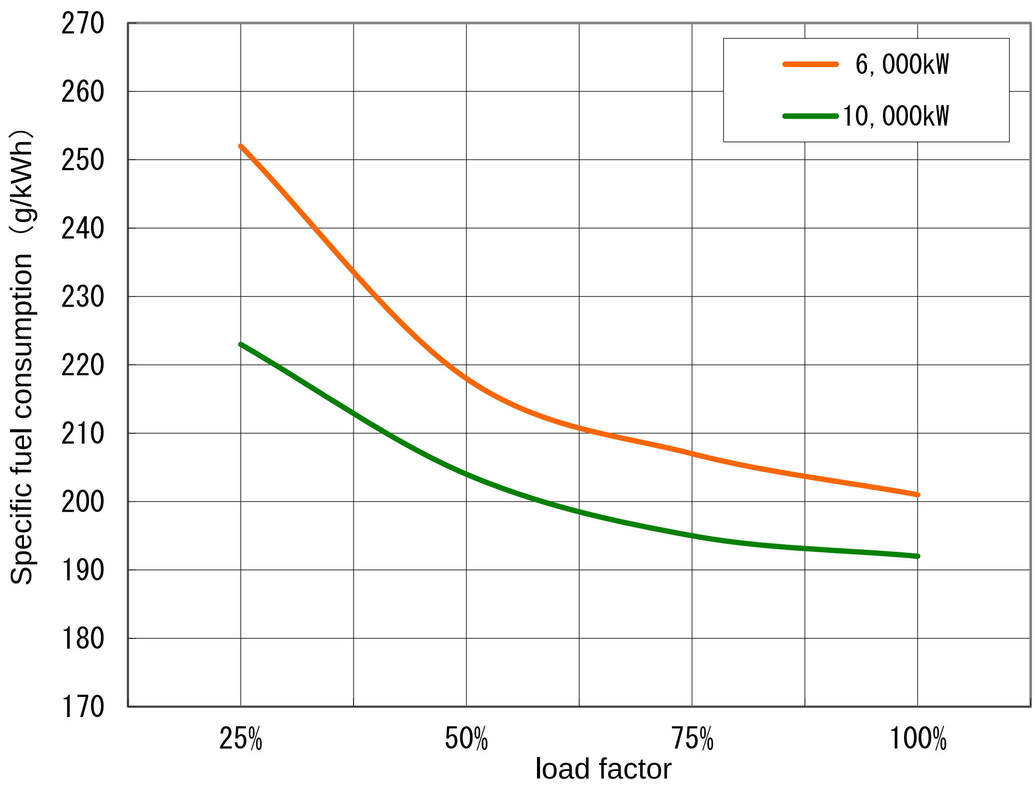
Engine type	W32			W32TS
VIC existence Fuel	W/O VIC (T>5℃) **	W VIC LFO(T>20℃) **	W VIC HFO, CRO, LBF(T>40℃), LFO(>5℃)**	W/VIC only HFO, CRO, LBF(T>40℃), LFO(>5℃)**
Idling (no load) duration (max.)	30min*	10hours*	30min*	30min*
Duration of intermittent low-output operation (max.)	10-20% max 3h, 20-30% max 10h*	10-20% max 3h, 20-30% max 50h*	10-20% max 10h, 20-30% max 30h*	–
Unrestricted continuous operation at minimum load	>30%	>30%	>30%	>35%
	*) Operate for 60 mins at 70% or more after reaching the max. duration **) air receiver temperature			

Source: WARTSILA

Table 6.2-2 Minimum output of Wartsila W46

Engine type	W46
Idling (no load) duration (max.)	10min before stop*
Duration of intermittent low-output operation (max.)	5-20%, max 100h*
Unrestricted continuous operation at minimum load	>20% *) Operate for 60 mins at 70% or more after reaching the max. duration

Source: WARTSILA



Source: prepared by the Study Team

Figure 6.2-3 Specific fuel consumption of the major units of Kyushu Electric Power

6.2.2 Issues and Measures toward Renewables Expansion

After the expansion of renewables use, diesel power will become more and more important not only as a base power source but also as that to balance output from renewable facilities, which fluctuates with weather. To this end, the diesel power facility must be operated and maintained in an appropriate manner to keep up with the renewables expansion. More specifically, it is desirable to implement measures listed below:

(1) Operation-related measures

- Select optimal units based on forecasted demand and renewables output
- Conduct patrol and inspection to better monitor the operation state such as exhaust temperature and to prepare for an increase in troubles
- Carry out voltage operation with consideration to the generator's voltage regulation capability (PQ curve)
- Carry out cleaning operation to burn and eliminate unburned carbon after low-output operation

(2) Maintenance-related measures

The state of diesel power generation changes with the operating condition. It is necessary to analyze and evaluate the inspection result, and review the maintenance intervals as needed. In particular:

- Maintain performance level through regular performance confirmation tests and measurement of specific fuel and lubricant consumptions, etc.
- Establish and implement the optimal maintenance criteria through analysis and evaluation of the inspection result.

(3) Facility-related measure

On most of the islands of Cabo Verde, the capacity per unit and installed capacity are too large for the demand scale. Thus, it is desirable to optimize the capacity per unit in future installations and additions.

7. Wind Power Generation

7.1 Operation Status of the Wind Power Generation System

This section summarizes the operation statuses of wind power generation systems in Cabo Verde.

7.1.1 Wind Power Generation System Installation Status

In Cabo Verde, the wind power generation systems that are owned by two wind power IPP operators (Cabeolica and Electric) are operating in five islands (Santo Antão, São Vicente, Sal, Boa Vista, and Santiago).
The total wind power generation capacity of the systems that are operating in the five islands of Cabo Verde is 26.0MW.
Cabeolica commenced the operation of the wind power generation systems in four islands during the period from October 2011 to April 2012 and Electric commenced the operation of the wind power generation systems in one island in April 2011.
Table 7.1-1 shows the capacities of the power generation systems by island.

Table 7.1-1 Capacity of the power generation system by island

Island	Operator	Power generation capacity (MW)	Operation commencement
Santo Antão	Electric	0.5	April 2011
São Vicente	Cabeolica	5.95	November 2011
Sal		7.65	February 2012
Boa Vista		2.55	April 2012
Santiago		9.35	October 2011
Total		26.0	

Source: JICA Study Team

7.1.2 Cabeolica Wind Power Generation System

For the positive introduction of renewable energies by the Government of Cabo Verde, the European Commission through the Europian Investment bank and African Development Bank jointly funded a total of 45 million EURO (EIB: 30 million EURO and AfDB: 15 million EURO) to the wind power IPP operator, Cabeolica of Cabo Verde. In four islands, Santiago, São Vicente, Sal, and Boa Vista, Cabeolica owns the wind power generation systems with the total capacity of 25.5 MW (950kw × 30 units), which is equivalent to about 13% of the total power generation systems (about 204MW) of Cabo Verde, thereby significantly contributing to the increase of the volume of renewable energies introduced into Cabo Verde. The future operation of Cabeolica is attracting attention as the first commercial PPP power generation project in the sub-Sahara/African region among the public and private partnership projects (PPP), which are funded by Electra and private investments.

(1) Overview of the system

The total capacity of the wind power generation systems that are owned by Cabeolica in four islands, Santiago, São Vicente, Sal, and Boa Vista is 25.5 MW, which accounts for almost the total capacity of the wind power generation project systems in Cabo Verde.

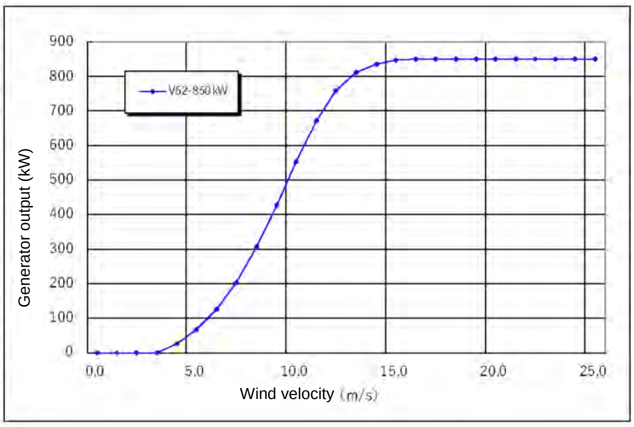
The systems of the same model (30 units), which is V52-850 kW manufactured by Vestas (Denmark) with the unit capacity of 850 kW, are installed in all the four islands.

Table 7.1-2 shows the specifications of the Cabeolica wind power generation systems.

Table 7.1-2 Specifications of the Cabeolica wind power generation systems

Location	Santiago	São Vicente	Sal	Boa Vista
Operation commencement	October 2011	November 2011	February 2012	April 2012
Manufacturer	Vestas			
Model	V52-850kW			
Rated output (kW)	850			
No. of units	11	7	9	3
Total output(MW)	9.35	5.95	7.65	2.55
Output control	Pitch			
Power generator type	Winding-type induction			
Generator voltage (V)	690			
Cut-in wind velocity (m/s)	4			
Rated wind velocity (m/s)	16			
Cut-out wind velocity (m/s)	25			
Survival wind velocity [instant] (m/s)	70			
Rotor diameter (m)	52			
Hub height (m)	55			
Performance curve (Power curve) [Air density 1.225kg/m^3]				

Wind velocity (m/s)	Output (kW)
0.0	–
1.0	–
2.0	–
3.0	–
4.0	26
5.0	67
6.0	125
7.0	203
8.0	304
9.0	425
10.0	554
11.0	671
12.0	759
13.0	811
14.0	836
15.0	846
16.0	849
17.0	850
18.0	850
19.0	850
20.0	850
21.0	850
22.0	850
23.0	850
24.0	850
25.0	850



Source: JICA Study Team

1) Conditions of the location sites

a. Santiago wind power generation system

The site of the 9.35 MW wind power generation system (850 kW × 11 units) is located at the South-East side of the island and it is located on the ridge extending from North West to South-East at the elevation within the range from about 230 m to 270 m.

At the site, there was an Electra wind power system (3 units manufactured by Nordtank), which is inactive at the current time.

Figure 7.1-1 shows the location where the Santiago wind power system is installed.

Figure 7.1-2 shows the conditions of the Santiago wind power generation system.

Table 7.1-3 shows the location site conditions of the Santiago wind power generation system.

Wind turbine position coordinates

WTG	East,UTM WGS84-27	North,UTM WGS84-27
1	228920	1657327
2	229103	1657229
3	229263	1657101
4	229423	1656974
5	229569	1656864
6	229687	1656682
7	229828	1656569
8	230028	1656484
9	230163	1656295
10	230317	1656188
11	230568	1656161

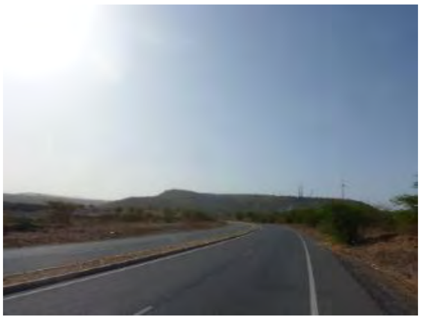
Note: The wind turbine position coordinates are based on the data provided by Cabeolica.

Photograph：Google Earth

Source: JICA Study Team

Figure 7.1-1 Location of the Santiago wind power generation system

Praia Port (International port)



Condition of the surrounding road

Unpaved road that leads to the power plant (Macadam operators exist alongside the road)

Land utilization conditions (Wind turbine of Vestas 850kW×11 units)

Road conditions inside of the power plant premises

Electra system that is currently inactive (Wind turbine of Nordtank × 3 units)

Nameplate placed on the control building (Operation commenced in October 2011)

Control building (Electric room)

Figure 7.1-2 Conditions of the Santiago wind power generation system

Table 7.1-3 Conditions at the location site of the Santiago wind power system

	Conditions at the location site
Equipment and material transportation	• The unloading port and equipment and material transportation route that were used for the construction could not be verified since no InfraCo FS report was provided from DGE. • The wind turbine sites are located at the area close to the Praia international port and the distance is about 7km in a straight line. Since there are many structures around the exit at the Praia international port, which intefere with the transportation of the equipment and materials for wind turbines, it is necessary to examine the detail transportation route, construction for transportation, and transportation vehicles if equipment and materials of large wind turbines of 2 MW class are to be unloaded and transported from the Praia Port. • A paved road is provided from the town center where Praia Port is located to the area near the wind turbine location sites. • The road that leads to the power plant premises by branching out from the paved road is unpaved and the width is 5m or wider. • There are macadam operators alongside of the road that leads to the power plant premises.
Land utilization	• Wind turbines are installed at the almost flat sites and there are no buildings that interfere with the construction. The surface layer consists of pebbles and a small amount of shrubbery.
Power plant premises	• Entry and exit are controlled by the guard station and gate at the entrance. • The roads inside of the premises (unpaved) are maintained to connect between wind turbines and are wide enough to prevent any problems in transportation of equipment and materials.
Laws and regulations	• There are no residential buildings visually recognized nearby, eliminating any possible impact of noise. • No specific contents of legal procedures associated with construction could be verified since no InfraCo FS report was provided from DGE.

Source: JICA Study Team

b. São Vicente wind power generation system

The site of the 5.95 MW wind power generation system (850 kW × 7 units) is located at the position slightly West from the center of the island. The site is located on the ridge that extends from the North-North West to the South-South East at the elevation within the range from about 80 m to 100 m.

The Electra wind power system (3 units manufactured by Nordtank), which is inactive at the current time due to the oversupply of the system, was observed.

On the North-East side of the site, where the Cabeolica wind power generation system is operating, the wind turbines that were constructed through the aid from Denmark were left without being removed. Although we asked Electra for the history of the installation of the wind turbines, no response was received.

Figure 7.1-3 shows the location where the São Vicente wind power system is installed.

Figure 7.1-4 shows the conditions of the São Vicente wind power generation system.

Table 7.1-4 shows the location site conditions of the São Vicente wind power generation system.

Wind turbine position coordinates

WTG	East,UTM WGS84-26	North,UTM WGS84-26
1	710688	1862503
2	710819	1862417
3	710928	1862269
4	710958	1862084
5	711066	1861962
6	711194	1861874
7	711284	1861749

Note: The wind turbine position coordinates are based on the data provided by Cabeolica.

Photograph: Google Earth

Source: JICA Study Team

Figure 7.1-3 Location of the São Vincente wind power generation system

Mindelo Port (International port)

Land utilization conditions
(Wind turbine of Vestas 850 kW×7 units)

Power plan premises entry gate

Road condition inside of the power plant premises

Nameplate placed on the control building
(Operation commenced in November 2011)

Control building (Electric room)

Electra system that is currently inactive
(Wind turbine of Nordtank × 3 units)

Wind turbine constructed through the aid from Denmark at the North-East of the Cabeolica site

Figure 7.1-4 Conditions of the São Vicente wind power generation system

Table 7.1-4 Conditions at the location site of the São Vicente wind power system

	Conditions at the location site
Equipment and material transportation	• The unloading port and equipment and material transportation route that were used for the construction could not be verified since no InfraCo FS report was provided from DGE. • The wind turbine sites are located at the area close to the Mindelo international port and the distance is about 6.5 km. Since there are many structures around the port exit, which may interfere with the transportation of wind turbine materials in the future, examination of detail transportation routes, construction for transportation, and selection of transportation vehicles are necessary if large wind turbine equipment and materials of the 2MW class are to be unloaded and transported from the Mindelo Port. • A paved road is provided from the town center where Mindelo Port is located to the area near the wind turbine location sites. • The road that leads to the power plant premises by branching out from the paved road is unpaved and the width is 5m or wider.
Land utilization	• The wind turbines are installed on the ridge at elevation within the range from about 80 m to 100 m and there are no buildings that may interfere with the construction. The surface layer consists of pebbles. • Macadam operation was carried out near the power plant.
Power plant premises	• Entry and exit are controlled by the guard station and gate at the entrance. • The roads inside of the premises (unpaved) are maintained to connect between the wind turbines and are wide enough to prevent any problems in transportation of equipment and materials.
Laws and regulations	• There are no residential buildings visually recognized nearby so that there seems to be no impact of noise. • No specific contents of legal procedures associated with construction could be verified since no InfraCo FS report was provided from DGE.

Source: JICA Study Team

c. Sal wind power generation system

The site at the 7.65 MW wind power generation system (850 kW × 9 units) is located on the flat land at elevation of about 60 m on the South-East side of the center of the island. Two units of wind turbines manufactured by Nordtank were left unattended near the Palmeira power plant.

Figure 7.1-5 shows the location where the Sal wind power system is installed.

Figure 7.1-6 shows the conditions of the Sal wind power generation system.

Table 7.1-5 shows the location site conditions of the Sal wind power generation system.

Photograph: Google Earth

Wind turbine position coordinates

WTG	East,UTM WGS84-27	North,UTM WGS84-27
1	296950	1848005
2	297021	1847865
3	297117	1847745
4	297216	1847618
5	297326	1847497
6	297414	1847363
7	297501	1847213
8	297603	1847079
9	297736	1846986

Note: The wind turbine position coordinates are based on the data provided by Cabeolica.

Source: JICA Study Team

Figure 7.1-5 Location of the Sal wind power generation system

Land utilization conditions
(Wind turbine of Vestas 850kW×9 units)

Road condition inside of the power plant premises

Namelate placed on the control building
(Operation commenced in February 2012

Control building (Electric room)

Entry guard station inside of the power plant premises

Inactive wind turbines of Nordtank × 2 units
(Near the Palmeira power plant)

Figure 7.1-6 Conditions of the Sal wind power generation system

Table 7.1-5 Conditions at the location site of the Sal wind power system

	Conditions at the location site
Equipment and material transportation	• The unloading port and equipment and material transportation route that were used for the construction could not be verified since no InfraCo FS report was provided from DGE. • The road that leads to the power plant premises is unpaved and the width is 5m or wider. • Although the unloading port at Sal could not be verified, examination of detail transportation routes and construction for transportation, and selection of transportation vehicles is necessary if large wind turbine equipment and materials of 2MW class are to be transported in the future.
Land utilization	• Wind turbines are installed at the almost flat sites and there are no buildings that interfere with the construction. The surface layer consists of pebbles and a small amount of shrubbery.
Power plant premises	• Entry and exit are controlled by the guard station and gate at the entrance. • The roads inside of the premises (unpaved) are maintained to connect between the wind turbines and are wide enough to prevent any problems in transportation of equipment and materials.
Laws and regulations	• The site is located within the wind power generation development zone (SL.1) that was announced in Cabo Verde Official Gazette No.7 in February 2012 for active promotion for the introduction of renewable energies. • There are no visual residential buildings nearby, eliminating the possibility of any impact of noise. When large wind turbines of 2MW class are to be installed in the future, environmental assessment such as the impact on the landscape and noise is necessary since a plan for large-scale resort development is progressing near the wind power generation development zone of Sal. • No specific contents of legal procedures associated with construction could be verified since no InfraCo FS report was provided from DGE.

Source: JICA Study Team

d. Boa Vista wind power generation system

The site on the 2.55MW wind power generationn system (850kW × 3 units) is located at the cape of the North-West end of the island at the elevation within the range from 80m to 100m.

Figure 7.1-7 shows the location where the Boa Vista wind power system is installed.

Figure 7.1-8 shows the conditions of the Boa Vista wind power generation system.

Table 7.1-6 shows the location site conditions of the Boa Vista wind power generation system.

Wind turbine position coordinates

WTG	East,UTM WGS84-27	North,UTM WGS84-27
1	296013	1793478
2	296201	1793410
3	296390	1793343

Note: The wind turbine position coordinates are based on the data provided by Cabeolica.

Photograph: Google Earth

Source: JICA Study Team

Figure 7.1-7 Location of the Boa Vista wind power generation system

Unpaved road that leads to the power plant premises

Land utilization conditions
(Wind turbine of Vestas 850kW × 3 units)

Entry guard station and entry gate inside of the power plant premises

Nameplate placed on the control building
(Operation commenced in April 2012)

Control building (Electric room)

Figure 7.1-8 Conditions of the Boa Vista wind power generation system

Table 7.1-6 Conditions at the location site of the Boa Vista wind power system

	Conditions at the location site
Equipment and material transportation	• The unloading port and equipment and material transportation route that were used for the construction could not be verified since no InfraCo FS report was provided from DGE. • The road that leads to the power plant premises is unpaved and the width is 5m or wider. • Although the unloading port in Boa Vista could not be verified, examination of detail transportation routes and construction for transportation, and selection of transportation vehicles are necessary if large wind turbine equipment and materials of 2MW class are to be transported in the future.
Land utilization	• Wind turbines are installed at the almost flat sites and there are no buildings that interfere with the construction. The surface layer consist of pebbles and a small amount of shrubbery.
Power plant premises	• Entry and exit are controlled by the guard station and gate at the entrance. • The roads inside of the premises (unpaved) are maintained to connect between the wind turbines and are wide enough to prevent any problems in transportation of equipment and materials.
Laws and regulations	• There are no residential buildings visually recognized nearby, eliminating the possiblity of any impact of noise. • No specific contents of legal procedures associated with construction could be verified since no InfraCo FS report was provided from DGE.

Source: JICA Study Team

2) Structure

a. Santiago wind power generation system

(a) Grid connection facilities (including the protection unit)

Eleven wind turbines with the unit capacity of 850 kW, after boosting the generator voltage 690 V to 20 kV inside of the tower of each wind turbine, are integrated by the 20 kV underground filled cable and are connected to the Gamboa power plant with one 20 kV power transmission line via the switching facility inside of the building.

In the control building, all the facilities required for grid connection are installed including the switching facility, a grid connection protection unit, and an integrating wattmeter for calculating the electric energy to be sold to Electra.

Although the cables are currently connected to the Gamboa power plant, they are planned to be connected to the São Filipe substation as a result of the preparation of the 60 kV and 20 kV power transmission systems by the power generation and transmission reinforcement project through the co-financing beween AfDB and JICA. Figure 7.1-9 shows the condition of the grid connection facilities.

20 kV switching facility (Inside of the control building)

20 kV transmission line tower (1 line)

Figure 7.1-9 Conditions of the grid connection facilities

(b) Electrical facilities

As the countermasure for grid power supply loss, DC power supply and emergency generator for the control unit are installed. Figure 7.1-10 shows the conditions of the electrical facilities.

DC power supply (lead storage battery)

Emergency generator

Figure 7.1-10 Conditions of the electrical facilities

b. São Vicente wind power generation system

(a) Grid connection facilities (including the protection unit)

Seven units of wind turbines of unit capacity of 850 kW are integrated into one 20 kV underground filled cable and are connected to the Lazareto power plant through the 20 kV underground filled cable via the switching facility inside of the building.

The same configuration is applied to the grid connection facilities at the four sites (Santiago, São Vicente, Sal, Boa Vista),including the grid connection protection units and integrating wattmeters inside of the control buildings.

Figure 7.1-11 shows the conditions of the grid connection facilities.

Grid connection circuit breaker

Inegrating wattmeter

Figure 7.1-11 Conditions of the grid connection facilities

(b) Electrical facilities

The same configuration is applied to the electrical facilities including the DC power supplies and emergency generators for the control units among the four sites (Santiago, São Vincente, Sal, and Boa Vista). Figure 7.1-12 shows the conditions of the electrical facilities.

Feeder panel

Vestas online server

Figure 7.1-12 Conditions of the electrical facilities

c. Sal wind power generation system

(a) Grid connection facilities (including the protection unit)

Nine units of wind turbines of unit capacity 859 kW are integrated into one 20 kV underground filled cable and are connected through the 20 kV underground filled cable via the switching facility inside of the building.

The same configuration is applied to the grid connection facilities at four sites (Santiago, São Vicente, Sal, and Boa Vista), including the grid connection protection units and integrating wattmeters inside of the control buildings.

Figure 7.1-13 shows the conditions of the grid connection facilities.

22 kV switching facility

Integrating wattmeter

Figure 7.1-13 Conditions of the grid connection facilities

(b) Electrical facilities

The same configuration is applied to the electrical facilities including the DC power supplies and emergency generators for the control units among the four sites (Santiago, São Vincente, Sal, and Boa Vista).

Figure 7.1-14 shows the conditions of the electrical facilities.

Emergency generator

Vestas online server

Figure 7.1-14 Conditions of the electrical facilities

d. Boa Vista wind power generation system

(a) Grid connection facilities (including the protection unit)

Three units of wind turbines of unit capacity of 850 kW are integrated into one 20 kV underground filled cable and are connected to Sal Rei power plant through the 20 kV underground filled cable via the switching facility inside of the building.

The same configuration is applied for the grid connection facilities at the four sites (Santiago, São Vicente, Sal, and Boa Vista), including the grid connection protection units and integrating wattmeters inside of the control buildings.

Figure 7.1-15 shows the conditions of the grid connection facilities.

20kV switching facility

Protection board

Figure 7.1-15 Conditions of grid connection facilities

(b) Electrical facilities

The same configuration is applied to the electrical facilities including the DC power supplies and emergency generators for the control units among the four sites (Santiago, São Vincente, Sal, and Boa Vista). Figure 7.1-16 shows the conditions of the electrical facilities.

DC power supply (lead storge battery)

Vestas online server

Figure 7.1-16 Conditions of the electrical facilities

3) Operation

a. Monitoring the wind power generation system

Cabeolica established an O&M contract with Vestas and the operation status of the wind power generation system is constantly monitored by the SCADA system (Vestas Online Business)in remote mode. Through the SCADA system, the head office of Cabeolica, maintenance staff, and maintenance staff of Vestas are able to verify, in real time, the wind turbine operation data and alarm information that are required for monitoring the operation status.

The operation data (voltage, frequency, wind velocity, and so on) are accumulated in the SCADA system, enabling data history management.

Figure 7.1-17 shows the condition of the Cabeolica remote monitoring system.

b. Cooperative operation between Electra and AEB

Electra, which receives wind-power energy from Santiago, São Vicente, and Sal, constantly monitors the wind turbine operation status through the Vestas SCADA system to secure the quality of electric power and is able to ajdust the wind power output and voltage.

AEB that supplies power from Boa Vista also applies the same operation.

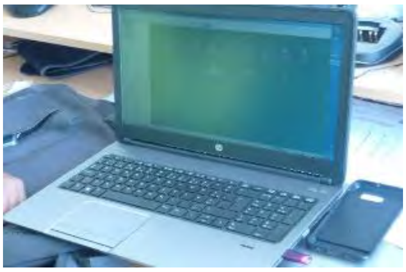
To receive the energy generated by wind power within the range that does not impact the power quality (voltage and frequency) and the operation of diesel power generation, which is the existing power generation system, Electra and AEB created a specific operation standard and implement cooperative operation between diesel power generation and wind power generation.

The specific contents of the cooperative operation with wind power generation are discussed in 7.4.

Wall-mounted monitoring screens

PC for monitorng

Monitoring status at the head office



Portable PC for monitoring

Operation data control screen

Monitoring by maintenance staff

Figure 7.1-17 Cabeolica remote monitoring system

4) Performance results and plans for new installation and repairs

a. Performance results and plans for new installation

(a) History

Cabeolica is the public and private project (PPP) that is funded by Electra and private investments and its future operation is attracting attention as the first commercial PPP power generation project in the Sub-Sahara/African region.

There are inactive wind turbines of Nordtank at the wind power generation location sites of Cabeolica at Santiago and São Vicente, giving site advantages to Cabeolica for selection of construction sites in terms of wind condition and transportation of wind turbine equipment and materials.

Although FS has been conducted by InfraCo prior to the construction, the specific history of the site selection could not be verified since the report was not made available.

(b) Construction process (performance result)

Regarding the construction period up to the completion of each wind power generation system, the systems of Santiago and São Vicente were completed in about one year, the system of Sal was completed two months later , and the system of Boa Vista was completed 5 months later. In total, all the sysatems were completed within less than 2 years.

Table 7.1-7 shows the construction process (performance result) based on the result of discussions with Cabeolica.

Table 7.1-7 Construction process (performance result)

Site (Output × No. of units)	Operation commencement time	2010	2011			2012	
		E	B	M	E	B	M
Construction period	-	←	—	—	—	→	
Santiago (850 kW×11 units)	October 2011				▼		
São Vicente (850 kW× units)	November 2011				▼		
Sal (850 kW×9 units)	February 2012					▼	
Boa Vista (850 kW×3 units)	April 2012						▼

Source: Cabeolica published material

(c) Construction cost (performance result)

Table 7.1-8 shows the construction cost (performance result).

Table 7.1-8 Construction cost (performance result)

Construction sites		4 sites: 25.5MW (Santiago (9.35MW), São Vicente (5.95MW), Sal (7.65MW), and Boavista (2.55MW))	
Total construction cost (Million EURO)	Breakdown	45	Full-turnkey contract with Vestas Construction cost: Wind turbine, installation, civil enginnering work (foundation, site preparation, and transportation road), electrical construction, and building construction
		15	Development cost and operating cost
	Total	60	

Source: Cabeolica published material

(d) Operating cost

An O&M contract was established between Cabeolica and Vestas. According to Cabeolica, it is difficult to present the accurate cost in terms of the contract with Vestas. The estimated annual operating cost was 2 million EURO.

b. Preformance results and plans for repairs

There are no acutal repairs for the four sites owned by Cabeolica(Santiago, São Vicente, Sal, and Boa Vista). There are no extension plans for the four sites either.

5) PPA-based annual power generation plans and performance results

a. Annual power generation performance results

Data of 10-minute operation that was provided from Cabeolica regarding the four sites (Santiago, São Vicente, Sal, and Boa Vista) was organized and analyzed.
Although data of power output (kW), reactive power (kVar), generated energy (kWh), power factor (%), SetPoint output (kW), and wind direction (°) was requested as the 10-minute operation data for verification of the power generation status and system status, the data was not made available.
Table 7.1-9 shows the contents of the operation data (10-minute value) that was provided by Cabeolica.
Table 7.1-10 shows the annual power generation performance result that was provided by Cabeolica.

Table 7.1-9 Contents of operation data (10-minute value)

		Data item
Operation data	10-minute values for 2015	• Voltage(V) • Frequency (Hz) • Wind velocity(m/s) • Temperature (°)〔Available for Santiago only〕

Source: Data provided by Cabeolica

Table 7.1-10 Annual power generation performance results

(Unit: kWh/year)

	2013	2014	2015
Santiago	- (40.3%)	- (42.3%)	32,341,174.80 (39.5%)
São Vicente	- (-)	- (-)	19,458,089.10 (37.3%)
Sal	- (25.3%)	- (25.4%)	19,171,213.10 (28.6%)
Boa Vista	- (23.5%)	- (37.3%)	7,812,829.20 (35.0%)

Source: Data provided by Cabeolica ((): Facility utilization rate, “-“: Not provided by Cabeolica)

(a) Santiago wind power generation system

a) Cabeolica operation data analysis

The annual average wind velocity in 2015 at the hub height (above ground height 55m) of 11 wind turbines was in the range from 8.1 m/s to 8.4 m/s. The monthly average wind velocity for the period from July to October was in the range from about 5m/s to 6 m/s, showing significant deterioration of wind velocity during the summer throughout the year.
The peak of the appearance rates by annual wind velocity scale were between 8m/s or more and less than 9 m/s and the appearance frequency of less than 4 m/s, which halts

power generation, was about 12% (around 1,039 hours in calendar year). The appearance frequency of stopping power generation due to the high wind velocity of 25 m/s or more was 0%. The performance result of the electrical energy sold (facility utilziation rate) in 2015 was 32,341,175 kWh (39.5%).
Table 7.1-11 shows the wind velocity data analysis result of the Santiago wind power generation system.

Table 7.1-11 Results of wind velocity data analysis of the Santiago wind power generation system

Santiago

Layout map (Photograph): Google Earth) and site condition


Layout map

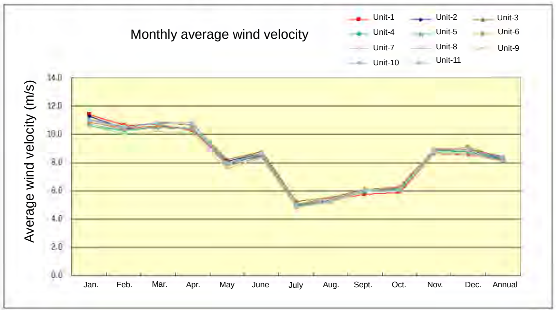

Site condition

Operation performance result

Annual and monthly average wind velocity (at 55 m) [2015]

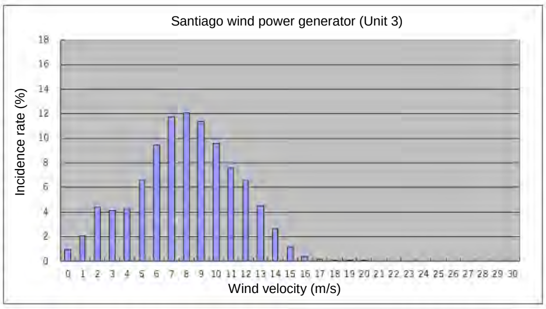
(Unit: m/s)

Windmill	2015 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Unit-1	11.4	10.7	10.7	10.3	8.0	8.6	5.0	5.3	5.7	5.9	8.6	8.6	8.2
Unit-2	11.3	10.4	10.5	10.4	8.1	8.7	5.1	5.3	5.9	6.0	8.8	8.9	8.3
Unit-3	11.1	10.6	10.8	10.7	8.2	8.7	5.2	5.5	6.1	6.2	9.0	9.0	8.4
Unit-4	10.6	10.2	10.5	10.4	7.9	8.5	5.0	5.3	6.0	6.1	8.8	8.7	8.2
Unit-5	10.7	10.3	10.6	10.4	8.0	8.4	4.9	5.3	6.0	6.1	8.8	8.9	8.2
Unit-6	10.8	10.5	10.6	10.3	7.9	8.6	5.0	5.4	6.1	6.2	8.8	9.1	8.3
Unit-7	10.7	10.3	10.5	10.4	7.8	8.4	4.9	5.2	5.9	6.0	8.8	8.7	8.1
Unit-8	10.9	10.4	10.5	10.4	7.7	8.4	4.9	5.3	5.9	6.0	8.7	8.6	8.1
Unit-9	10.6	10.0	10.2	10.1	7.6	8.3	4.8	5.2	5.9	6.0	8.6	8.7	8.0
Unit-10	11.0	10.5	10.8	10.8	8.0	8.7	5.1	5.4	6.1	6.1	9.0	8.9	8.4
Unit-11	11.0	10.5	10.8	10.7	7.9	8.6	5.0	5.3	6.0	6.1	8.9	8.9	8.3



Appearance rate by wind velocity scale (at 55 m) [2015]

Wind velocity (m/s)		Incidence rate (%)
0	0<V<1	1.0
1	1≦V<2	2.1
2	2≦V<3	4.4
3	3≦V<4	4.2
4	4≦V<5	4.3
5	5≦V<6	6.6
6	6≦V<7	9.5
7	7≦V<8	11.7
8	8≦V<9	12.1
9	9≦V<10	11.4
10	10≦V<11	9.6
11	11≦V<12	7.6
12	12≦V<13	6.6
13	13≦V<14	4.5
14	14≦V<15	2.7
15	15≦V<16	1.2
16	16≦V<17	0.4
17	17≦V<18	0.2
18	18≦V<19	0.0
19	19≦V<20	0.0
20	20≦V<21	0.0
21	21≦V<22	0.0
22	22≦V<23	0.0
23	23≦V<24	0.0
24	24≦V<25	0.0
25	25≦V<26	0.0
26	26≦V<27	0.0
27	27≦V<28	0.0
28	28≦V<29	0.0
29	29≦V<30	0.0
30	30≦V	0.0



Source: JICA Study Team based on the materials provided by Cabeolica

b) Operation status at the inspection of the Palmarejo power plant

The Electra diesel power plant was inspected on March 9, 2016 and this inspection verified the condition of the cooperative operation with the Cabeolica wind power generation system.

According to the discussions with Electra, the wind condition of Praia is good, the wind force is stable, almost cosntant output of wind power is generated, and no grid problem has occurred due to the sudden output fluctation.

Wind power generation and diesel power generation are operated at the ratio of 7:3 based on the energy generated as the guideline. Each diesel generator operates under the guideline of 55% as the minimum output and 60% as the economic performance.

At the inspection, the output of the wind power generation system was set to 9.35 MW and the power factor is set to 0.95, which is less than that of the grid side.

At the inspection, although the wind power output was set to 9.35 MW, the output fluctuated within the range between 5,000 kW and 7.500 kW due to the influence of the wind velociy.

When the voltage values were checked with the monitor visually, hardly any fluctuation was observed.

Figure 7.1-18 shows the personal computer used for monitoring the wind power generation system of the Palmarejo power plant in remote mode.

Table 7.1-12 shows the values monitored by the wind power generation system monitor at the inspection.

Figure 7.1-19 shows the wind power output fluctuation status (displayed on the PC monitor) at the inspection.

PC for monitoring

Wind power generation system monitor screen

Figure 7.1-18 PC for monitoring the wind power generation system of the Palmarejo power plant in remote mode

Table 7.1-12 Values monitored by the wind power generation system monitor

Wind velocity/power output

Wind turbine No.	1	2	3	4	5	6	7	8	9	10	11
Wind velocity (m/s) [Above ground height 55 m]	8.8	11.5	13.9	11.9	9.2	11.8	10.7	10.5	9.6	8.1	9.4
Power output (kW)	475.8	662.0	637.8	559.0	526.9	609.6	602.3	523.9	360.4	319.1	407.1

Plant data

Active Power		Reactive Power		Grid Data			
P	6359 kW	Q	1735 kVAr	S	6088 kVA	L1-L2	20687V 170A
Possible	6397 kW	Possible	4468 kVAr	PF	-0.96 cosϕ	L2-L3	20364V 173A
Setpoint	9350 kW	Setpoint	1.05 cosϕ	F	50.00	L3-L1	20549V 172A

Soruce: Verified at the Palmarejo power plant

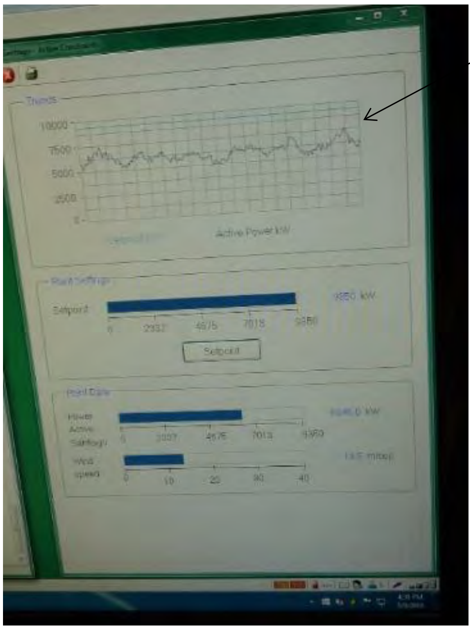


Figure 7.1-19 Wind power output fluctuation status (displayed on the PC monitor)

(b) São Vicente Santiago wind power generation system

a) Cabeolica operation data analysis

The annual average wind velocity in 2015 at the hub height (above ground height 55 m) of 11 wind turbines was in the range from 9.9m/s to 11.1 m/s. The monthly average wind velocity for the period from July to October was in the range from about 7 m/s to 9 m/s, showing significant deterioration of wind velocity during the summer.

The peak of the appearance rates by annual wind velocity scale were between 9m/s or more and less than 10 m/s and the appearance frequency of less than 4m/s, which causes power generation to halt, was about 6% (around 482 hours in calendar year). The appearance frequency of halting power generation due to the high wind velocity of 25 m/s or more was 0%. The performance result of the electrical energy sold (facility utilziation rate) in 2015 was 19,458,089 kWh (37.3%).

Table 7.1-13 shows the wind velocity data analysis result of the São Vincente wind power generation system.

Table 7.1-13 Results of wind velocity data analysis of the São Vicente wind power generation system

	São Vicente

Layout map (Photograph): Google Earth) and site condition

Layout map

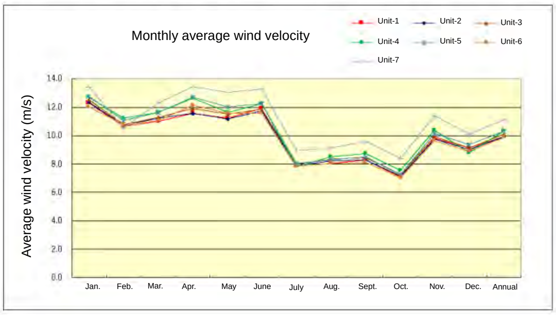
Site condition

Operation performance result

Annual and monthly average wind velocity (at 55 m) [2015]

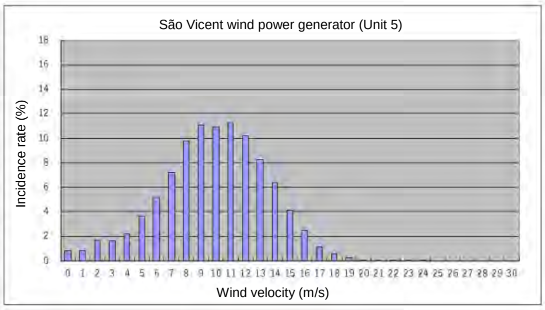
(Unit: m/s)

Windmill	2015												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Unit-1	12.3	10.7	11.0	11.6	11.2	11.9	7.9	8.0	8.3	7.1	9.8	9.2	9.9
Unit-2	12.3	10.7	11.2	11.6	11.2	11.8	7.9	8.2	8.3	7.2	9.8	9.0	9.9
Unit-3	12.5	10.8	11.3	11.9	11.5	11.8	8.0	8.3	8.4	7.3	9.9	9.2	10.1
Unit-4	12.7	11.2	11.7	12.6	11.6	12.3	7.8	8.5	8.8	7.5	10.4	8.8	10.3
Unit-5	12.8	11.1	11.6	12.7	12.0	12.2	8.1	8.3	8.5	7.3	10.2	9.4	10.4
Unit-6	12.0	10.8	11.1	12.2	11.6	11.6	7.8	8.1	8.1	7.1	9.7	8.9	9.9
Unit-7	13.4	10.5	12.3	13.4	13.1	13.3	9.0	9.1	9.6	8.4	11.4	10.1	11.1



Appearance rate by wind velocity scale (at 55 m) [2015]

Wind velocity (m/s)		Incidence rate (%)
0	0<V<1	0.8
1	1≦V<2	0.9
2	2≦V<3	1.7
3	3≦V<4	1.6
4	4≦V<5	2.2
5	5≦V<6	3.7
6	6≦V<7	5.2
7	7≦V<8	7.2
8	8≦V<9	9.8
9	9≦V<10	11.1
10	10≦V<11	10.9
11	11≦V<12	11.2
12	12≦V<13	10.2
13	13≦V<14	8.3
14	14≦V<15	6.4
15	15≦V<16	4.2
16	16≦V<17	2.5
17	17≦V<18	1.2
18	18≦V<19	0.6
19	19≦V<20	0.2
20	20≦V<21	0.1
21	21≦V<22	0.0
22	22≦V<23	0.0
23	23≦V<24	0.0
24	24≦V<25	0.0
25	25≦V<26	0.0
26	26≦V<27	0.0
27	27≦V<28	0.0
28	28≦V<29	0.0
29	29≦V<30	0.0
30	30≦V	0.0



Source: JICA Study Team based on the materials provided by Cabeolica

b) Operation status at the inspection of the Lazareto power plant

The Electra diesel power plant was inspected on March 10, 2016 and this inspection verified the condition of the cooperative operation with the Cabeolica wind power generation system.

According to the discussions with Electra, the wind power output of São Vincente is constant. Diesel power output is used as the basis and wind power output is accepted as the supplement. To prevent distabilization of the grid, the wind power output (kW) was restricted to 50% as the maximum out of the total demand (kW) as 100%.

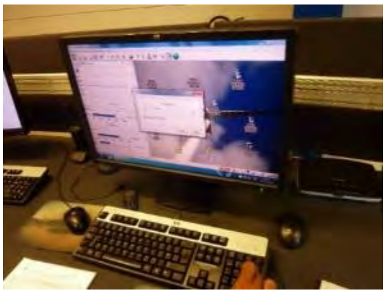
At the inspection, the output of the wind power generation system was set to 4.5MW and the power factor is set to 0.95, which is less than that of the grid side.

The wind power output at the inspection was constant due to the output control operation performed by setting the output to 4.5 MW.

Figure 7.1-20 shows the personal computer used for monitoring the wind power generation system of the Lazareto power plant in remote mode.

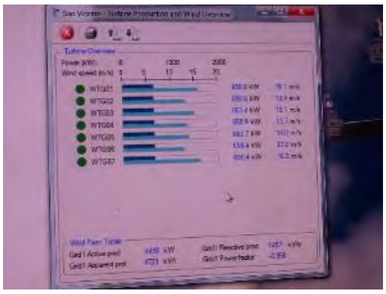
Table 7.1-14 shows the values monitored by the wind power generation system monitor.

Figure 7.1-21 shows the wind power output fluctuation status (displayed on the PC monitor) at the inspection.



PC for monitoring

Monitor screen 1



Monitor screen 2

Wind power output setting screen

Figure 7.1-20 PC for monitoring the wind power generation system of the Lazareto power plant in remote mode

Table 7.1-14 Values monitored by the wind power generation system monitor

Wind velocity/power output

Wind turbine No.	1	2	3	4	5	6	7
Wind velocity (m/s) [Above ground height 55m]	13.5	15.3	15.5	15.5	15.9	14.1	15.6
Power output (kW)	652.5	661.1	660.6	661.0	661.7	658.9	662.1

Plant data

Active Power		Reactive Power		Grid Data			
P	4498 kW	Q	1486 kVAr	S	4753 kVA	L1-L2	20334V 134A
Possible	5950 kW	Possible	2513 kVAr	PF	-0.95 cosϕ	L2-L3	20393V 135A
Setpoint	4500 kW	Setpoint	1.05 cosϕ	F	50.00	L3-L1	20364V 135A

Source: JICA Study Team based on the materials provided by Cabeolica

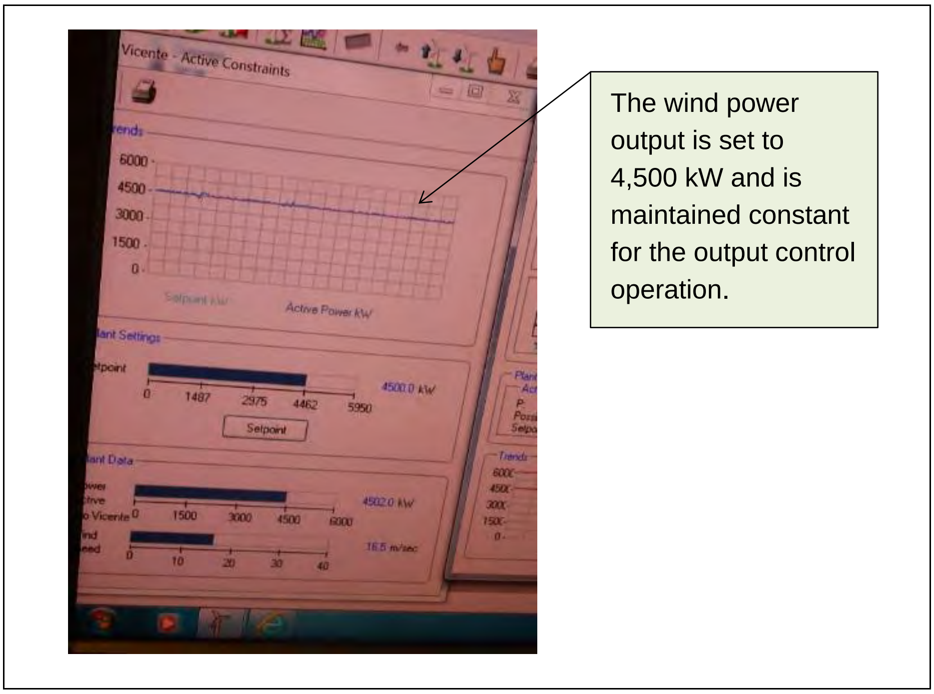


Figure 7.1-21 Wind power output fluctuation status (displayed on the PC monitor)

(c) Sal wind power generation system

a) Cabeolica operation data analysis

The annual average wind velocity in 2015 at the hub height (above ground height 55m) of 9 wind turbines was in the range from 8.2 m/s to 9.5 m/s. The monthly average wind velocity for the period from July to October was in the range from about 6m/s to 7m/s, showing significant deterioration of wind velocity in the summer each year.

The peak of the appearance rates by annual wind velocity scale were between 9m/s or more and less than 10m/s and the appearance frequency of less than 4m/s, which causes power generation to halt, was about 5% (around 403 hours in calendar year). The appearance frequency of halting power generation due to the high wind velocity of 25 m/s or more was 0%. The performance result of the electrical energy sold (facility utilization rate) in 2015 was 19,171,213 kWh (28.6%).

Table 7.1-15 shows the wind velocity data analysis result of the Sal wind power generation system.

b) Operation status at the inspection of the Palmeria power plant

We inspected the Electra diesel power plant on March 14, 2016 and verified the condition of the cooperative operation with the Cabeolica wind power generation system.

At the inspection, the output of the wind power generation system was set to 2 MW and the power factor was set to 0.98, which is less than that of the grid side.

Although output control operation was performed by setting the wind power output to 2 MW, the output fluctated gradually within the range from 1,000 kW to 2,000 kW.

Figure 7.1-22 shows the personal computer used for monitoring the wind power generation system of the Palmeira power plant in remote mode.

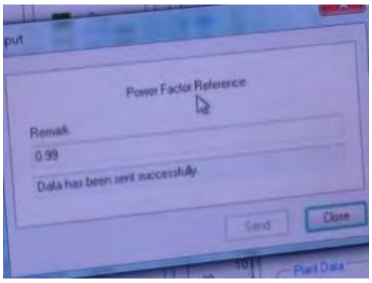
Table 7.1-16 shows the values monitored by the wind power generation system monitor.

Figure 7.1-23 shows the wind power output fluctuation status (displayed on the PC monitor) at the inspection.


PC for monitoring


Monitor screen


Wind power output setting screen



Wind power generation power factor setting screen

Figure 7.1-22 PC for monitoring the wind power generation system of the Palmeira power plant in remote mode

Table 7.1-15 Results of wind velocity data analysis of the Sal wind power generation system

Sal

Layout map (Photograph): Google Earth) and site condition

Layout map

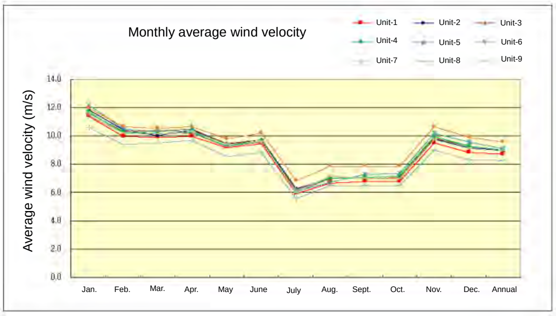
Site condition

Operation performance result

Annual and monthly average wind velocity (at 55 m) [2015]

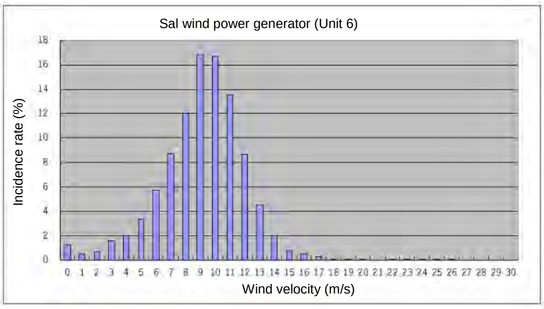
(Unit: m/s)

Windmill	2015 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Unit-1	11.4	9.9	9.9	10.0	9.1	9.4	5.9	6.6	6.8	6.8	9.5	8.8	8.7
Unit-2	11.8	10.4	10.0	10.4	9.4	9.7	6.3	7.0	7.0	7.0	9.8	9.1	9.0
Unit-3	11.6	10.3	10.3	10.4	9.5	9.7	6.0	7.0	7.0	7.0	9.8	9.3	9.0
Unit-4	11.7	10.2	10.2	10.2	9.3	9.6	6.1	7.0	7.1	7.2	9.9	9.3	9.0
Unit-5	12.1	10.5	10.3	10.4	9.4	9.6	6.1	6.7	7.3	7.3	10.2	9.6	9.1
Unit-6	11.9	10.6	10.5	10.6	9.8	10.2	6.8	7.8	7.8	7.8	10.6	9.9	9.5
Unit-7	10.6	9.4	9.5	9.7	8.6	8.8	5.6	6.5	6.5	6.5	9.0	8.3	8.2
Unit-8	11.4	10.2	10.1	10.2	9.2	9.6	6.1	7.1	7.0	7.0	9.7	9.1	8.9
Unit-9	11.6	10.2	10.1	10.3	9.4	9.6	6.0	7.2	7.0	6.9	9.7	9.1	8.9



Appearance rate by wind velocity scale (at 55 m) [2015]

Wind velocity (m/s)		Incidence rate (%)
0	0<V<1	1.3
1	1≦V<2	0.5
2	2≦V<3	0.7
3	3≦V<4	1.6
4	4≦V<5	2.0
5	5≦V<6	3.3
6	6≦V<7	5.7
7	7≦V<8	8.8
8	8≦V<9	12.0
9	9≦V<10	16.9
10	10≦V<11	16.7
11	11≦V<12	13.6
12	12≦V<13	8.7
13	13≦V<14	4.5
14	14≦V<15	2.0
15	15≦V<16	0.8
16	16≦V<17	0.5
17	17≦V<18	0.2
18	18≦V<19	0.1
19	19≦V<20	0.0
20	20≦V<21	0.0
21	21≦V<22	0.0
22	22≦V<23	0.0
23	23≦V<24	0.0
24	24≦V<25	0.0
25	25≦V<26	0.0
26	26≦V<27	0.0
27	27≦V<28	0.0
28	28≦V<29	0.0
29	29≦V<30	0.0
30	30≦V	0.0



Source: JICA Study Team based on the materials provided by Cabeolica

Table 7.1-16 Values monitored by the wind power generation system monitor

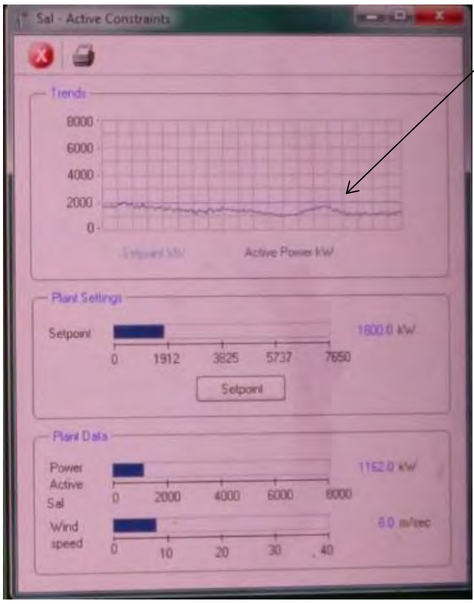
Wind velocity/power output

Wind turbine No.	1	2	3	4	5	6	7	8	9
Wind velocity (m/s) [Above ground height 55 m]	7.2	6.9	7.4	7.0	8.6	4.2	7.6	7.2	7.0
Power output (kW)	87.2	91.4	138.2	133.5	136.5	98.8	142.2	161.6	27.9

Plant data

Active Power		Reactive Power		Grid Data			
P	1221 kW	Q	-241 kVAr	S	1244kVA	L1-L2	20011V 36 A
Possible	1038 kW	Possible	3049 kVAr	PF	0.98cosϕ	L2-L3	20031V 35 A
Setpoint	2000 kW	Setpoint	0.98 cosϕ	F	50.00	L3-L1	19989V 37 A

Source: Verified by the Palmeira power plant



Although the power output is set to 2,000 kW and output control operation is performed, the output fluctuates gradually within the range from 1,000 kW to 2,000 kW due to the influence of the wind velocity.

Figure 7.1-23 Wind power output fluctuation status (displayed on the PC monitor)

(d) Boa Vista wind power generation system

a) Cabeolica operation data analysis

The annual average wind velocity in 2015 at the hub height (above ground height 55m) of 3 wind turbines was in the range from 8.1 m/s to 9.4 m/s. The monthly average wind velocity for the period from July to October was in the range from about 5m/s to 7m/s, showing significant deterioration of wind velocity during the summer each year.

The peak of the appearance rates by annual wind velocity scale were between 10m/s or more and less than 11m/s and the appearance frequency of less than 4m/s, which causes power generation to halt, was about 7% (around 638 hours in calendar year). The appearance frequency of halting power generation at the high wind velocity of 25 m/s or more was 0%. The performance result of the electrical energy sold (facility utilization rate) in 2015 was 7,812,829 kWh (35.0%).

Table 7.1-17 shows the wind velocity data analysis result of the Boa Vista wind power generation system.

b) Operation status at the inspection of the Chavez power plant

We inspected the Electra diesel power plant on May 23, 2016 and verified the condition of the cooperative operation with the Cabeolica wind power generation system.

At the inspection, the output of the wind power generation system was set to 1.2 MW and the power factor was set to 0.97, which is less than that of the grid side. At the inspection, since the power output was set to 1.2 MW and output control operation was performed, the constant output was observed.

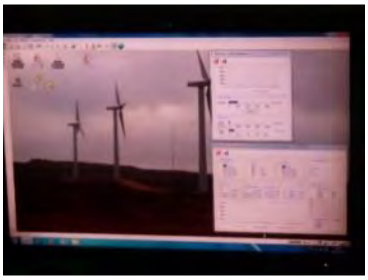
Figure 7.1-24 shows the personal computer used for monitoring the wind power generation system of the Chavez power plant in remote mode.

Table 7.1-18 shows the values monitored by the wind power generation system monitor.

Figure 7.1-25 shows the wind power output fluctuation status (displayed on the PC monitor) at the inspection.

PC for monitoring

Monitor screen 1



Monitor screen 2

Wind power output setting screen

Figure 7.1-24 PC for monitoring the wind power generation system of the Chavez power plant in remote mode

Table 7.1-17 Results of wind velocity data analysis of the Boa Vista wind power generation system

		Boa Vista
Layout map (Photograph): Google Earth) and site condition		see below
Operation performance result	Annual and monthly average wind velocity (at 55 m) [2015]	see below
	Appearance rate by wind velocity scale (at 55 m) [2015]	see below

Layout map (Photograph): Google Earth) and site condition

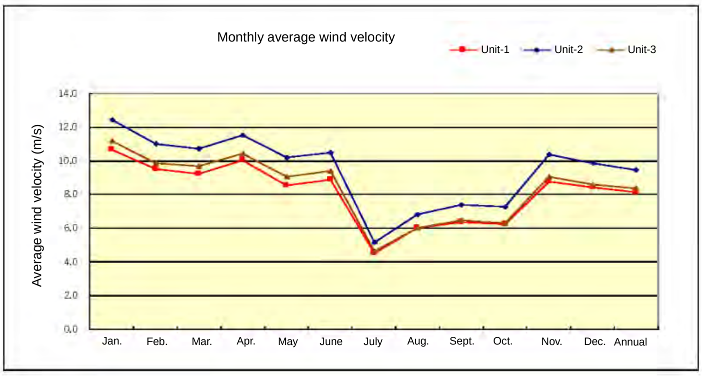
Layout map

Site condition

Operation performance result – Annual and monthly average wind velocity (at 55 m) [2015]

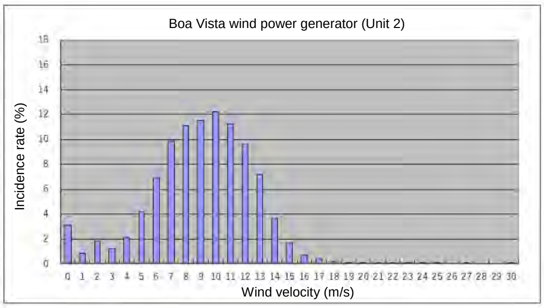
(Unit: m/s)

Windmill	2015 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Unit-1	10.7	9.5	9.3	10.0	8.6	8.9	4.6	6.0	6.4	6.3	8.8	8.5	8.1
Unit-2	12.5	11.0	10.7	11.6	10.2	10.5	5.1	6.8	7.4	7.3	10.4	9.8	9.4
Unit-3	11.2	9.9	9.7	10.4	9.1	9.4	4.6	6.0	6.5	6.3	9.1	8.6	8.4



Operation performance result – Appearance rate by wind velocity scale (at 55 m) [2015]

Wind velocity (m/s)		Incidence rate (%)
0	0<V<1	3.1
1	1≦V<2	0.8
2	2≦V<3	1.8
3	3≦V<4	1.2
4	4≦V<5	2.1
5	5≦V<6	4.2
6	6≦V<7	7.0
7	7≦V<8	9.9
8	8≦V<9	11.1
9	9≦V<10	11.5
10	10≦V<11	12.2
11	11≦V<12	11.2
12	12≦V<13	9.6
13	13≦V<14	7.2
14	14≦V<15	3.6
15	15≦V<16	1.8
16	16≦V<17	0.7
17	17≦V<18	0.4
18	18≦V<19	0.2
19	19≦V<20	0.0
20	20≦V<21	0.0
21	21≦V<22	0.0
22	22≦V<23	0.0
23	23≦V<24	0.0
24	24≦V<25	0.0
25	25≦V<26	0.0
26	26≦V<27	0.0
27	27≦V<28	0.0
28	28≦V<29	0.0
29	29≦V<30	0.0
30	30≦V	0.0



Source: JICA Study Team based on the materials provided by Cabeolica

Table 7.1-18 Values monitored by the wind power generation system monitor

Wind velocity/power output

Wind turbine No.	1	2	3
Wind velocity (m/s) [Above ground height 55 m]	9.0	11.4	8.6
Power output (kW)	408.5	333.9	305.2

Plant data

Active Power		Reactive Power		Grid Data			
P	1026 kW	Q	279 kVAr	S	1050 kVA	L1-L2	19979V 30 A
Possible	1065 kW	Possible	500 kVAr	PF	-0.96 cosϕ	L2-L3	19964V 31 A
Setpoint	1200 kW	Setpoint	1.03 cosϕ	F	50.00	L3-L1	20005V 30 A

Source: Verified at the Chavez power plant.

The wind power output is set to 1,2000 kW and is maintained constant due to output control operation.

Figure 7.1-25 Wind power output fluctuation status (displayed on the PC monitor)

b. Comparison between actual energy generated and logical energy generated

For the four Cabeolica wind power generation sites (Santiago, São Vicente, Sal, and Boa Vista), logical power generated was calculated from the wind velocity data (10-minute values in 2015) that is provided from Cabeolica to verify the wind power generation potential and the condition of the output control operation since output control operation is performed for grid stabilizzation.

The output control statuses were also verified for the four sites through the comparison between actual energy generated and logical energy generated.

Regarding the output control status,since output control is not performed by Electra at Santiago according to the result of field research, the total loss rate of 10% was calculated from the actual energy generated that is provided by Cabeolica targeting Santiago and the logical energy generated. The logical energy generated of the net base was calculated by applying the total loss rate of 10% to the three islands except for Santiago.

The total loss rate of 10% refers to all the losses including the control loss and stop loss for maintenance.

The result of the comparison between the actual energy generated and the logical energy generated of the net base indicates that output control is performed for about 40% of energy generated in São Vincente and Sal for grid stabilization.

Table 7.1-19 and Figure 7.1-26 show the results of the comparison between the actual energy generated and the logical energy generated at the four sites.

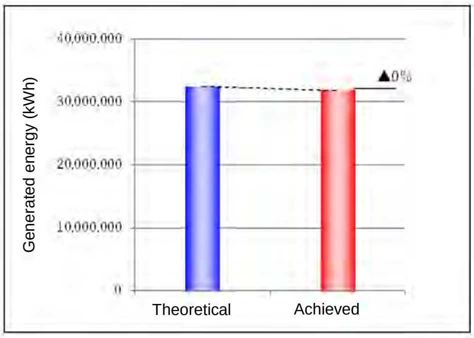
Tables 7.1-20 to 27 show the calculations results of logical energy generated (gross/net).

Table 7.1-19 Results of the comparison between the actual energy generated and logical energy generated at the four sites

		Santiago	São Vicente	Sal	Voa Vista	Remarks
①	Recorded generated energy (KWh/year) [Net])	31,859,912	19,044,650	18,776,460	7,611,858	• Performance record for 2015 (Source: Electra)
②	Theoretical generated energy (KWh/year) [gross])	36,101,784	33,078,912	34,424,312	10,898,481	• Calculated from actually measured wind velocity (55 m above ground (hub height)) and V52 performance curve • Based on acquired energy without including the shutdown loss caused by control loss, maintenance or other losses
③	Theoretical generated energy (KWh/year) [net])	32,491,605	29,771,021	30,981,881	9,808,633	• In Santiago, output control is not performed. So the overall loss rate was calculated based on the recorded generated energy. The result was 10%. Thus, for São Vicente, Sal and Boa Vista, the overall loss rate was assumed at 10%, and the theoretical generated energy (net) was calculated. ① Recorded generated energy for 2015 (kWh/year) [net]/ ② Theoretical generated energy for 2015 (kWh/year) [gross] × 100 (31,859,912/36,101,784) × 100 ≒ 90(%) Overall loss rate = 100(%) – 90(%) = 10(%) • ② × 0.9
④	Output-controlled generated energy (KWh/year)	All volume accepted	-10,726,371	-12,205,421	-2,196,775	• ① - ③ • Generated energy where the output is controlled for stable system operation

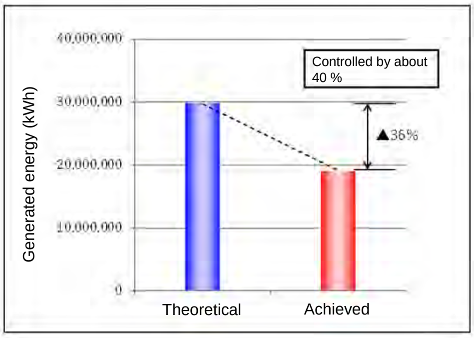
Source: JICA Study Team based on the data provided by Electra and Cabeolica.

Theoretical generated energy [net] [Capacity factor]	32,491,605 kWh (Base) (39.7%)
Generated energy (2015 record) [Capacity factor]	31,859,912 kWh (▲ 0%) (38.9%)



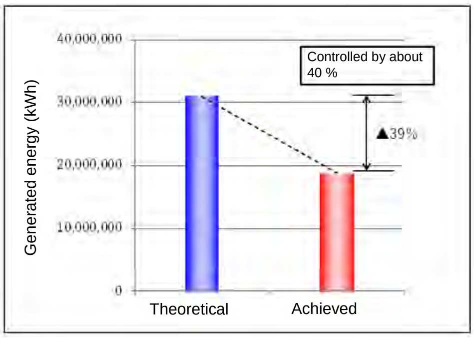
Santiago

Theoretical generated energy [net] [Capacity factor]	29,771,021 kWh (Base) (57.1%)
Generated energy (2015 record) [Capacity factor]	19,044,650 kWh (▲ 36%) (36.5%)



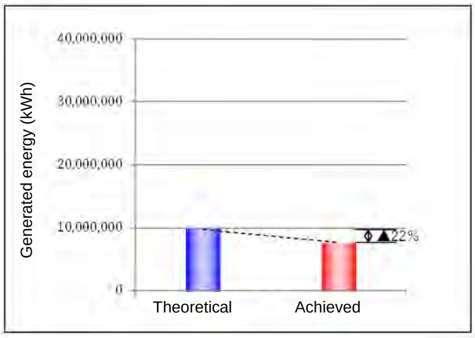
São Vicente

Theoretical generated energy [net] [Capacity factor]	30,981,881 kWh (Base) (46.2%)
Generated energy (2015 record) [Capacity factor]	18,776,460 kWh (▲ 39%) (28.0%)



Sal

Theoretical generated energy [net] [Capacity factor]	9,808,633 kWh (Base) (43.9%)
Generated energy (2015 record) [Capacity factor]	7,611,858 kWh (▲ 22%) (34.1%)



Boa Vista

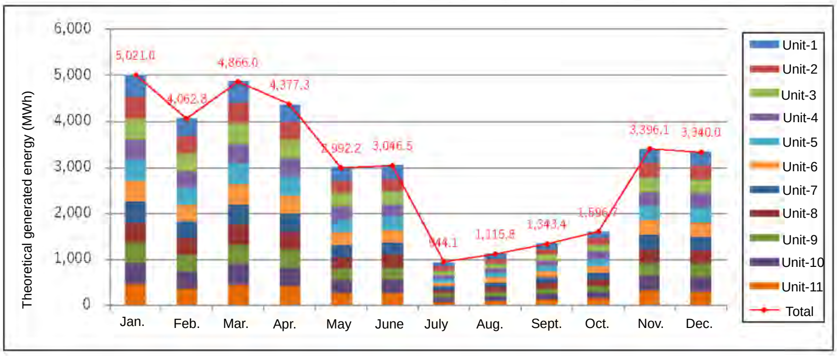
Source: JICA Study Team based on the data provided by Electra and Cabeolica.

Figure 7.1-26 Comparison between the actual energy generated and logical energy generated at the four sites

Table 7.1-20 Calculation result of the logical energy generated by the Santiago wind power generation system (gross)

(Unit: MWh)

Windmill	2015												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Unit-1	480.6	384.4	450.2	385.6	274.9	279.1	87.9	102.2	111.4	134.7	295.4	285.8	3,272.0
Unit-2	474.7	373.9	434.7	391.1	283.4	285.9	90.9	102.0	119.8	142.3	307.5	309.4	3,315.6
Unit-3	464.2	379.0	458.0	406.5	289.3	290.8	97.1	111.5	129.7	155.3	319.5	314.9	3,415.7
Unit-4	439.1	361.1	434.9	393.6	271.9	272.0	85.2	98.9	122.7	147.1	304.7	299.9	3,231.1
Unit-5	444.7	362.5	443.9	395.0	275.1	268.4	80.0	96.9	122.1	148.1	310.2	309.2	3,256.3
Unit-6	452.7	371.3	442.5	393.2	274.7	283.6	88.7	102.1	128.9	153.5	316.1	327.3	3,334.5
Unit-7	444.5	362.0	438.7	393.9	263.7	265.9	80.3	96.7	121.3	144.0	309.3	297.1	3,217.3
Unit-8	456.4	367.9	435.1	396.4	259.6	267.6	81.1	100.2	118.8	142.3	301.4	285.8	3,212.5
Unit-9	438.9	351.5	417.7	382.4	251.0	263.9	78.5	95.5	117.8	138.2	296.0	292.8	3,124.0
Unit-10	465.1	374.9	457.3	422.9	277.4	286.7	89.2	108.0	128.6	147.6	323.1	310.4	3,391.2
Unit-11	460.2	374.3	452.9	416.9	271.2	282.7	85.2	101.8	122.4	143.6	312.9	307.5	3,331.6
Total	5,021.0	4,062.8	4,866.0	4,377.3	2,992.2	3,046.5	944.1	1,115.8	1,343.4	1,596.7	3,396.1	3,340.0	36,101.8

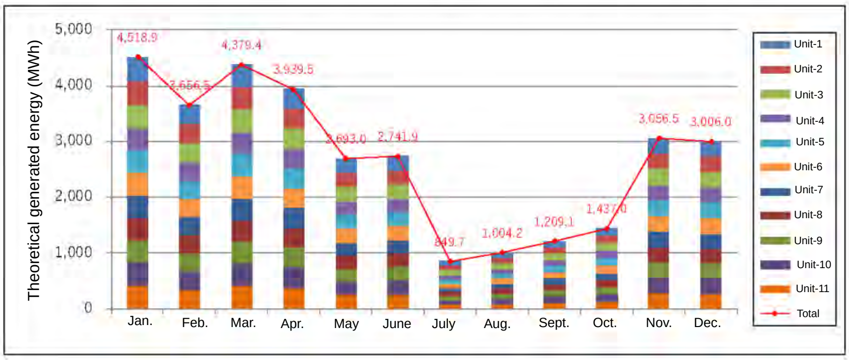


Source: JICA Study Team based on the data provided by Cabeolica.

Table 7.1-21 Calculation result of the logical energy generated by the Santiago wind power generation system (net)

(Unit: MWh)

Windmill	2015												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Unit-1	432.5	345.9	405.2	347.0	247.4	251.2	79.1	92.0	100.2	121.2	265.8	257.2	2,944.8
Unit-2	427.2	336.5	391.2	352.0	255.1	257.3	81.8	91.8	107.9	128.1	276.8	278.5	2,984.0
Unit-3	417.8	341.1	412.2	365.9	260.4	261.7	87.4	100.3	116.7	139.8	287.5	283.4	3,074.1
Unit-4	395.2	324.9	391.4	354.2	244.7	244.8	76.7	89.0	110.4	132.4	274.3	269.9	2,908.0
Unit-5	400.2	326.3	399.6	355.5	247.6	241.6	72.0	87.2	109.9	133.3	279.2	278.3	2,930.7
Unit-6	407.4	334.2	398.2	353.9	247.2	255.3	79.8	91.9	116.1	138.2	284.5	294.5	3,001.1
Unit-7	400.0	325.8	394.9	354.5	237.3	239.3	72.3	87.0	109.2	129.6	278.4	267.4	2,895.6
Unit-8	410.8	331.1	391.6	356.8	233.6	240.8	73.0	90.2	106.9	128.1	271.2	257.2	2,891.2
Unit-9	395.0	316.3	376.0	344.1	225.9	237.5	70.7	85.9	106.0	124.4	266.4	263.5	2,811.6
Unit-10	418.6	337.4	411.6	380.6	249.7	258.0	80.3	97.2	115.7	132.8	290.8	279.4	3,052.1
Unit-11	414.2	336.9	407.6	375.2	244.1	254.4	76.7	91.6	110.2	129.3	281.6	276.8	2,998.4
Total	4,518.9	3,656.5	4,379.4	3,939.5	2,693.0	2,741.9	849.7	1,004.2	1,209.1	1,437.0	3,056.5	3,006.0	32,491.6

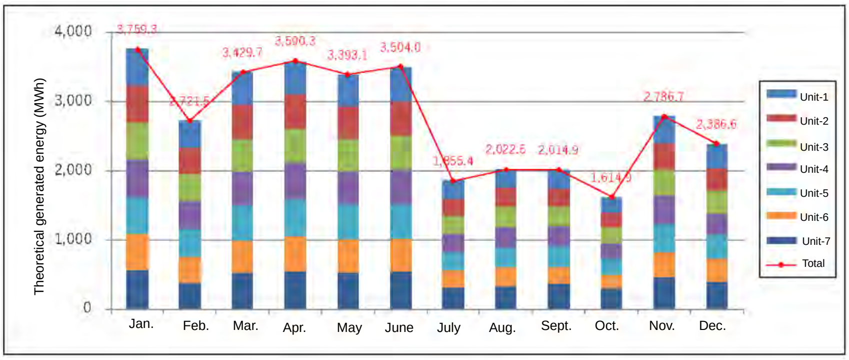


Source: JICA Study Team based on the data provided by Cabeolica.

Table 7.1-22 Calculation result of the logical energy generated by the São Vicente wind power generation system (gross)

(Unit: MWh)

Windmill	2015												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Unit-1	527.6	380.6	471.9	484.7	463.2	495.0	251.4	265.4	269.4	214.2	383.2	339.5	4,546.2
Unit-2	532.4	388.3	483.4	489.5	464.4	490.4	252.9	278.2	268.4	215.2	376.6	331.2	4,571.0
Unit-3	535.3	386.7	482.8	501.0	476.8	490.9	259.7	286.3	277.4	221.7	385.4	336.3	4,640.2
Unit-4	543.2	407.2	500.6	528.3	481.7	508.4	258.3	301.3	300.6	241.4	413.0	311.3	4,795.4
Unit-5	540.7	394.8	494.8	527.1	494.0	502.2	263.6	283.9	282.5	222.9	396.6	348.0	4,751.2
Unit-6	515.5	385.8	471.4	507.9	479.1	473.7	246.0	268.5	256.9	207.0	367.8	321.2	4,500.7
Unit-7	564.6	378.1	524.7	551.6	534.0	543.3	323.7	338.9	359.7	292.5	464.0	399.0	5,274.1
Total	3,759.3	2,721.5	3,429.7	3,590.3	3,393.1	3,504.0	1,855.4	2,022.5	2,014.9	1,614.9	2,786.7	2,386.6	33,078.9

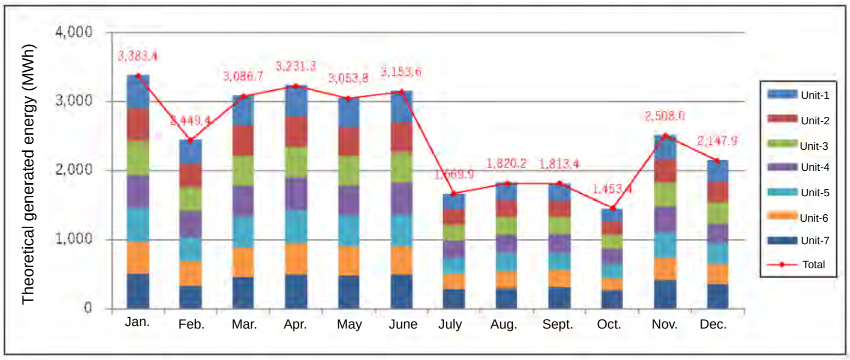


Source: JICA Study Team based on the data provided by Cabeolica.

Table 7.1-23 Calculation result of the logical energy generated by the São Vicente wind power generation system (net)

(Unit: MWh)

Windmill	2015												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Unit-1	474.8	342.5	424.7	436.3	416.9	445.5	226.2	238.9	242.4	192.8	344.9	305.6	4,091.6
Unit-2	479.1	349.5	435.1	440.6	418.0	441.4	227.6	250.4	241.5	193.7	338.9	298.1	4,113.9
Unit-3	481.8	348.0	434.5	450.9	429.1	441.8	233.7	257.6	249.6	199.5	346.9	302.7	4,176.2
Unit-4	488.9	366.5	450.6	475.5	433.6	457.6	232.5	271.1	270.5	217.2	371.7	280.2	4,315.9
Unit-5	486.6	355.3	445.3	474.4	444.6	452.0	237.2	255.6	254.3	200.6	357.0	313.2	4,276.1
Unit-6	463.9	347.2	424.3	457.1	431.2	426.3	221.4	241.6	231.2	186.3	331.0	289.1	4,050.6
Unit-7	508.1	340.3	472.2	496.5	480.6	489.0	291.3	305.0	323.8	263.3	417.6	359.1	4,746.7
Total	3,383.4	2,449.4	3,086.7	3,231.3	3,053.8	3,153.6	1,669.9	1,820.2	1,813.4	1,453.4	2,508.0	2,147.9	29,771.0

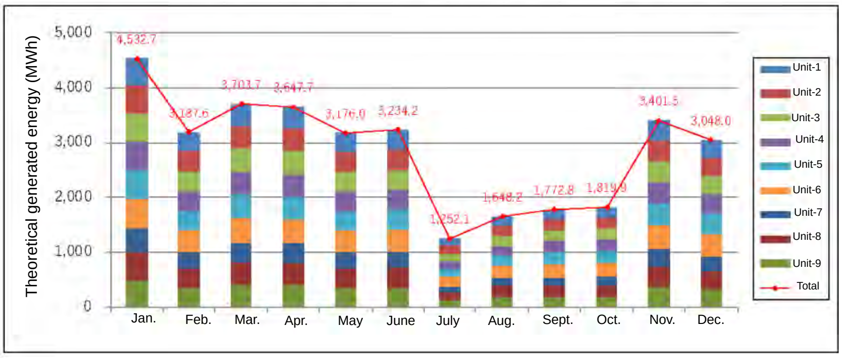


Source: JICA Study Team based on the data provided by Cabeolica.

Table 7.1-24 Calculation result of the logical energy generated by the Sal wind power generation system (gross)

(Unit: MWh)

Windmill	2015												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Unit-1	488.9	336.1	394.0	383.6	339.9	347.0	127.1	160.5	176.7	184.0	356.4	313.0	3,607.2
Unit-2	516.8	366.1	409.2	415.4	359.8	369.2	148.2	183.2	191.7	198.8	376.3	334.4	3,869.0
Unit-3	506.2	359.0	428.5	420.5	365.9	370.3	139.9	182.5	192.5	200.4	379.2	346.5	3,891.5
Unit-4	511.9	358.5	415.4	406.8	352.6	362.9	138.6	181.9	198.6	208.1	387.1	347.9	3,870.3
Unit-5	537.6	371.1	428.3	415.7	359.0	361.0	137.3	167.7	218.1	221.8	403.2	369.8	3,990.5
Unit-6	526.5	378.3	443.2	433.0	391.2	404.1	179.8	235.6	251.5	252.8	429.7	397.5	4,323.3
Unit-7	442.0	310.2	364.8	362.2	297.7	298.6	106.2	149.8	156.6	160.7	320.7	273.6	3,243.1
Unit-8	498.2	354.8	411.5	401.9	349.2	360.2	140.1	192.3	192.8	197.5	374.6	334.4	3,807.6
Unit-9	504.6	353.4	408.8	408.7	360.6	361.0	134.9	194.8	194.2	195.8	374.3	330.8	3,821.9
Total	4,532.7	3,187.6	3,703.7	3,647.7	3,176.0	3,234.2	1,252.1	1,648.2	1,772.8	1,819.9	3,401.5	3,048.0	34,424.3

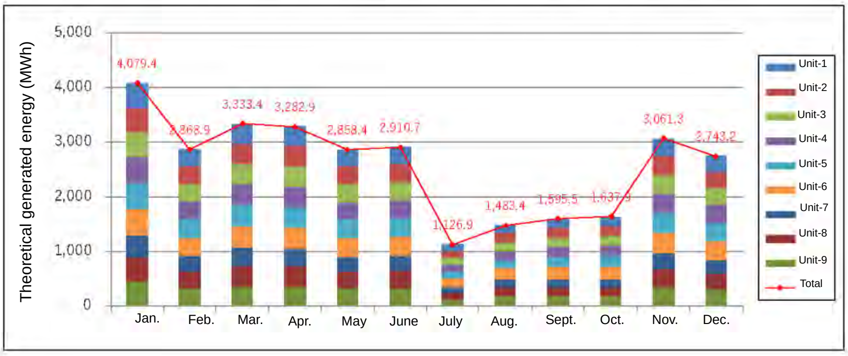


Source: JICA Study Team based on the data provided by Cabeolica.

Table 7.1-25 Calculation result of the logical energy generated by the Sal wind power generation system (net)

(Unit: MWh)

Windmill	2015												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Unit-1	440.0	302.5	354.6	345.2	305.9	312.3	114.4	144.4	159.0	165.6	320.8	281.7	3,246.5
Unit-2	465.1	329.5	368.3	373.9	323.9	332.3	133.4	164.9	172.5	178.9	338.6	301.0	3,482.1
Unit-3	455.6	323.1	385.7	378.4	329.4	333.3	125.9	164.2	173.3	180.4	341.3	311.8	3,502.3
Unit-4	460.7	322.7	373.9	366.1	317.3	326.6	124.7	163.7	178.8	187.3	348.4	313.1	3,483.3
Unit-5	483.8	334.0	385.4	374.1	323.1	324.9	123.5	150.9	196.3	199.6	362.9	332.8	3,591.4
Unit-6	473.8	340.5	398.9	389.7	352.1	363.7	161.8	212.0	226.4	227.5	386.7	357.8	3,891.0
Unit-7	397.8	279.2	328.4	326.0	267.9	268.7	95.6	134.8	140.9	144.7	288.6	246.2	2,918.7
Unit-8	448.4	319.3	370.4	361.7	314.3	324.2	126.1	173.1	173.6	177.8	337.1	300.9	3,426.8
Unit-9	454.1	318.0	367.9	367.8	324.5	324.9	121.4	175.3	174.8	176.2	336.9	297.7	3,439.7
Total	4,079.4	2,868.9	3,333.4	3,282.9	2,858.4	2,910.7	1,126.9	1,483.4	1,595.5	1,637.9	3,061.3	2,743.2	30,981.9

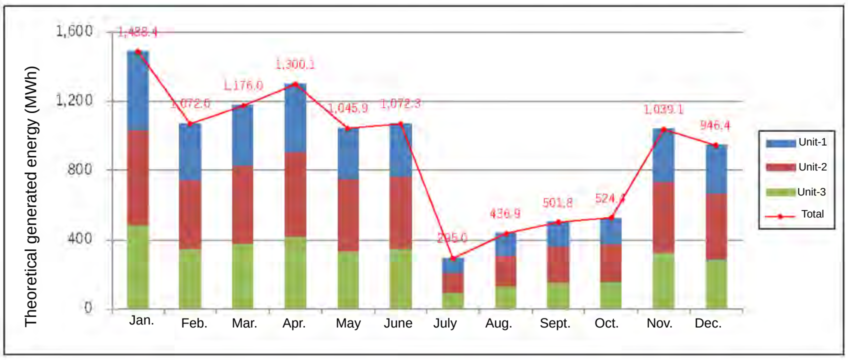


Source: JICA Study Team based on the data provided by Cabeolica.

Table 7.1-26 Calculation result of the logical energy generated by the Boa Vista wind power generation system (gross)

(Unit: MWh)

Windmill	2015												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Unit-1	453.6	324.6	345.8	392.8	295.0	306.3	85.3	127.3	141.8	148.2	304.4	278.6	3,203.5
Unit-2	546.8	401.7	450.8	485.4	414.0	419.5	118.9	177.1	210.9	220.3	409.4	377.3	4,232.1
Unit-3	488.0	345.7	379.4	421.9	337.0	346.6	90.9	132.4	149.1	156.0	325.2	290.5	3,462.8
Total	1,488.4	1,072.0	1,176.0	1,300.1	1,045.9	1,072.3	295.0	436.9	501.8	524.4	1,039.1	946.4	10,898.5

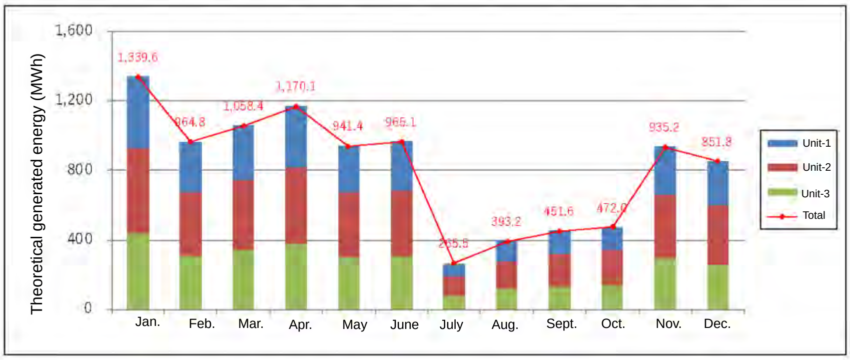


Source: JICA Study Team based on the data provided by Cabeolica.

Table 7.1-27 Calculation result of the logical energy generated by the Boa Vista wind power generation system (net)

(Unit: MWh)

Windmill	2015												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Unit-1	408.2	292.2	311.2	353.5	265.5	275.6	76.7	114.6	127.6	133.4	274.0	250.7	2,883.2
Unit-2	492.1	361.5	405.7	436.9	372.6	377.6	107.0	159.4	189.8	198.2	368.5	339.6	3,808.9
Unit-3	439.2	311.1	341.5	379.7	303.3	311.9	81.8	119.2	134.2	140.4	292.7	261.5	3,116.6
Total	1,339.6	964.8	1,058.4	1,170.1	941.4	965.1	265.5	393.2	451.6	472.0	935.2	851.8	9,808.6



Source: JICA Study Team based on the data provided by Cabeolica.

c. PPA-based annual power generation plan and the performance result

(a) Outline of PPA

Cabeolica and Electra established a capital cost guarantee (Take or Pay) type PPA (Purchase Price Agreement). PPA was established comprehensively for all the systems, not the individual systems that are owned by Cabeolica.

According to the discussion with Electra, the purchase obligatory amount was always achieved. Table 7.1-28 shows the outline of the PPA.

Table 7.1-28 Outline of PPA

Purchase price and obligatory amount	• The purchase price and obligatory amount (wind power energy generated that must be acceped by Cabeolica each month) are set.
Part of the contents that were reviewed after establishment of the contract	• Change of the purchase obligatory amount target values of Santiago and Sal • Change the settlement cycle from once a month to once in three months (settlement schedule: March, June, September, and December)

Source: Verbal information provided by Electra

(b) Obligatory purchase amount under the original PPA

Under the original PPA, the settlement for the obligatory purchase amount was implemented monthly. Therefore, the obligatory purchase amount of 2015 based on the schedule table at the establishment of the PPA was compared with the amount of energy sold to Electra by Cabeolica in 2015.

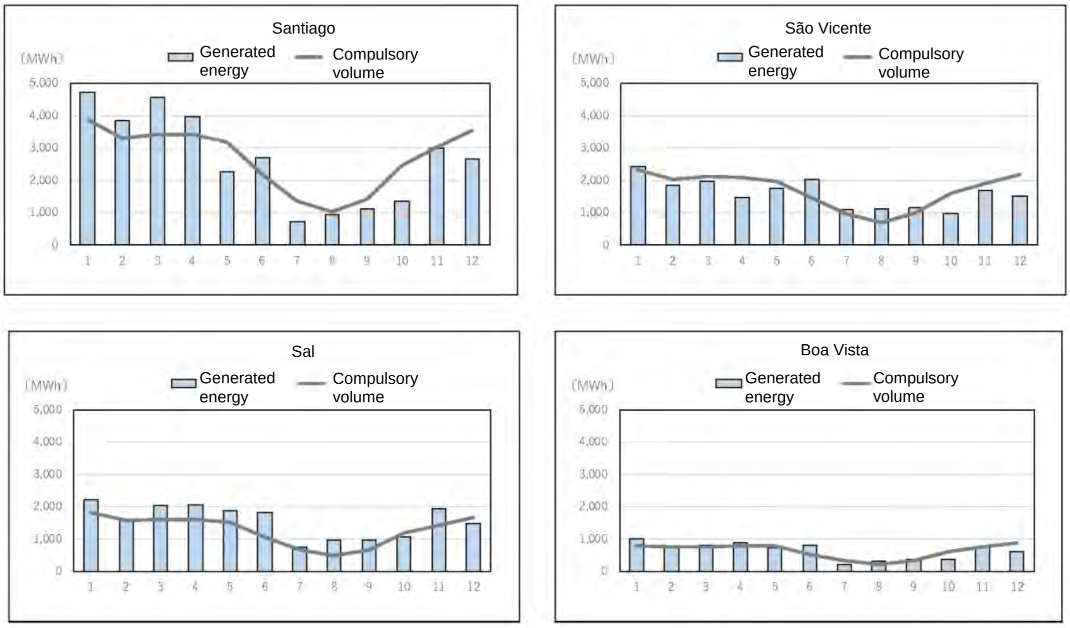
Table 7.1-29 and Figure 7.1-27 show the comparison of the obligatory purchase amount based on the original PPA and the actual energy generated (monthly/annually).

Table 7.1-29 Comparison of the obligatory purchase amount based on the original PPA and the actual energy generated (monthly/annually)

		2015												Annual
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Compulsory volume (MWh)	Santiago	3,871	3,316	3,435	3,417	3,181	2,188	1,352	1,017	1,418	2,444	3,028	3,533	32,200
	Sao Vicente	2,326	2,039	2,116	2,089	1,978	1,446	958	697	993	1,620	1,908	2,179	20,349
	Sal	1,808	1,564	1,615	1,603	1,503	1,052	663	483	669	1,171	1,432	1,676	15,238
	Boa Vista	788	750	743	775	772	518	319	222	323	594	747	867	7,418
Generated energy (MWh)	Santiago	4,733	3,861	4,565	3,960	2,266	2,685	713	928	1,118	1,371	2,995	2,663	31,860
	Sao Vicente	2,415	1,840	1,963	1,498	1,749	2,025	1,084	1,135	1,149	984	1,694	1,510	19,045
	Sal	2,206	1,611	2,026	2,045	1,880	1,829	757	981	964	1,049	1,946	1,483	18,776
	Boa Vista	1,009	737	812	890	730	802	221	314	359	370	762	606	7,612

Note) (yellow) : Level below

Source: Provided by Electra



Source: JICA Study Team based on the data provided by Electra

Figure 7.1-27 Comparison between the obligatory amount based on the original PPA and the actual energy generated

(c) Obligatory purchase amount after the change of the part of the contents of PPA

After establishment of the PPA, the obligatory purchase amount target values of Santiago and Sal and the settlement schedule were changed as a result of the discussion between Electra and Cabeolica.

Therefore, the obligatory purchase amounts and the amounts of electric energy sold for 3-month period were compared.

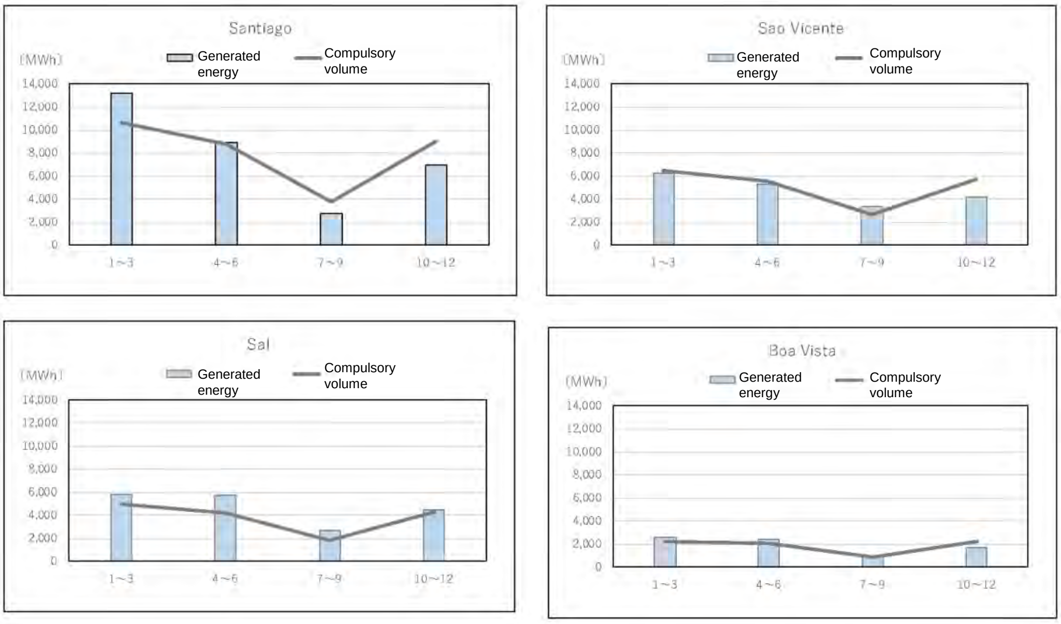
Table 7.1-30 and Figure 7.1-28 show the comparison between the obligatory purchse amount and the actual energy generated after the partial change of the PPA.

Table 7.1-30 Comparison between the obligatory purchase amount based on PPA and the actual energy generated

		2015				Annual
		Jan. to Mar.	Apr. to June	July to Sept.	Oct. to Dec.	
Compulsory volume (MWh)	Santiago	10,622	8,785	3,787	9,006	32,200
	Sao Vicente	6,482	5,512	2,648	5,707	20,349
	Sal	4,986	4,157	1,815	4,279	15,238
	Boa Vista	2,281	2,065	864	2,208	7,418
Generated energy (MWh)	Santiago	13,159	8,911	2,759	7,030	31,860
	Sao Vicente	6,218	5,272	3,367	4,188	19,045
	Sal	5,844	5,754	2,702	4,477	18,776
	Boa Vista	2,558	2,422	894	1,738	7,612

Note) [yellow] :Without reaching the target level at the time of adjustment every three month

Source: Data provided by Electra



Source: JICA Study Team based on the data provided by Electra

Figure 7.1-28 Comparison between the obligatory purchase amounts based on PPA and the actual energy generated

6) Operational and maintenance statuses

a. Operational status

Cabeolica established a 95% operation rate guarantee contract of their wind power generation system with Vestas and the system is operating smoothly without any long-term halt due to any serious problem since the commencement of the operation except for minor problems (filter and electrical problems and battery fault).

According to the discussion with Cabeolica,the operation rate of the system has not dropped below 95% since its commencement, however, there are some concerns regarding the problems in strong wind such as the weather problems, the problems with sand, and the problems with rust caused by salt.

Table 7.1-31 shows the operation rates (actual) that are provided by Cabeolica.

Table 7.1-31 Operation rates (actual)

		Santiago	São Vicente	Sal	Boa Vista
Operation rate	2013	99.7%	-	99.5%	99.4%
	2014	99.6%	-	99.7%	99.9%
	2015	99.7%	99.8%	99.9%	99.3%

Source: Data provided by Cabeolica (blank column: Unconfirmed)

b. Management structure and maintenance status

The Head Office of Cabeolica is located in Praia, the capital of Cabo Verde. The Cabeolica management structure comprises 10 employees (CEO: 1, CFO:1, Technical Manager: 1, Administration (accounting and general affairs): 3, and Sales contacts of 4 islands: 4).

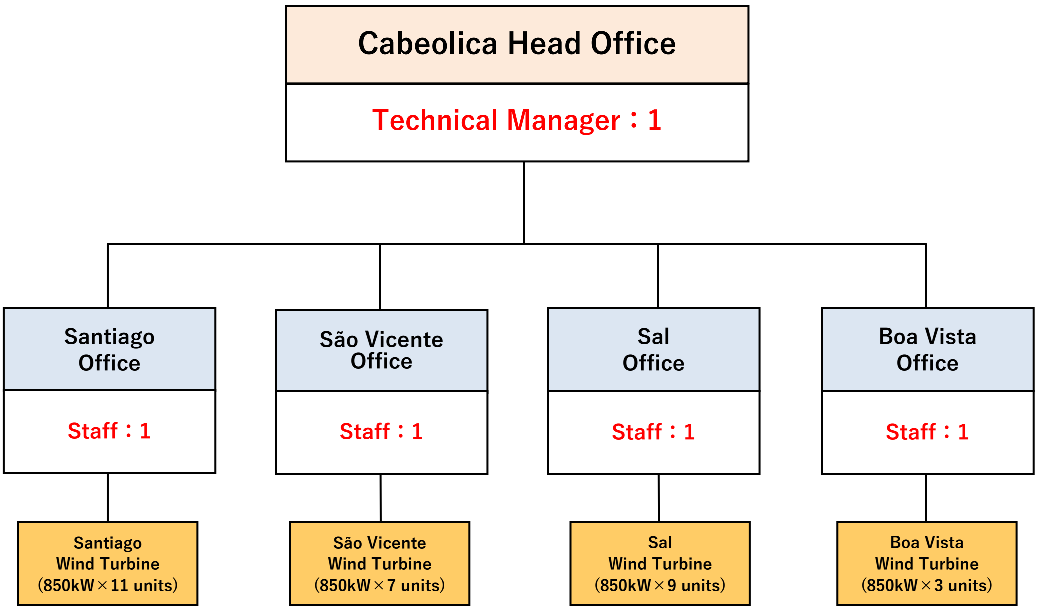
Maintenance of the wind power generation syatem is implemented according to the annual maintenance schedule and contents that are proposed by Vestas.

Cabeolica assigns one staff member to each of the four islands where the wind power genration system operates as the sales contact and is engaged in the operation and maintenance through the cooperation with the employees of Vestas.

Of the six employees of Vestas, four employees are stationed in Santiago and two employees are stationed in Sal for maintenance of the wind power generation systems that are intalled in the four islands through cooperation.

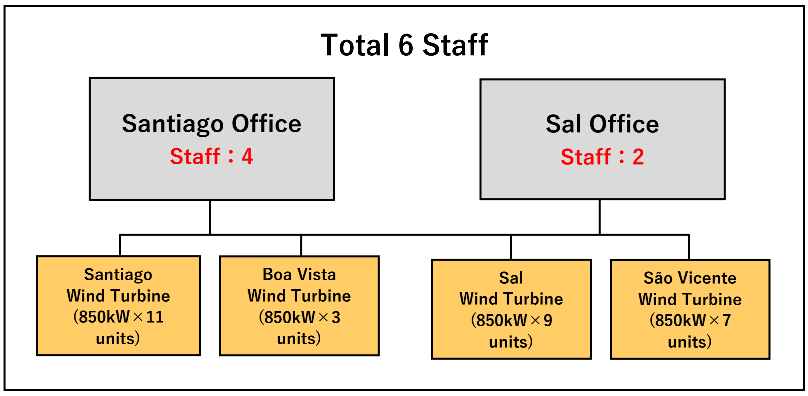
Figure 7.1-29 shows the structure of Cabeolica employees.

Figure 7.1-30 shows the Vestas employee structure.



Source: Verbal information obtained from Cabeolica

Figure 7.1-29 Cabeolica engineer structure



Source: Verbal information obtained from Cabeolica

Figure 7.1-30 Vestas employee structure

7.1.3 Electric Wind Power Generation System

According to the discussion with Electric, Electric was founded in 2010 and is not engaged in any services other than wind power IPP.

(1) Outline of the system

The total capacity of the wind power generation system owned by Electric in one island, Santo Antão, of Cabo Verde is 0.5MW.

The system is a unit capacity of 250kW manufactured by Micon (now absorbed by Vestas) and the type is M530-250/50kW. For the system, wind turbines about 12 years old were installed at the time.

This power plant commenced its operation in April 2011 so that the wind turbines are about 18 years old now.

Table 7.1-32 lists the specifications of the Electric wind power generation system.

(2) Conditions of the location sites

The 0.5MW wind power generation system (250kW × 2 units) is located at the East side of the island and the turbines are positioned at elevation of about 240m.

Figure 7.1-31 shows the location where the Santo Anto wind power system is installed.

Figure 7.1-32 shows the conditions of the Santo Antão wind power generation system.

Table 7.1-33 shows the location site conditions of the Santo Antão wind power generation system.

Wind turbine location coordinates

WTG	Latitude	Longitude
1	17°5′16.67″	24°58′16.51″
2	17°5′14.49″	24°58′15.44″

Note) World geodetic system

(Photograph: Google Earth)

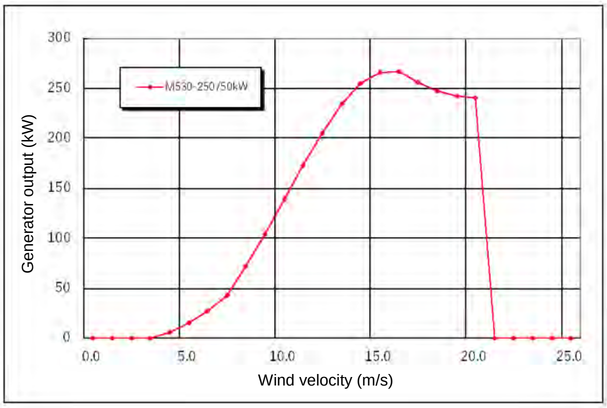
Source: JICA Study Team

Figure 7.1-31 Location of the Santo Antão wind power generation system

Table 7.1-32 Electric wind power generation system specifications

Location	Santo Antão
Operation commencement	April 2011
Manufacturer	Micon
Model	M530-250/50 kW
Rated output (kW)	250/50
No. of units	2
Total output (MW)	0.5
Output control	Stall
Power generator type	Basket type induction
Generator voltage (V)	400
Cut-in wind velocity (m/s)	4
Rated wind velocity (m/s)	—
Cut-out wind velocity (m/s)	25
Survival wind [instant](m/s)	65
Rotor diameter (m)	26
Hub height (m)	30
Performance curve (Power curve) [Air density 1.225 kg/m^3]	

Wind velocity (m/s)	Output (kW)
0.0	-
1.0	-
2.0	-
3.0	-
4.0	6
5.0	15
6.0	28
7.0	43
8.0	72
9.0	105
10.0	139
11.0	174
12.0	206
13.0	234
14.0	255
15.0	266
16.0	267
17.0	256
18.0	247
19.0	243
20.0	240
21.0	0
22.0	0
23.0	0
24.0	0
25.0	0



Source: JICA Study Team based on the data provided by Electric

Condition of the surrounding road

Unpaved road that leads to the power plant premises

Land utilization conditions
(Wind turbines of Micon 250 kW × 2 units)

Road conditions inside of power plant premises

Electric panel inside of the towr

Electric room

Figure 7.1-32 Conditions of the Santo Antão wind power generation system

Table 7.1-33 Conditions of the location site of the Santo Antão wind power system

	Conditions of location sites
Equipment and material transportation	• The road from the town center near the port to the area near the wind turbine location sites is paved. • The road that leads to the power plant premises by branching out from the paved road is unpaved and the width is 5m or wider.
Land utilization	• The wind turbines are installed at the sites at an elevation of about 240 m facing the sea. There are no buildings that interfere with the construction nearby. The surface layer consists of pebbles.
Power plant premises	• The roads inside of the premises (unpaved) are maintained to connect between the wind turbines and are wide enough to prevent any problems in transportation of equipment and materials.
Laws and regulations	• There are no residential buildings visually recognized nearby so that there seems to be no impact of noise.

Source: JICA Study Team

1) Configuration

a. Grid connection facilities (including the protection unit)

Two wind turbines of unit capacity of 250 kW are integrated into an underground filled cable after boosting the generator voltage 400 V to 10 kV outside of the tower of each turbine and are connected to the grid with 10 kV via the switching facility inside of the electric room.

All the necesary facilities for the grid interconnection are installed in the electric room including the switching facility and grid connection protection unit.

Figure 7.1-33 shows the conditions of the grid connection facilities.

Switching facility (inside of the electric room)

Step-up transformer

Figure 7.1-33 Conditions of the grid connection facilities

b. Electrical facilities

A power distribution board containing a switching facility and a protection unit is installed inside of the electric room.

Figure 7.1-34 shows the condition of the electrical facilities.

Power distribution board

Electrical facility controller

Figure 7.1-34 Condition of the electrical facilities

2) Operation

a. Monitoring the wind power generation system

The system is constantly monitored in remote mode by the SCADA system at the Head Office of Electric (São Vicente). According to the discussion with Electric, the system itself is older than the system of Cabeolica and less items are monitored in remote mode. Operation data are not accumulated.

b. Cooperative operation with Electra

The facilities of Electric utilizes stall control,which is incapable of output control. Therefore, cooperative operation such as output control and voltage adjustment is not exercised between Electra and Electric and the facilities of Electric are operating in irregular output mode (so called “electricity as generated”) according to the wind condition.

3) Performance result and plan of new installation and repairs

a. Performance and plan for new installation

(a) Progress

Wind conditions have been observed (above ground height 12m) for about one year since May 2008. Due to the excellent observation results of 9m/s as the annual average and 60% or more as the predominant wind direction appearance frequency, this site was selected.

Table 7.1-34 shows the result of the Santo Antão wind condition observation data analysis.

(b) Construction process (actual)

The plant commenced its commercial operation in April 2011. The specific schedule such as the construction process (actual) is unavailable.

(c) Construction cost (actual)

The construction cost (actual) is unavailable.

(d) Operating cost

The operating cost is unavailable.

Table 7.1-34 Result of the Santo Antão wind condition observation data analysis

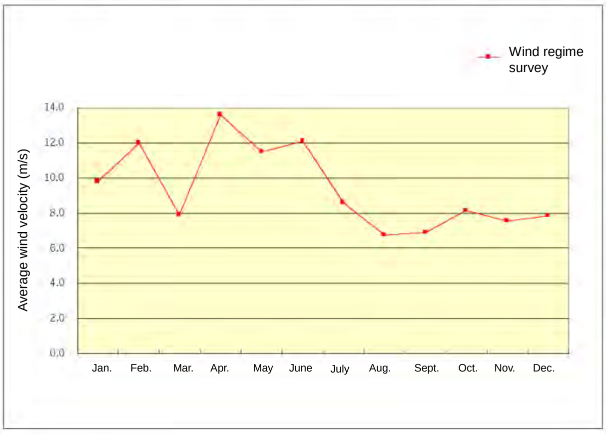
	Santo Antão
Layout map (Photograph): Google Earth) and site condition	 Layout map  Site condition

Result of wind condition observation

Monthly/annual average wind velocity (at 12m) [May 2008~ April 2009]

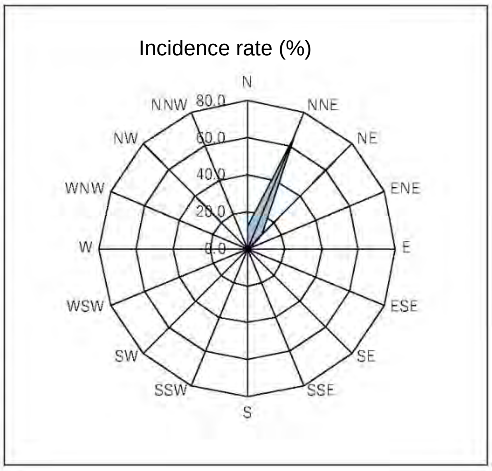
(Unit: m/s)

Obser-vation No.	2009				2008								Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
No. 1 pillar	9.8	12.0	7.9	13.6	11.5	12.1	8.6	6.7	6.9	8.1	7.5	7.9	9.4



Wind direction appearance rate (at 12m) [May 2008~ April 2009]

Bearing	Percentage
N	12.1
NNE	65.8
NE	11.2
ENE	2.4
E	2.0
ESE	0.9
SE	1.1
SSE	1.0
S	1.0
SSW	0.9
SW	0.3
WSW	0.3
W	0.1
WNW	0.2
NW	0.2
NNW	0.6
	100.0



Note) Analysis data (one-hour value) Number: 5,668

Source: JICA Study Team based on the data provided by Cabeolica.

b. Performance result and plan for repairs

According to the discussion with Electric, a plan for new installation/extension of a 20kV power transmisison line is developing at Santo Antão and as a result of the enhancement of the grid, addition of two more units is planned for the next year. The same model as the existing ones is assumed for the new units for the maintainability. According to Electra, there is a plan for installing a wind power generator as the independent power supply for the seawater desalination plant at São Nicolau and the wind condition is being examined.

4) Contents of the annual power generation performance and the electric power sales contract

a. Annual power generation performance

Electric provided the monthly/annual power generation amount performance data from April 2011 to December 2015.

The result of calculation of the annual system utilzation rate based on the annual power generation amount was between about 26% and 40%.

Table 7.1-35 shows the performance result of the annual power generation amount that is provided by Electric.

Table 7.1-35 Performance result of annual power generation amount

(Unit: kWh/year)

Year	Performance of annual power generation amount
2011	779,355(23.6%)
2012	1,333,048(30.4%)
2013	1,131,061(25.8%)
2014	1,737,011(39.7%)
2015	1,687,104(38.5%)

Source: JICA Study Team based on the data provided by Electric ((): Annual system utilization rate, Commenced commercial operation in April 2011)

b. Contents of the electric power sales contract

No capital guarantee type PPA was established between Electric and Electra, unlike Cabeolica.

5) Operational and maintenance conditions

a. Operational condition

According to the discussion with Electric, there have been no serious problems that caused any long-term system failure up to the current point since the commencement of the operation except for minor faults such as wind direction/velocity sensors and electrical faults.

Stall control is performed by rotating the tip of the blade through hydraulic control and there may have been a problem in the hydraulic system (disconnection of the hydraulic pipe inside of the blade). There has been no impact from lightning. Towers and nacelles have been painted for protection from salt damage.

b. Management structure and maintnance conditions

The Head Office of Electric is located at São Vicente. Three operators are stationed at Santo Antão and two of them are engaged in the operation from 8 a.m. to 5 p.m.in shift mode. Regular preventive maintenance is performed every three months. Wind turbines are stopped and maintained for one week in very six months when the wind velocity is low.

7.1.4 Wind Power Generation System Installed at Brava

An inactive wind turbine manufactured by Nordtank was left unattended at Brava. According to Cabeolica, its power output is about 150kW and seems to have been used for performing dump load operation (consuming energy with dummy load (resistance) when there is excessive energy). As a result of the site inspection with Electra to confirm the situation, the road was prepared for the wind turbine construction.

The tower is a raised/lowered type and a power distribution board without electrical parts, which may have been stolen, was left unattended.

Although the road is surfaced from the section near the Favatal Plant that is owned by Electra, a large volume of general rubbish was piled up at the entry of the road near the plant.

According to Electra, the wind turbine is connected to the power distribution facility at the port with a cable. A wind condition observation facility is intalled at the site and last year, GESTO Energy Consulting (GESTO), Portugal's energy consultant, seems to have conducted research on the wind condition last year.

Figure 7.1-35 shows the condition surrounding the Brava wind power generation system.

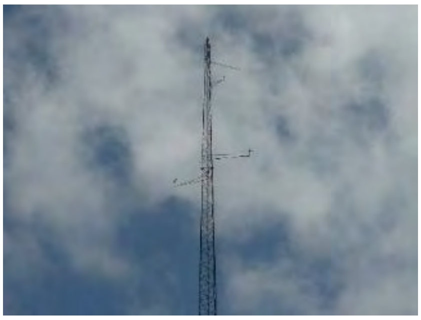

Full view of the wind turbine/wind condition observation facility


Wind turbine nacelle


Power distribution board inside of the tower


Dummy load (resistance) [Installed below the tower]


Tower (raised/lowered type)


Wind condition observation facility (GESTO examined the wind condition last year)


Road preparation condition


General rubbish piled up

Figure 7.1-35 Condition surrounding the Brava wind power generation system

7.2 Issues of Wind Power Generation

In Cabo Verde, wind power generation systems that are owned by two wind power IPP operators (Cabeolica and Electric)are operating in five islands (Santo Antão, São Vicente, Sal, Boa Vista, and Santiago).
Although the total wind power generation capacity of the systems that are operating in the five islands is 26.0MW, the unit capacities are 250kW and 850kW, which is less than 1,000kW.
The following section describes the issues regarding wind power generation including the current issues based on the field study and also the issues regarding installation of wind turbines in the wind power generation development zones that are published in Official Gazette No.7 (2012) of Cabo Verde with the assumption of 2MW as the future installation scale since the recent unit capacities of the main stream ground-installed wind turbines are 2MW or more.
Section 7.3 describes the specific abundance of the wind power generation development zone.

7.2.1 Current Issues

For the future operation, Cabeolica expressed their concern regarding the problems with sand and the impact of salt damage.
The towers of the wind turbines that are installed by Cabeolica apply the salinity tolerance specification in the same way as for offshore wind turbines as the measures against salt damage.
At the site inspection, repairs of the paint were found as the paint seemed to have been peeled off from some sections on the tower by the stones picked up by the strong wind.
Since the surfaces of the land of Cabo Verde are often covered by pebbles and the land faces the ocean, examination of the measures against salt damage and regular repairs of the surface of tower is necessary at the installation of the system.
Figure 7.2-1 shows the condition of the repairs at the bottom of the tower (Boa Vista).

Figure 7.2-1 Condition of the repairs at the bottom of the tower (Boa Vista)

7.2.2 Issues Regarding the Installation of Wind Turbines in the Wind Power Generation System Development Zone

In Cabo Verde, a renewable energy development area has been announced through the Official Gazette No. 7 (2012) as the area that is not to be environmentally impacted by controlling the construction of residential buildings and agricultural operations in advance to promote renewable energy.
In the renewable energy development area, a wind power generation development zone is specified.
In Cabo Verde, wind power potentials are examined by targeting this zone.

(1) Aspect of wind condition

To evaluate wind conditions for specifying a wind power generation development zone, a wind condition map that has been analyzed by the Riso National Laboratory (Denmark) in 2007 is used.
The wind velocity values that are displayed on this wind condition map are hourly-average values and cannot be used for evaluation of the impact of terrain turbulence on the blade surface, which is recently becoming evident as the cause of the failures of wind turbines and some accidents.
In Cabo Verde, there are many locations whose terrain gradients exceed 10% so that proper evaluation of the impact of terrain turbulence is necessary at examination of the installation of wind turbines.
The impact of terrain turbulence is a serious issue in Cabo Verde to avoid failures of wind turbines and accidents since the blade diameters increase as the size of wind turbine increases.

(2) Environmental aspect

The potential target model for wind power development in Cabo Verde is of unit capacity of 850kW, which is the same model as that installed by Cabeolica. The blade diameter of this model is 52m and the height up to the tip of the blade is 81m.
The 2MW type, which is currently applied as the main stream, utilizes a large blade with the diameter of about 100m. In many models, the tips of the blades exceed a height of 120m, imposing a serious impact on the landscape. In the area surrounding the wind power generation development zone (LS.1) at Sal, a plan for large scale resort development is progressing. Therefore, re-evaluation is necessary regarding the environmental aspect such as the impact on the landscape and associated noise.
Figure 7.3-19 shows the Sal wind power generation development zone.

(3) Aspect of transportation

Cabo Verde has two international ports (Paria Port at Santiago and Mindelo Port at São Vicente).
There are many structures that may interfere with transportation of equipment and materials for wind turbines in the section from the unloading wharf to the area around the exit at both ports. Therefore, when equipment and materials for large wind turbines are to be unloaded

and transported, detail examinations of the transportation route up to the wind turbine construction site, the measures for construction, and selection of transportation vehicles are necessary.
The issues regarding transportation from the unloading port to the wind turbine construction site are serious issues for the areas including the seven islands except Santiago and São Vicente.
Figure 7.2-2 shows the conditions surrounding the ports at Santiago and São Vicente.

Condition of the wharf at Praia Port (Santiago)

Condition at the exit of Praia Port (Santiago)

Condition of the road near the Mindelo Port (São Vicente)

Figure 7.2-2 Conditions surrounding the Ports at Santiago and São Vicente

(4) Aspect of installation and maintenance

Maintenance such as installation or replacement of a blade of 2MW class requires a crane of 500t capacity or more.

According to Cabeolica, the 400t crane that was used for installation of the wind turbines (unit capacity 850kW) was brought from Portual. However, since there is no large crane of 500t in Cabo Verde, procurement of such a crane is necessary.

7.2.3 Issues Regarding the Operating Characteristics of the Wind Power Generation System

The wind conditions of Cabo Verde are not constant throughout the year and the wind velocity drops significantly during the summer from July to October. In particular, at Sal and Boa Vista, where the tourism industry is flourishing, the demand for energy is high during summer.

Wind turbine power generation halting hours were calculated targeting Sal and Boa Vista by using the wind velocity 10-minute data of 2015 that was provided by Cabeolica. The halting hours were calculated by accumulating the hours during which the wind velocity is less than 4m/s and 25m/s or more, since the cut-in wind velocity (power generation starting velocity) is 4m/s or more and the cut-out wind velocity (velocity that causes power generation to halt) is 25m/s in the case of V52-859kW model manufactured by Vestas. According to the calculation result, for both islands, the longest power generation halting hours fall in July. At Sal, the duration was 147 hours (equivalent to about 6 days) and at Boa Vista, the duration was 256 hours (equivalent to about 11 days).

In Electra, the output upper limit value is set manually on the remote monitoring personal computer of the internal combustion power plant to control the output of the Cabeolica wind power generation system. However, Electra may not be able to handle the wind power generation halt due to the sudden drop of wind velocity.

Although a diesel power generation system is secured as the standby system, it takes about one hour for startup. Therefore, it is necessary to examine the operation method to handle sudden wind power generation halt for grid stabilization, including the operation method of the number of diesel power generators.

Table 7.2-1 shows the power generation halt duration by month and year.

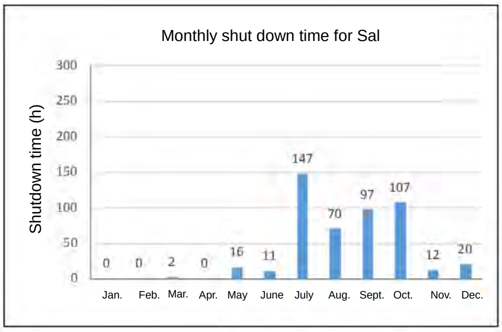
Figure 7.2-3 shows the power generation halt duration by month.

Table 7.2-1 Power generation halt duration by month and year

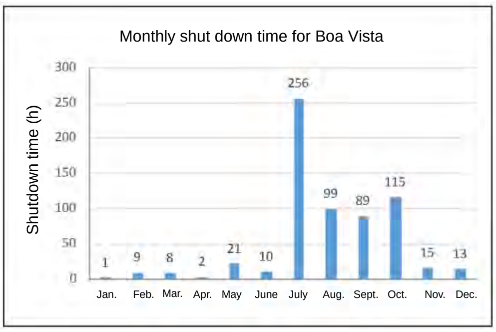
Year	Month	Shutdown time (h)	
		Sal	Boa Vista
2015	1	0	1
	2	0	9
	3	2	8
	4	0	2
	5	16	21
	6	11	10
	7	147	256
	8	70	99
	9	97	89
	10	107	115
	11	12	15
	12	20	13
	Total	482	638

Note) The power generation shutdown time is represented by the total of the wind velocity occurrence times other than those for wind velocity that enables power generation (4m/s or more, less than 25m/s).

Source: JICA Study Team based on the data provided by Cabeolica



Sal



Boa Vista

Source: JICA Study Team based on the data provided by Cabeolica

Figure 7.2-3 Power generation halt duration by month

7.2.4 Issues Regarding the Securement of Power Quality Associated with the Expansion of Wind Power Generation System Installation

At São Vicente, three wind turbines manufactured by Nordtank that are owned by Electra (unit capacity of 250kW) were inactive due to oversupply of the systems.

At Brava, although one wind turbine manufactured by Nordtank was installed, a part of the power generated was left abandoned due to the dump load operation at the time of operation.

This system was left without being removed after the operation stopped.

Since the Cabeolica wind power generation system (wind turbines manufactured by Vestas, unit capacity 850kW x 30 units) applies a control mode that allows output control, cooperative operation with Electra diesel power generation system is exercised for grid stabilization. In the wind power generation systems at São Vicente and Sal, about 40% of the amount of energy generated annually is controlled.

At the same time, the preparation for the bidding system of wind power generation IPP providers is progressing in Cabo Verde and future installation of wind power generation systems is planned. According to DGE, the bidding procedure is scheduled to be completed by September this year; however, it is unknown whether the installation capacity of wind power generation system for eaach island is to be announced.

Therefore, as the preconditions for bidding, it is necessary to comprehensively examine the cooperative operation with diesel power generation systems, reinforcement of the power transmission network, and grid stabilization measures such as installation of batteries based on the future demand status and grid status and to calculate the wind power generation installation capacity for each island.

It is also necessary to conduct technical examination including whether there are any problems in the specification of the wind power generation systems that are connected regarding the securement of the power quality that is indicated in the grid code (schedule to become effective in February 2016) of Cabo Verde, and frequency and voltage fluctuations in each project.

In addition, according to the comments from Cabeolica, private companies are not financially capable of installing batteries. Therefore, it is necessary to clearly indicate in the bidding procedure the battery installer when batteries are required and the cost allocation method between the wind power generation IPP operator and the grid operator.

7.3 Study of Wind Power Potential

7.3.1 Acquisition of Wind Condition Observation Data

To evaluate potential of wind-power generation, we obtained meteorological statistical data from the National Institute of Meteorology and Geophisics (hereafter referred to as INMG) of Cabo Verde.
In this investigation, we requested INMG to provide meteorological statistical data that can be obtained at three observation points [Mindelo (São Vicente), Sal, and Praia (Santiago)] where INMG conducts meteorological observations.
We studied wind power potential based on the wind condition data (wind speed and wind direction) included in the meteorological statistical data provided by INMG.
Figure 7.3-1 shows meteorological observation points.

① Mindelo(16 50 01N, 25 03 17W)
② Sal(16 44 31N, 22 56 56W)
③ Praia(14 56 28N, 23 29 05W)

Figure 7.3-1 Meteorological observation points

7.3.2 Long-term Fluctuation Situation of Wind Speed

(1) Observation overview

As the result of confirming the observation situation of wind conditions in Mindelo and Sal, data was being measured at a ground height of approximately 30 meters (building roof) in Mindelo and at 10 meters above ground (observation pole) in Sal.
When we had an interview with INMG and confirmed the height at which wind conditions are observed, INMG said that the height is 10 meters above ground in Sal and approximately 30 meters above ground in other locations.
Figure 7.3-2 shows the observation situation of wind conditions [approx. 30 meters above ground] in Mindelo (São Vicente).
Figure 7.3-3 shows the observation situation of wind conditions [approx. 10 meters above ground] in Sal.

Figure 7.3-2 shows the observation situation of wind conditions [approx. 30 meters above ground] in Mindelo (São Vicente).

Figure 7.3-3 shows the observation situation of wind conditions [approx. 10 meters above ground] in Sal.

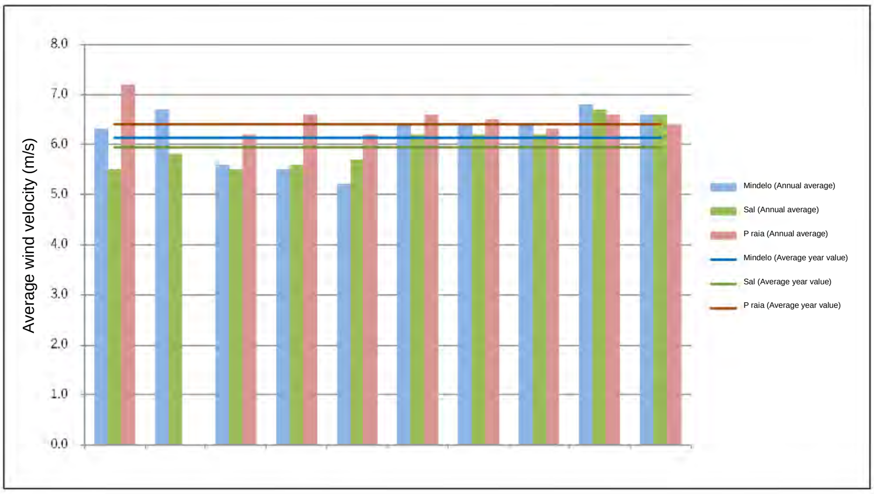
(2) Analysis result of the 2015 average annual value and the normal value

Based on the average daily wind speed (m/s) in Mindelo, Sal, and Praia for the past ten years (from January 2006 to December 2015) provided by INMG, we evaluated how was the wind conditions in 2015 during which wind speed data, provided by Cabeolica, was being collected.

Average wind speed in Mindelo, Sal, and Praia of Cabo Verde for the past ten years (from January 2006 to December 2015) was 6.1m/s, 5.9m/s, and 6.4m/s, respectively.

As the wind speed data provided by Cabeolica for this investigation was the data for one year of 2015, we compared the average wind speed between the investigation year (from January 2015 to December 2015) and the past nine years (from January 2006 to December 2014). As a result, the 2015 average annual wind speed in Mideleo, Sal, and Praia was 6.6m/s, 6.6m/s, and 6.4m/s, respectively, and the average wind speed for past nine years (hereafter, referred to as a normal value) was 6.1m/s, 5.9m/s, and 6.4m/s, respectively. The average wind speed in 2015 was slightly faster than the normal value.

There was no information as to whether observation locations and the observation height in Mindelo, Sal, and Praia had been changed. Figure 7.3-4 shows the average annual value and the normal value at each observation point. Table 7.3-1 shows the average annual value and the normal value at each observation point.



Source: Prepared by the investigation team based on the data provided by the National Institute of Meteorology and Geophisics

Figure 7.3-4 Average annual value and normal value at each observation point

Table 7.3-1 Average annual value and normal value at each observation point

(Unit: m/s)

	Mindelo (Average wind velocity)											
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average *	Wind velocity ratio
Jan.	6.3	5.8	5.7	8.9	4.1	5.6	6.5	6.6	7.4	8.1	6.3	1.3
Feb.	7.0	7.6	5.7	8.5	3.5	7.8	8.1	7.0	8.3	7.3	7.1	1.0
Mar.	7.5	8.4	5.9	6.5	5.7	7.7	6.2	6.3	7.1	7.2	6.8	1.1
Apr.	8.2	6.9	7.2	6.5	5.2	6.5	7.7	6.8	7.1	7.9	6.9	1.1
May	7.9	7.2	6.7	6.8	7.8	7.0	7.7	7.7	7.6	7.1	7.4	1.0
June	7.6	6.8	5.9	6.4	6.3	6.3	6.8	7.2	7.7	7.5	6.8	1.1
July	5.8	5.5	4.1	3.8	5.6	6.3	6.3	6.4	6.6	5.8	5.6	1.0
Aug.	4.5	6.1	4.3	3.4	4.6	5.5	5.5	4.9	5.5	6.1	4.9	1.2
Sept.	4.4	6.5	5.1	3.7	4.9	6.1	5.3	5.8	6.2	5.6	5.3	1.1
Oct.	5.4	6.5	6.2	3.7	5.4	4.9	5.2	6.4	5.8	5.2	5.5	0.9
Nov.	4.5	6.4	4.6	4.0	4.5	6.5	6.0	5.8	6.3	6.4	5.4	1.2
Dec.	6.3	6.7	5.7	3.6	4.5	6.5	6.2	6.6	5.7	5.4	5.8	0.9
Average	6.3	6.7	5.6	5.5	5.2	6.4	6.4	6.4	6.8	6.6	6.1	1.1

Note) [ ] : Survey period
＊ : Average of past nine-year period (average of yellow-colored values)
Wind velocity ratio : 2015/average of past nine-year period

(Unit: m/s)

	Sal (Average wind velocity)											
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average *	Wind velocity ratio
Jan.	6.1	5.5	5.9	7.4	5.9	5.6	7.1	7.0	7.8	8.6	6.5	1.3
Feb.	6.2	7.0	5.6	6.7	5.5	7.7	7.8	6.4	9.3	7.7	6.9	1.1
Mar.	6.3	6.9	5.8	5.3	7.2	6.9	6.4	6.3	7.2	7.7	6.5	1.2
Apr.	6.3	6.2	6.3	6.6	5.8	6.5	7.0	6.7	6.8	7.6	6.5	1.2
May	5.7	6.7	6.7	7.0	7.4	6.8	7.2	7.5	7.2	7.0	6.9	1.0
June	6.7	6.1	6.1	5.8	6.4	5.9	6.6	6.8	7.2	7.2	6.4	1.1
July	5.1	4.5	5.2	4.2	5.4	5.5	5.0	5.6	5.8	4.7	5.1	0.9
Aug.	4.4	4.8	4.0	4.3	4.8	5.3	5.0	4.8	4.9	5.4	4.7	1.1
Sept.	4.3	5.3	4.2	4.4	5.2	5.7	4.7	5.3	5.6	5.4	5.0	1.1
Oct.	4.5	5.7	5.3	5.1	5.3	5.1	5.0	5.6	5.7	4.9	5.3	0.9
Nov.	4.7	5.3	5.0	5.4	4.7	6.2	5.7	5.9	6.1	7.0	5.4	1.3
Dec.	6.1	6.1	5.7	4.8	4.7	7.1	6.9	6.6	7.1	6.3	6.1	1.0
Average	5.5	5.8	5.5	5.6	5.7	6.2	6.2	6.2	6.7	6.6	5.9	1.1

Note) [ ] : Survey period
＊ : Average of past nine-year period (average of yellow-colored values)
Wind velocity ratio : 2015/average of past nine-year period

(Unit: m/s)

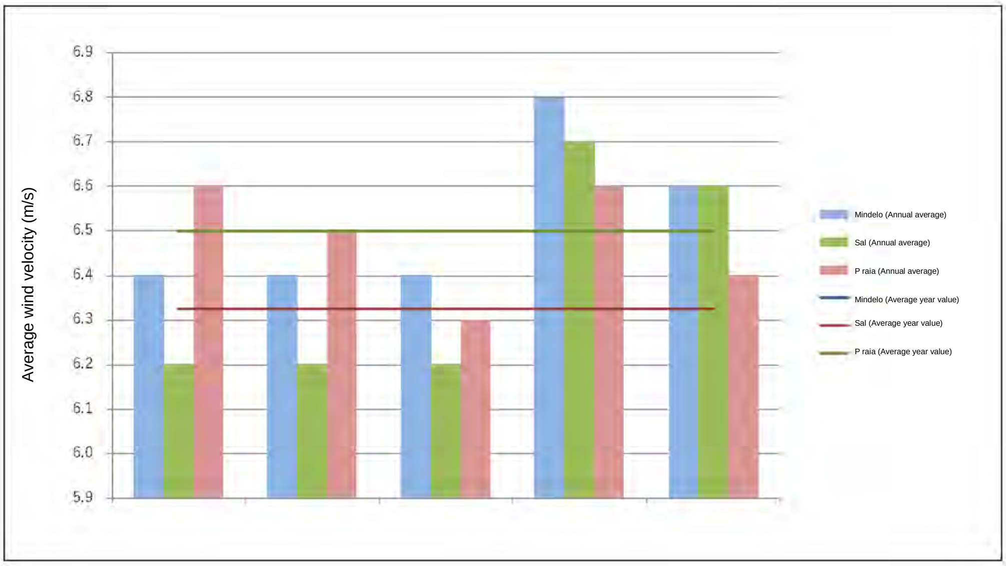
	Praia (Average wind velocity)											
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average *	Wind velocity ratio
Jan.	8.5	–	–	9.1	7.1	6.5	7.5	7.8	8.0	8.7	7.8	1.1
Feb.	8.7	–	–	8.9	6.5	8.6	9.1	7.4	9.2	8.2	8.3	1.0
Mar.	7.9	–	–	7.3	8.3	8.1	7.5	6.9	7.5	8.1	7.6	1.1
Apr.	7.9	–	7.4	8.3	6.9	7.5	8.5	6.8	6.8	7.6	7.5	1.0
May	7.7	–	8.3	7.4	8.2	7.7	7.3	7.5	7.1	6.2	7.7	0.8
June	7.8	–	6.9	6.6	6.7	5.6	6.3	6.3	7.1	6.6	6.7	1.0
July	5.9	–	5.0	4.4	5.2	5.5	4.8	4.9	5.3	4.6	5.1	0.9
Aug.	4.5	–	4.2	4.7	4.2	4.8	4.4	4.1	4.4	4.5	4.4	1.0
Sept.	3.6	–	4.5	4.2	4.5	5.2	4.2	4.5	4.8	4.7	4.4	1.1
Oct.	–	–	6.1	5.6	5.3	5.0	5.0	5.3	5.3	4.5	5.4	0.8
Nov.	–	–	6.1	6.8	5.4	7.5	6.2	6.3	6.4	6.5	6.4	1.0
Dec.	–	–	7.0	6.4	5.9	7.5	7.3	7.2	6.8	6.6	6.9	1.0
Average	7.2	–	6.2	6.6	6.2	6.6	6.5	6.3	6.6	6.4	6.4	1.0

Note) [ ] : Survey period
＊ : Average of past nine-year period (average of yellow-colored values)
Wind velocity ratio : 2015/average of past nine-year period

Source: Prepared by the investigation team based on the data provided by the National Institute of Meteorology and Geophisics

However, as shown in Table 7.3-2, the data pick-up rate at each observation point was 90% or more in Mindelo until 2010 and 75% or more in Praia until 2008. Statistically, data is regarded unreliable if 10% or more of the data is missing annually. Therefore, we regarded the average value for the four years from 2011 to 2014 when the data pick-up rate in Mindelo is 90% or more as a semi-normal value, and we compared the values with the 2015 average annual value. The result is as shown in Table 7.3-3. The semi-normal value in Mindelo, Sal, and Praia was 6.5m/s, 6.3m/s, and 6.5m/s, respectively; and the average value in 2015 was 6.6m/s, 6.6m/s, and 6.4m/s, respectively. The difference from the semi-normal value is relatively small. As to the monthly data, the average wind speed in January in Mindelo and Praia is 1.2 times the semi-normal value, the average wind speed in January in Sal is 1.3 times the semi-normal value, and the average wind speed in November in Sal is 1.2 times the semi-normal value. Other than that, the monthly average wind speed in 2015 is almost the same as the semi-normal value (the wind speed ratio of 0.9 to 1.1). Accordingly, it is considered that wind conditions in 2015 during which wind condition data, provided by Cabeolica, were being collected were not specifically abnormal when compared to a normal year.

Table 7.3-3 shows the wind speed data pick-up rate at each observation point, used for wind speed evaluation.



(Note) The semi-normal value in Mindelo and Praia is the same; 6.5 m/s.

Source: Prepared by the investigation team based on the data provided by the National Institute of Meteorology and Geophisics

Figure 7.3-5 Average annual value and semi-normal value at each observation point

Table 7.3-2 Wind velocity data pick-up rate at each observation point

Month/ Year	Mindelo (Average wind velocity)									Unit: %
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Jan.	77.4	83.9	87.1	87.1	83.9	83.9	100.0	100.0	100.0	100.0
Feb.	85.7	85.7	79.3	85.7	82.1	82.1	100.0	100.0	100.0	100.0
Mar.	87.1	87.1	83.9	83.9	87.1	87.1	100.0	100.0	100.0	100.0
Apr.	83.3	83.3	70.0	86.7	86.7	86.7	100.0	100.0	100.0	100.0
May	87.1	87.1	87.1	83.9	83.9	93.5	100.0	100.0	100.0	100.0
June	86.7	86.7	83.3	86.7	86.7	100.0	100.0	100.0	100.0	100.0
July	83.9	80.6	87.1	83.9	87.1	100.0	100.0	100.0	100.0	100.0
Aug.	87.1	87.1	83.9	83.9	83.9	100.0	100.0	100.0	100.0	100.0
Sept.	86.7	83.3	80.0	73.3	86.7	100.0	100.0	100.0	100.0	100.0
Oct.	83.9	87.1	87.1	87.1	83.9	100.0	96.8	100.0	100.0	100.0
Nov.	86.7	80.0	86.7	83.3	86.7	100.0	100.0	100.0	100.0	100.0
Dec.	83.9	83.9	83.9	74.2	83.9	96.8	100.0	100.0	100.0	100.0
Average	84.9	84.7	83.3	83.3	85.2	94.2	99.7	100.0	100.0	100.0

Month/ Year	Sal (Average wind velocity)									Unit: %
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Jan.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Feb.	100.0	100.0	100.0	100.0	92.9	100.0	100.0	100.0	100.0	100.0
Mar.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Apr.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
May	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
June	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
July	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Aug.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sept.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Oct.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Nov.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Dec.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Average	100.0	100.0	100.0	100.0	99.5	100.0	100.0	100.0	100.0	100.0

Month/ Year	Praia (Average wind velocity)									Unit: %
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Jan.	100.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	93.5	100.0
Feb.	100.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mar.	100.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Apr.	100.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
May	100.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	96.8
June	100.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
July	100.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	90.3
Aug.	100.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	93.5	100.0
Sept.	43.3	0.0	100.0	100.0	100.0	100.0	100.0	93.3	93.3	100.0
Oct.	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	87.1	100.0
Nov.	0.0	0.0	100.0	100.0	100.0	100.0	100.0	96.7	100.0	93.3
Dec.	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Average	70.1	0.0	75.1	100.0	100.0	100.0	100.0	99.2	97.3	98.4

Source: Prepared by the investigation team based on the data provided by the National Institute of Meteorology and Geophisics

Table 7.3-3 Average annual value and semi-normal value at each observation point

Item	Mindelo							Sal							Praia						
	2011	2012	2013	2014	2015	Average value	Wind velocity ratio	2011	2012	2013	2014	2015	Average value	Wind velocity ratio	2011	2012	2013	2014	2015	Average value	Wind velocity ratio
Jan.	5.6	6.5	6.6	7.4	8.1	6.5	1.2	5.6	7.1	7.0	7.8	8.6	6.9	1.3	6.5	7.5	7.8	8.0	8.7	7.5	1.2
Feb.	7.8	8.1	7.0	8.3	7.3	7.8	0.9	7.7	7.8	6.4	9.3	7.7	7.8	1.0	8.6	9.1	7.4	9.2	8.2	8.6	1.0
Mar.	7.7	6.2	6.3	7.1	7.2	6.8	1.1	6.9	6.4	6.3	7.2	7.7	6.7	1.1	8.1	7.5	6.9	7.5	8.1	7.5	1.1
Apr.	6.5	7.7	6.8	7.1	7.9	7.0	1.1	6.5	7.0	6.7	6.8	7.6	6.8	1.1	7.5	8.5	6.8	6.8	7.6	7.4	1.0
May	7.0	7.7	7.7	7.6	7.1	7.5	0.9	6.8	7.2	7.5	7.2	7.0	7.2	1.0	7.7	7.3	7.5	7.1	6.2	7.4	0.8
June	6.3	6.8	7.2	7.7	7.5	7.0	1.1	5.9	6.5	6.8	7.2	7.2	6.6	1.1	5.6	6.3	6.3	7.1	6.6	6.3	1.0
July	6.3	6.3	6.4	6.6	5.8	6.4	0.9	5.5	5.0	5.6	5.8	4.7	5.5	0.9	5.5	4.8	4.9	5.3	4.6	5.1	0.9
Aug.	5.5	5.5	4.9	5.5	6.1	5.4	1.1	5.3	5.0	4.8	4.9	5.4	5.0	1.1	4.8	4.4	4.1	4.4	4.5	4.4	1.0
Sept.	6.1	5.3	5.8	6.2	5.6	5.9	1.0	5.7	4.7	5.3	5.6	5.4	5.3	1.0	5.2	4.2	4.5	4.8	4.7	4.7	1.0
Oct.	4.9	5.2	6.4	5.8	5.2	5.6	0.9	5.1	5.0	5.6	5.7	4.9	5.4	0.9	5.0	5.0	5.3	5.3	4.5	5.2	0.9
Nov.	6.5	6.0	5.8	6.3	6.4	6.2	1.0	6.2	5.7	5.9	6.1	7.0	6.0	1.2	7.5	6.2	6.3	6.4	6.5	6.6	1.0
Dec.	6.5	6.2	6.6	5.7	5.4	6.3	0.9	7.1	6.9	6.6	7.1	6.3	6.9	0.9	7.5	7.3	7.2	6.8	6.6	7.2	0.9
Average	6.4	6.4	6.4	6.8	6.6	6.5	1.0	6.2	6.2	6.2	6.7	6.6	6.3	1.0	6.6	6.5	6.3	6.6	6.4	6.5	1.0

Note: [ ] the semi-normal value; red letters indicate that average wind speed of each month is 1.2 times more compared to the semi-normal value.

Source: Prepared by the investigation team based on the data provided by the National Institute of Meteorology and Geophisics

7.3.3 Potential Evaluation According to the Wind Condition Map

(1) Overview of the GSM data

Overview of the GSM data is shown in Table 7.3-4, the computational grid is shown in Figure 7.3-6, and the predicted elements are shown in Table 7.3-5. The wind (u: east-west direction, v: north-south direction) of the sea-level physical quantity for one year from January 2015 to December 2015 was used for creating the wind condition map.

Table 7.3-4 Overview of GSM data

Data name	Global area
	00, 06, 12, 18UTC (Four times a day)
Prediction time	84-hour report 00, 06, 12, 18UTC)
	At intervals of 6 hours
	96- and 264-hour report (12UTC)
	At intervals of 12 hours
Data format	International synoptic code FM92 GRIB binary lattice point data weather report format (Version 2) * Abbreviated as GRIB2
Area	Parallel of latitude and longitude
Calculation lattice	Ground level to 100h Pa: 0.5 deg. × 0.5 deg. (about 60 km lattice) (Number of lattices: 720 × 361) 70 to 10h Pa: 1.0 deg. × 1.0 deg. (Number of lattices: 360 ×181)

Source: Website of The Meteorological Agency

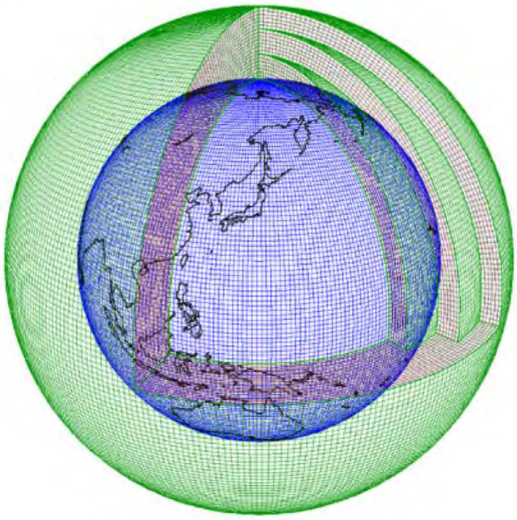


Figure 7.3-6 Computational grid of global model

Source: Website of The Meteorological Agency

Table 7.3-5 Predicted elements

Sea-level physical quantity (global)

Item	Sea-level reduced atmospheric pressure (hPs)	Ground atmospheric pressure (hPs)	Wind (m/s)	Temperature (°C)	Relative humidity (%)	Hourly precipitation (mm)	Cloud volume *
Ground height of 10m	○	○	②	○	○	○	④

Atmospheric pressure surface physical quantity (global)

Item / Atmospheric pressure surface	Altitude (m)	Temperature (m/s)	Wind (°C)	Upwelling flow (m/s)	Relative humidity (%)
1000	○	②	○	○	○
925	○	②	○	○	○
850	○	②	○	○	○
700	○	②	○	○	○
600	○	②	○	○	○
500	○	②	○	○	○
400	○	②	○	○	○
300	○	②	○	○	○
250	○	②	○	○	
200	○	②	○	○	
150	○	②	○	○	
100	○	②	○	○	
70	○	②	○	○	
50	○	②	○	○	
30	○	②	○	○	
20	○	②	○	○	
10	○	②	○	○	

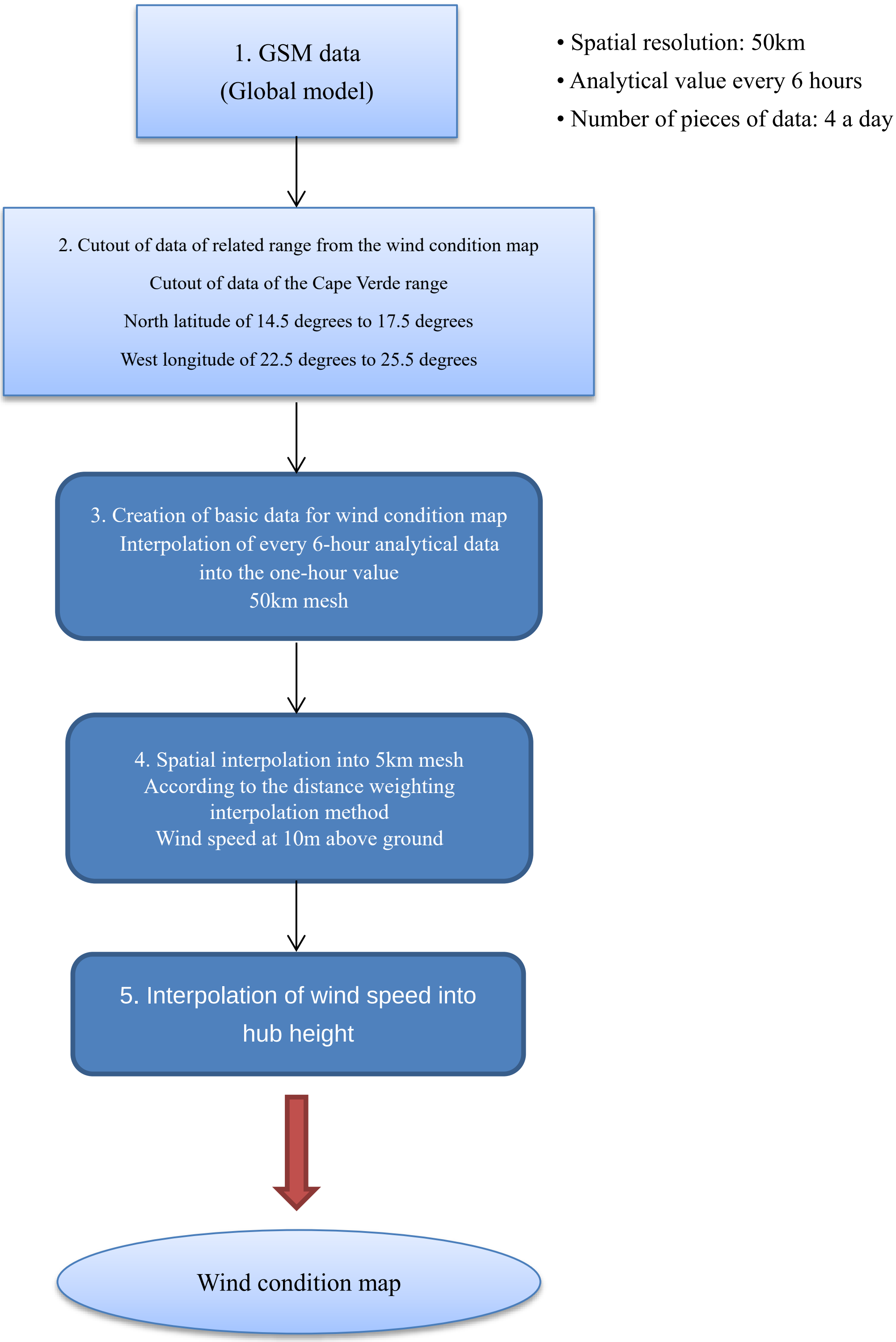
② indicates the data for two factors (two factors of east-west direction and north-south direction in the case of wind).
④ indicates the data for four factors (four factors of overall cloud volume, high-level cloud, intermediate-level cloud and lo -level cloud in the case of cloud volume).

* The cloud volume indicates the percentage of the portion covered with cloud relative to the entire sky. It is represented by the integral numbers from 0 to 10.
(Source: A guide to Meteorology published from the Meteorological Agency in September, 1998)

Source: Website of The Meteorological Agency

(2) Creation of the wind condition map

Figure 7.3-7 shows the flow of creation of the wind condition map.



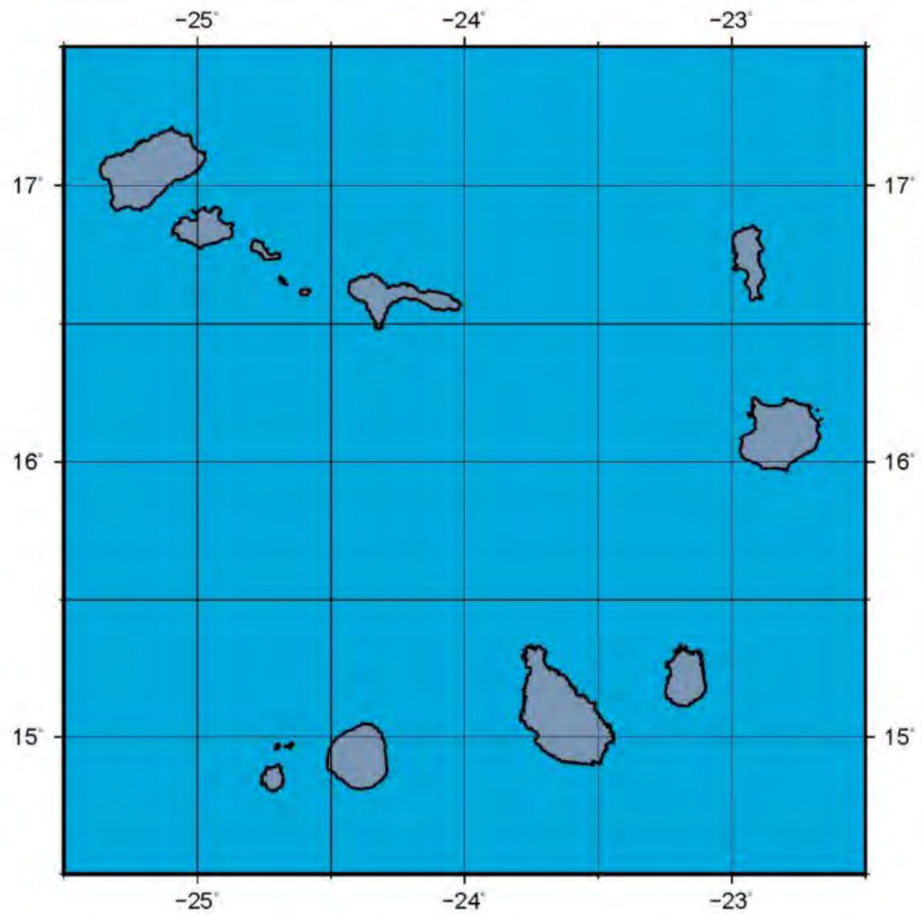
Source: JICA Study Team

Figure 7.3-7 Flow of creation of the wind condition map

(3) Cutout of data of a related range from the wind condition map

Data of the range that covers Cabo Verde was cut out from the global prediction data. The range that covers Cabo Verde consists of the north latitude of 14.5 degrees to 17.5 degrees and the west longitude of 22.5 degrees to 25.5 degrees.

Figure 7.3-8 shows the range of the wind condition map.



Source: JICA Study Team

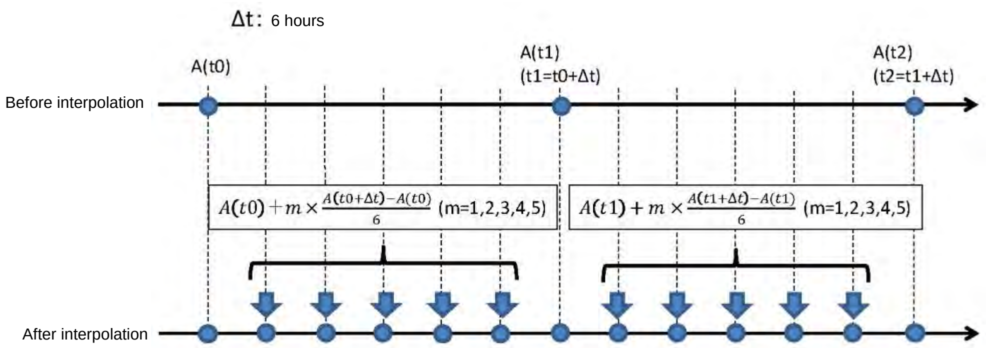
Figure 7.3-8 Range of the wind condition map

(4) Creation of basic data for the wind condition map

As for the GSM data, spatial resolution is 50 km, and the number of pieces of data is obtained four times a day (every six hours). The data was linearly interpolated as shown below by use of the analytical value (east-west components and north-south components of wind speed) of each time (every six hours).

Figure 7.3-9 shows the image of temporal interpolation of the analytical value.

• Temporal interpolation of the analytical value



Source: JICA Study Team

Figure 7.3-9 Image of temporal interpolation of the analytical value

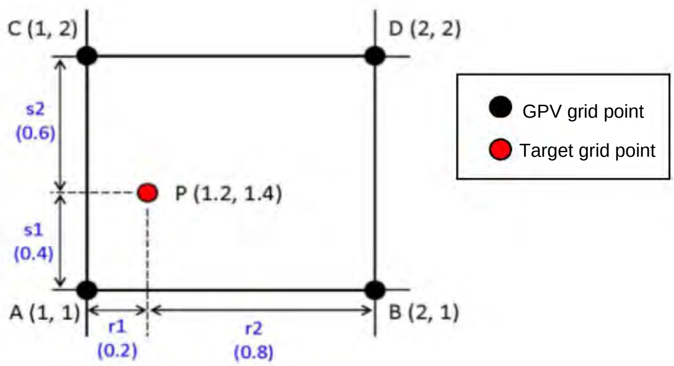
(5) Spatial interpolation into values in the 5km mesh

The 5km mesh data is created based on the wind condition data with spatial resolution of 50km by use of the distance weighting interpolation method.

The 5km mesh distance weighting interpolation method is as shown in Figure 7.3-10.

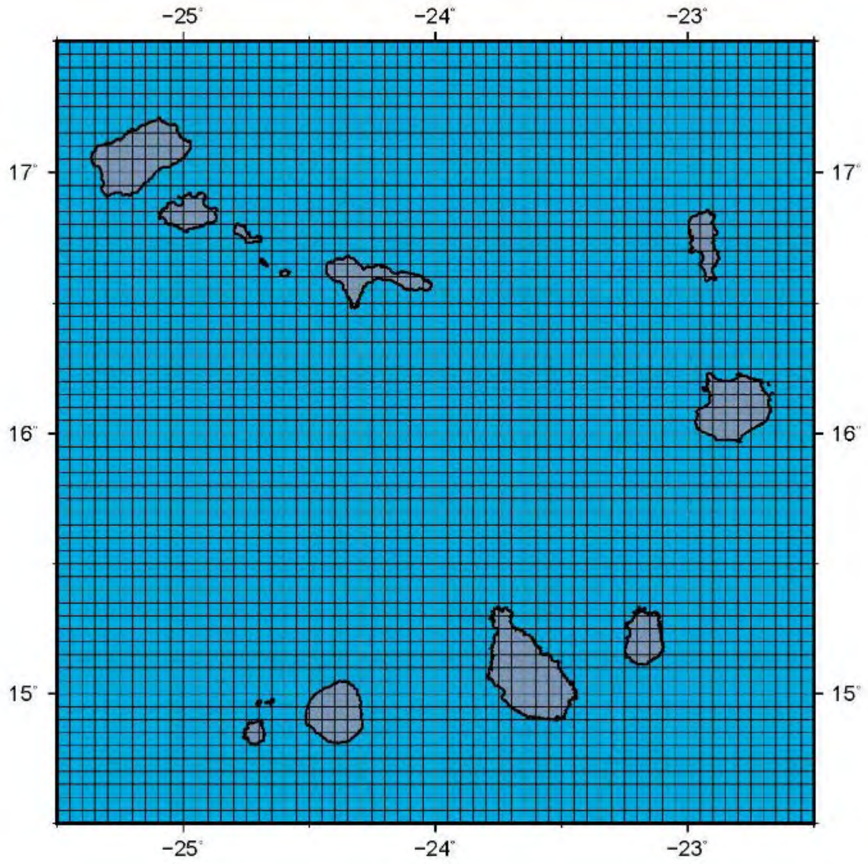
Weight determining of distance with respect to four peripheral meshes

$$
\begin{aligned}
P = &(1-r1)\times(1-s1)\times A \\
&+(1-r2)\times(1-s1)\times B \\
&+(1-r1)\times(1-s2)\times C \\
&+(1-r2)\times(1-s2)\times D
\end{aligned}
$$



Source: JICA Study Team

Figure 7.3-10 Distance weighting interpolation method



Source: JICA Study Team

Figure 7.3-11 5 km mesh for wind conditions

(6) Interpolation of wind speed into hub height

Compensation coefficient M was set at each observation point so that the value obtained by multiplying the average annual wind speed value, calculated by the 5km mesh spatial interpolation, by the compensation coefficient M will match the average annual wind speed value at the hub height (ground height of 55 meters) of each observation point in Mindelo, Sal, and Praia. Compensation coefficient M was spatially interpolated and set at each grid point. The interpolation method is as shown below.

1) Interpolation of wind speed

Interpolation of wind speed into the hub height (ground height of 55 meters) was performed according to the following formula:

Wind speed at the hub height = wind speed (ground height 10m; 5km mesh)×M

$$\text{Wind speed } (m/s) = \sqrt{u^2 \times v^2}$$

2) Method of setting compensation coefficient M

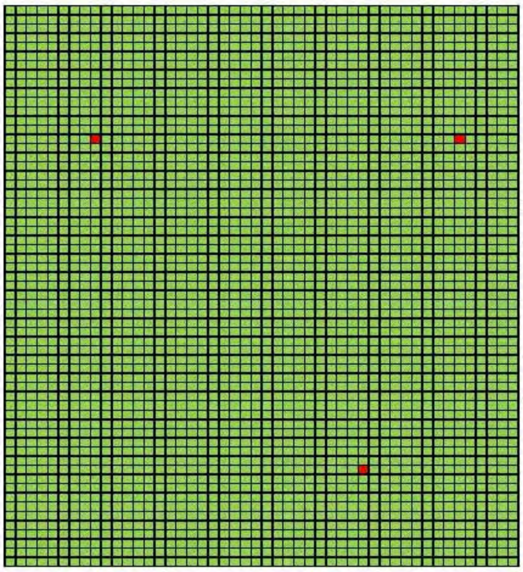
Compensation coefficient M was set according to the following steps:

(STEP 1) M is calculated by use of the value of the windmill (ground height of 55 meters) at each of three observation points as shown in Figure 7.3-13.

$$\mathrm{M} = \frac{\text{Average annual measurement value of wind speed of a windmill}}{\text{Average annual analytical GFS value (a value at the closest grid point after 5km interpolation)}}$$

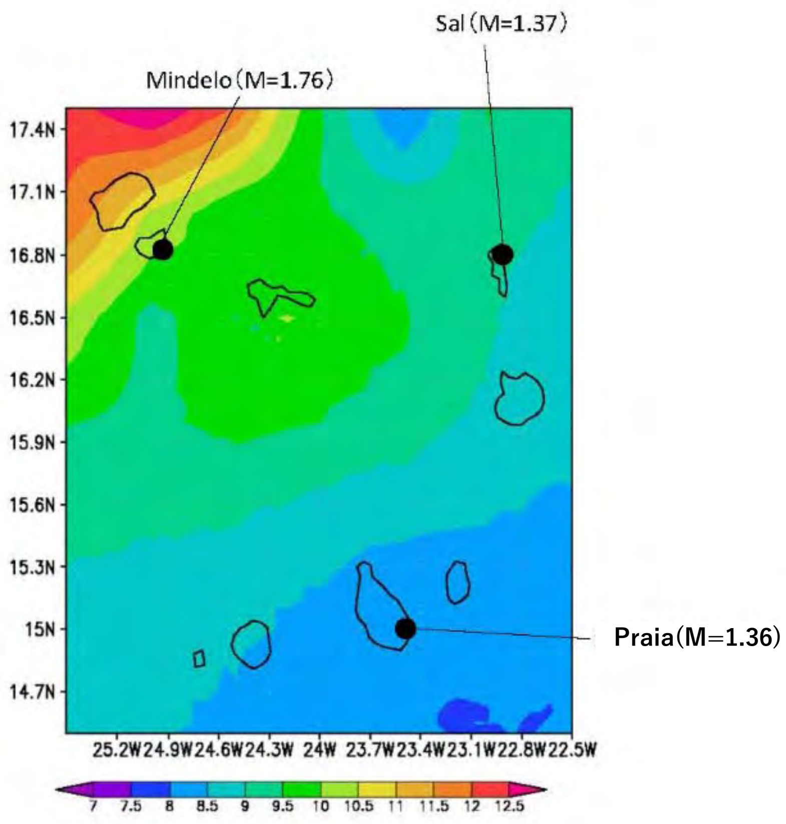
→ In the 5km mesh, the obtained value is applied to the grid point closest to each of the three observation points (red spots in Figure 7.3-12).

(STEP 2) M that has been obtained at three actual measuring points is applied to the closest grid points (red spots in Figure 7.3-1), and M at the three grid points is interpolated, thereby obtaining M at the grid points in the 5km mesh (green area in Figure 7.3-12).



Source: JICA Study Team

Figure 7.3-12 Image of grid points (red) closest to three actual measuring points in the 5km mesh and grid points (green) calculated by interpolation



Source: JICA Study Team

Figure 7.3-13 2015 average annual wind velocity (m/s) at the ground height of 55m calculated by use of M

7.3.4 Condition of Wind Direction

As one-year wind direction data in 2015 was not provided by Cabeolica, evaluation of the long-term fluctuation situation of the wind direction was not possible.
Therefore, we evaluated the characteristics of the wind direction in Cabo Verde based on the wind direction data provided by INMG. We used the statistical data observed at the Rabil airport and the ten-minute value for the past three years (from January 2013 to December 2015) measured in Mindelo and Sal for the wind direction data.

(1) Statistical result observed at the Rabil airport

INMG provided statistical data of the monthly wind direction for the past six years observed at the Rabil airport in Boa Vista.
According to the statistical data, the main wind direction was northeast (NE) throughout the year.
Table 7.3-6 shows the statistical data of the main wind direction observed at the Rabil airport (Boa Vista).

Table 7.3-6 Statistical data of the main wind direction observed at the Rabil airport (Boa Vista)

Month/Year	January	February	March	April	May	June	July	August	September	October	November	December
2010	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
2011	NE	NE	NE	NE	NE	NE	NE	N	NE	NE	NE	NE
2012	NE	NE	NE	NE	NE	NE	NE	N	NE	NE	NE	NE
2013	NE	NE	NE	NE	NE	NE	NE	N	NE	NE	NE	NE
2014	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
2015	NE	NE	NE	NE	***	***	***	***	***	***	***	***

Source: JICA Study Team based on the data provided by the National Institute of Meteorology and Geophisics (Note) *** indicates a missing value.

(2) Analysis result of the annual wind direction incidence

The annual wind direction incidence was analyzed based on the value (degrees) of the ten-minute average wind direction in Mindelo and Sal for the past three years (January 2013 to December 2015). The data was provided by INMG.

As a result, the main wind direction in Mindelo and Sal of Cabo Verde was northeast (NE) for the past three years (January 2013 to December 2015).

The incidence of the northeast (NE) wind in Mindelo for the past three years (from 2013 to 2015) was significant; between 51.7% and 54.3%.

Also, the incidence of the northeast (NE) wind in Sal for the past three years (from 2013 to 2015) was between 37.3% and 40.1%, which is as significant as in Mindelo.

Table 7.3-7 shows the annual wind direction incidence at each observation point.

Figure 7.3-14 shows the annual wind rose.

Table 7.3-8 shows the wind direction data pick-up rate at each observation point used for the wind direction analysis.

Table 7.3-7 Annual wind direction incidence at each observation point

Wind direction	Mindelo(wind direction incidence) Unit: %		
	2013	2014	2015
N	0.4	0.2	0.3
NNE	2.5	2.1	2.5
NE	51.7	52.8	54.3
ENE	38.2	40.6	38.8
E	2.3	1.9	1.9
ESE	0.6	0.4	0.3
SE	0.6	0.3	0.2
SSE	0.6	0.4	0.2
S	0.5	0.2	0.2
SSW	0.4	0.1	0.2
SW	0.3	0.1	0.2
WSW	0.2	0.1	0.1
W	0.2	0.1	0.1
WNW	0.3	0.2	0.2
NW	0.7	0.4	0.3
NNW	0.4	0.2	0.2
Total	100.0	100.0	100.0

(Note) : Main wind direction

Source: JICA Study Team based on the data provided by the National Institute of Meteorology and Geophisics

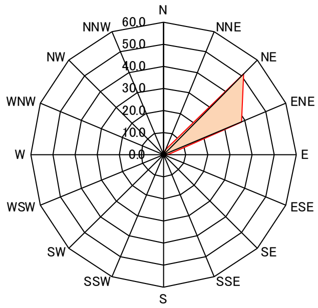
Wind direction	Sal(wind direction incidence) Unit: %		
	2013	2014	2015
N	10.1	12.0	10.7
NNE	32.2	34.9	34.2
NE	37.3	40.1	39.6
ENE	9.2	7.2	8.6
E	2.6	1.7	1.6
ESE	1.2	0.3	0.4
SE	0.8	0.3	0.3
SSE	0.3	0.1	0.1
S	0.1	0.0	0.0
SSW	0.1	0.0	0.0
SW	0.1	0.0	0.0
WSW	0.1	0.0	0.0
W	0.2	0.0	0.0
WNW	0.3	0.1	0.1
NW	0.8	0.4	0.5
NNW	4.6	2.8	3.5
Total	100.0	100.0	100.0

(Note) : Main wind direction

Source: JICA Study Team based on the data provided by the National Institute of Meteorology and Geophisics

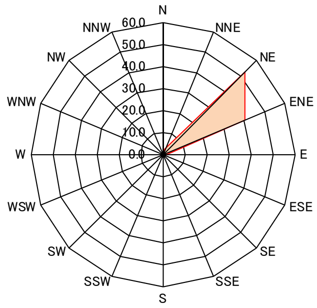
Mindelo Unit: %

2013



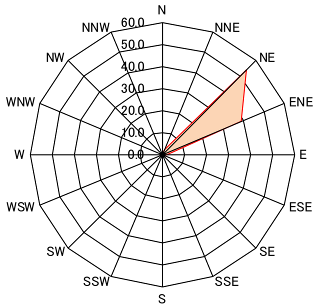
Main wind direction:Northeast (NE) Incidence:51.7%

2014



Main wind direction:Northeast (NE) Incidence:52.8%

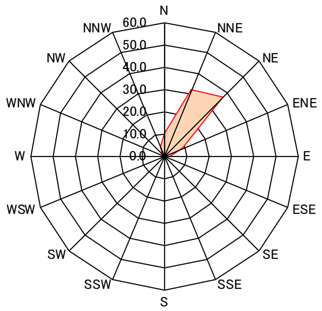
2015



Main wind direction:Northeast (NE) Incidence:54.3%

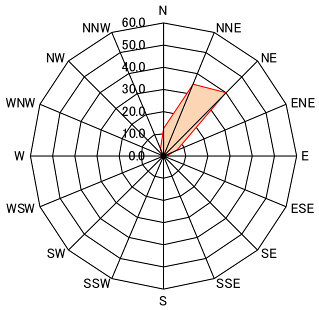
Sal Unit: %

2013



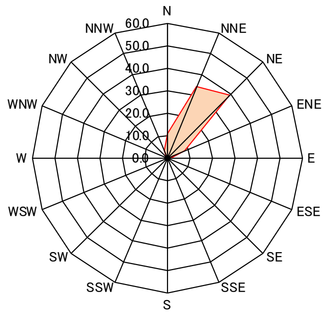
Main wind direction:Northeast (NE) Incidence:37.3%

2014



Main wind direction:Northeast (NE) Incidence:40.1%

2015



Main wind direction:Northeast (NE) Incidence:39.6%

Source: JICA Study Team based on the data provided by the National Institute of Meteorology and Geophysics

Figure 7.3-14 Annual wind rose

Table 7.3-8 Wind direction data pick-up rate at each observation point

	Mindelo (Wind direction : data pick-up rate) Unit: %		
	2013	2014	2015
Annual	100.0	100.0	100.0

	Sal (Wind direction : data pick-up rate) Unit: %		
	2013	2014	2015
Annual	99.8	99.9	99.3

Source: JICA Study Team based on the data provided by the National Institute of Meteorology and Geophysics

7.3.5 Evaluation of Wind Conditions

Table 7.3-9 shows the criteria for the evaluation of feasibility of introducing wind-power generation facilities in Japan.

Table 7.3-9 Criteria for the evaluation of wind conditions

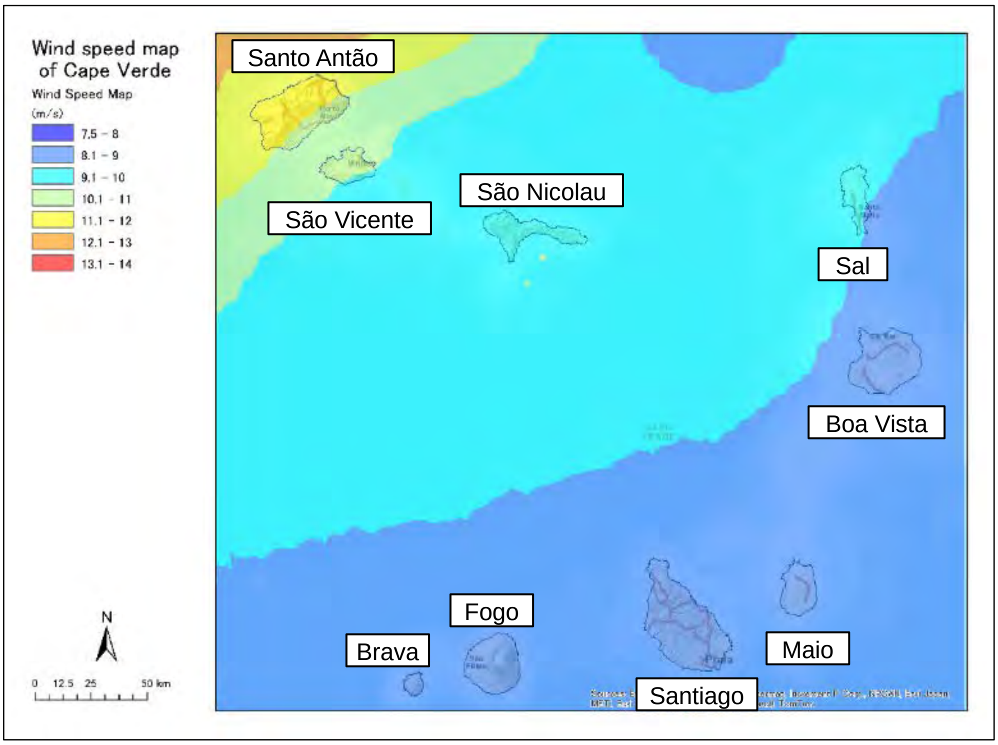
Item	Evaluation criteria
Average wind velocity	As a criterion for the feasibility of business, it is desirable that the average annual wind velocity at a ground height of 30 meters be 6 m/s or more.
Wind direction incidence	When the annual wind direction incidence along the wind axis is 60% or more, the wind direction can be considered stable. Herein, among sixteen target wind directions, altogether six wind directions, which are the main wind direction and adjacent two wind directions and the wind directions symmetrical to those wind directions, are each referred to as a wind axis.

Source: "Guidebook for introducing wind-power generation" by the New Energy and Industrial Technology Development Organization (9th edition revised in February 2008)

(1) Average wind velocity

The average wind velocity in Mindelo, Sal, and Praia of Cabo Verde for the past five years (from 2011 to 2015) exceeds 6m/s. Also, result of creation of the 2015 wind condition map of Cabo Verde indicates that the average annual wind velocity at the windmill hub height (ground height of 55 meters) exceeds 8m/s in the entire area of Cabo Verde; the area's wind conditions are favorable.

Figure 7.3-15 shows the average annual wind velocity (2015) calculated according to numerical prediction data [ground height of 55 meters].



Source: JICA Study Team

Figure 7.3-15 Average annual wind velocity (2015) calculated according to numerical prediction data [ground height of 55 meters]

(2) Wind direction incidence

The wind direction incidence in Mindelo and Sal from 2013 to 2015 based on the Japanese evaluation method is 60% or more; the wind direction is stable.
Table 7.3-10 shows the wind direction incidence based on the Japanese evaluation method.

Table 7.3-10 Wind direction incidence based on the Japanese evaluation method

(Unit: %)

Wind direction	Mindelo			Sal		
	2013	2014	2015	2013	2014	2015
NNE	2.5	2.1	2.5	32.2	34.9	34.2
NE	51.7	52.8	54.3	37.3	40.1	39.6
ENE	38.2	40.6	38.8	9.2	7.2	8.6
SSW	0.4	0.1	0.2	0.1	0.0	0.0
SW	0.3	0.1	0.2	0.1	0.0	0.0
WSW	0.2	0.1	0.1	0.2	0.0	0.0
Total	93.3	95.8	96.1	79.1	82.2	82.4

(Note): [shaded] Main wind direction

Source: JICA Study Team based on the data provided by the National Institute of Meteorology and Geophisics

(3) Result of the evaluation of wind conditions

The average wind speed and the wind direction incidence were evaluated based on the analysis result of the data provided by INMG and the average annual wind speed (2015) [ground height of 55 meters] calculated according to numerical prediction data. The result indicates that the average annual wind speed exceeds 8 m/s [ground height of 55 meters], and the wind direction is stable and the main wind direction is mostly northeast (NE). Therefore, Cabo Verde has favorable wind conditions and it is feasible to introduce wind-power generation facilities in the area.

7.3.6 Evaluation of Potential of the Wind-power Generation Development Zone

(1) Wind-power generation development zone

In Cabo Verde, the renewable energy sector strategic plan that specifies the renewable energy development zone (ZDER) has been approved in accordance with Law No1, which came into force in January 3, 2011, and the second paragraph of Article 265 of the Constitution.
To evaluate the potential, it was necessary to accurately understand the range of the wind-power generation development zone. So, we requested DGE to provide GIS data, but the data was not provided.
Therefore, we converted the area map (image) of the wind-power generation development zone obtained from DGE into GIS data and used the data for the potential evaluation in this investigation.
However, it should be noted that the number of development zones shown in the area map of each island, obtained from DGE, is different from the number of development zones shown in the official gazette in respect to four islands: Santo Antão, São Vicente, Boa Vista, and

Santiago.

Table 7.3-11 shows the list of wind-power generation development zones and the potential based on the area map obtained from DGE.

Table 7.3-12 shows the comparison of the number of development zones between the data provided by DGE and the data shown in the official gazette.

Figure 7.3-16 to Figure 7.3-24 show the area map of the wind-power generation development zone in nine islands, obtained from DGE.

Table 7.3-11 List of wind-power generation development zones and potential

Name of island		Zone ID	Area of zone (km^2)	Potential quantity (MW)
1	Santo Antão	ZDER_SA.1	1.04	11.1
2		ZDER_SA.2	0.64	11.1
3		ZDER_SA.3	1.91	12.8
4	São Vicente	ZDER_SV.1	0.64	10.2
5		ZDER_SV.2	0.53	7.7
6		ZDER_SV.3	0.12	2.6
7	São Nicolau	ZDER_SN.1	3.15	14.5
8		ZDER_SN.2	2.18	1.32
9	Sal	ZDER_SL.1	22.10	38.4
10	Boa Vista	ZDER_BV.1	1.36	20.4
11	Maio	ZDER_MA.1	1.71	14.5
12	Santiago	ZDER_ST.1	36.00	96.9
13		ZDER_ST.2	0.52	6.8
14		ZDER_ST.3	0.43	6.0
15	Fogo	ZDER_FG.1	2.90	17.9
16		ZDER_FG.2	0.04	1.7
17	Brava	ZDER_BR.1	0.37	6.0
Total		-	75.64	279.92

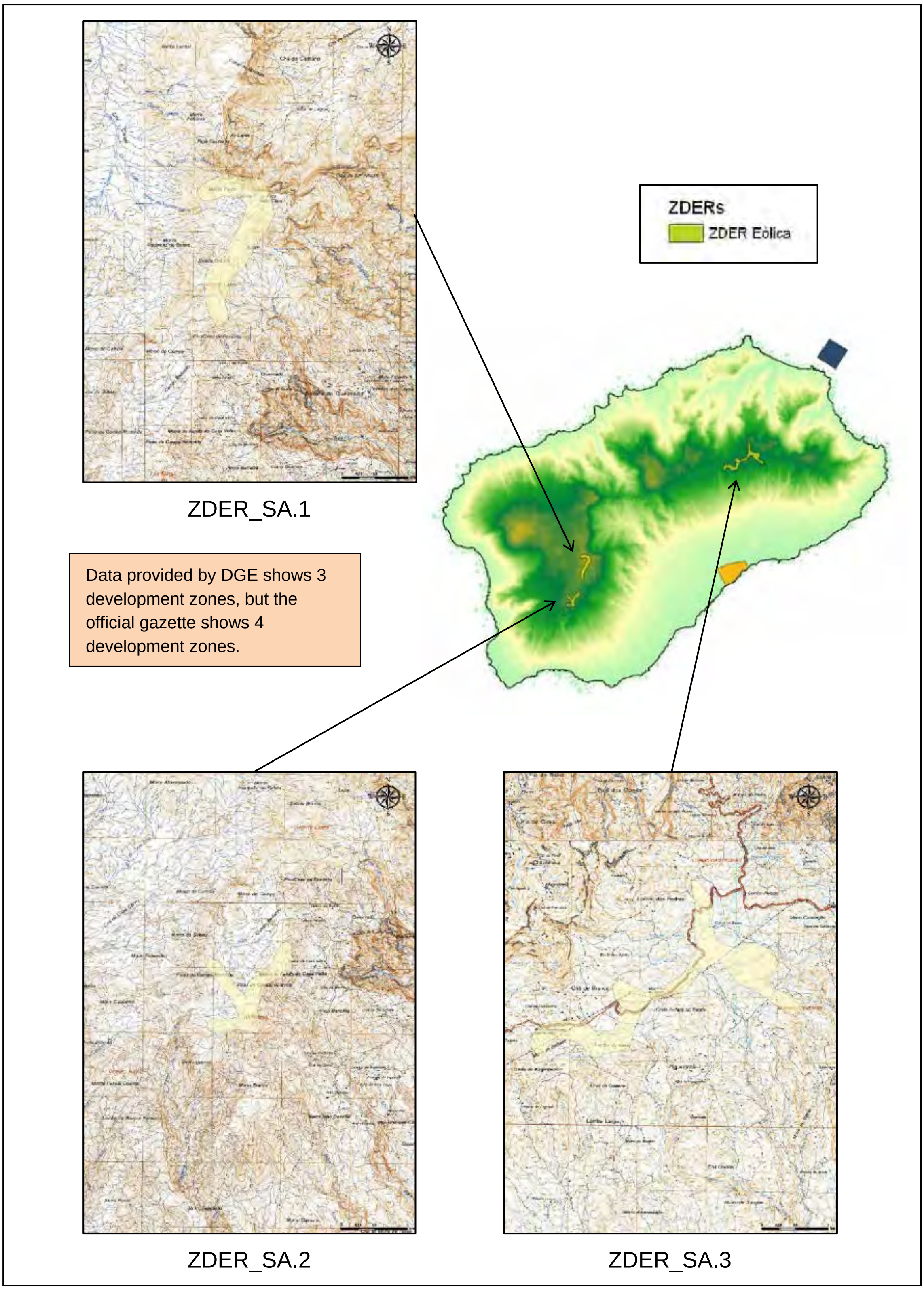
Source: JICA Study Team

Table 7.3-12 Comparison of the number of development zones between data provided by DGE and the data in the official gazette

Name of island	DATA PROVIDED BY DGE	Official gazette (February 2012)
Santo Antão	3	4
São Vicente	3	4
São Nicolau	2	2
Sal	1	1
Boa Vista	1	2
Maio	1	1
Santiago	3	4
Fogo	2	2
Brava	1	1
Total	17	21

Note): [green box] : Island where the number of development zones is different

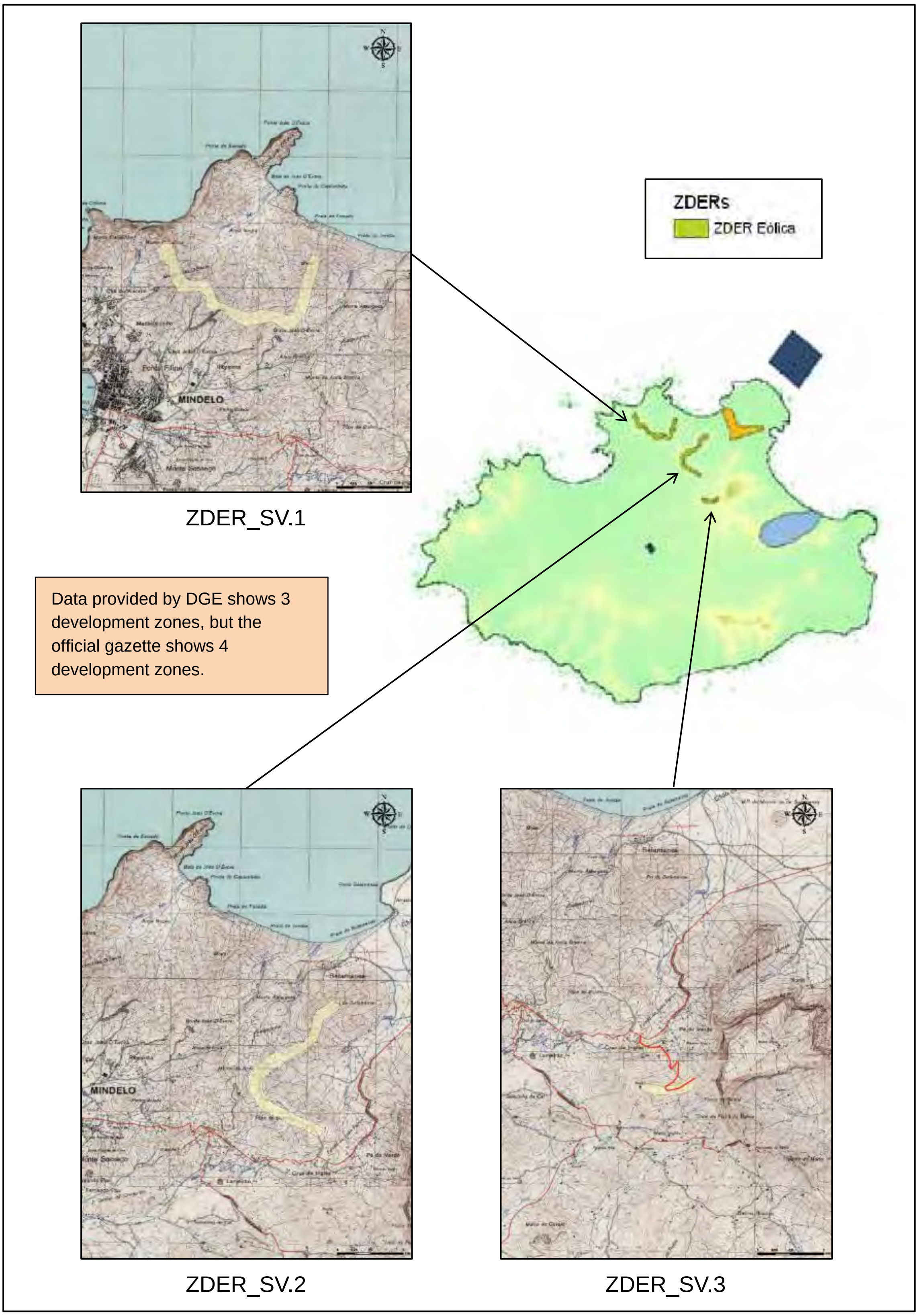
Source: JICA Study Team



Map of the entire island : Cabo Verde 100% Renewable Energy Plan for 2020 (October 2013) •Enlarged view of the wind-power generation development zones

Source: JICA Study Team based on the data provided by DGE

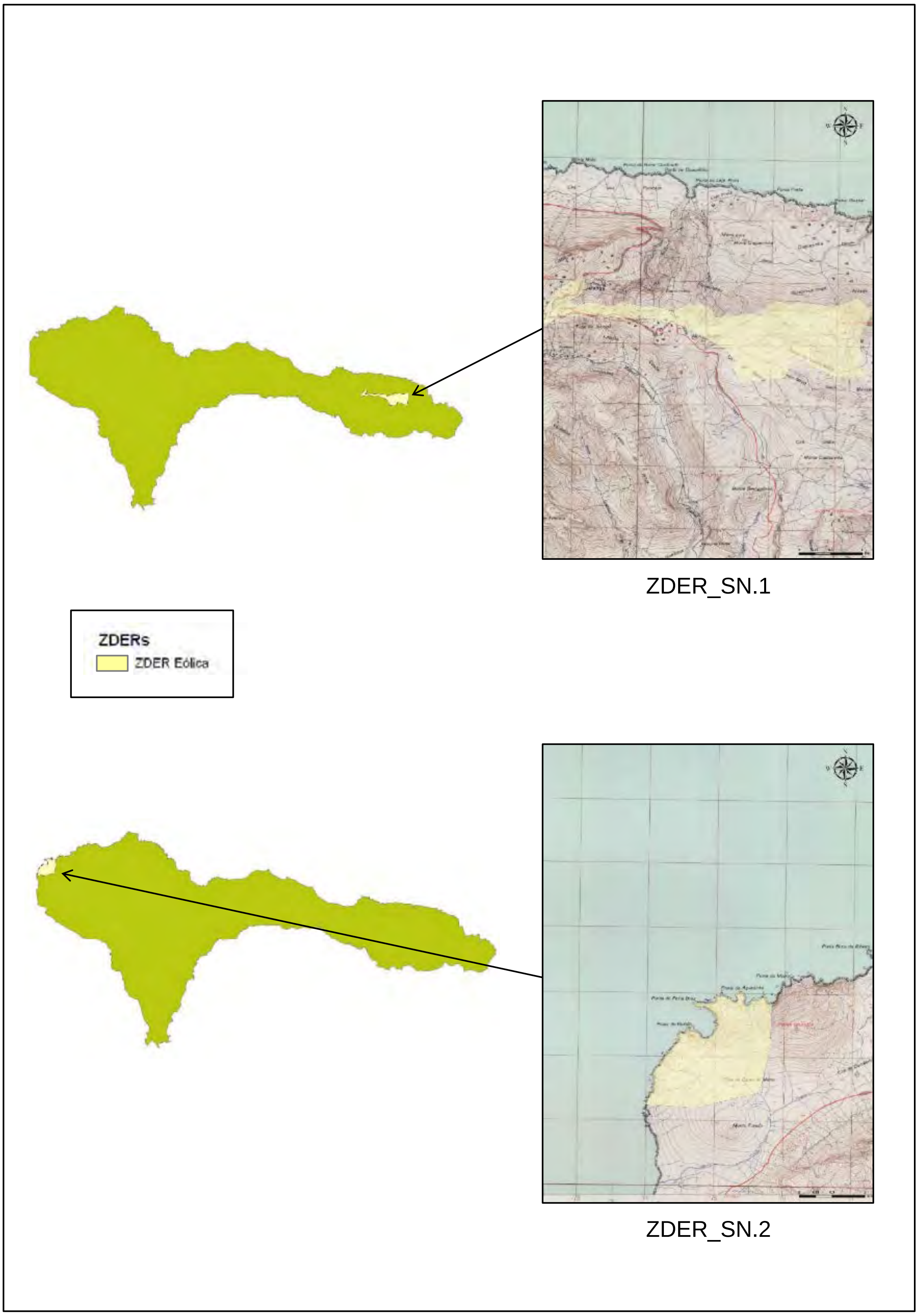
Figure 7.3-16 Wind-power generation development zones in Santo Antão



Map of the entire island: Cabo Verde 100% Renewable Energy Plan for 2020 (October 2013) •Enlarged view of the wind-power generation development zones

Source: JICA Study Team based on the data provided by DGE

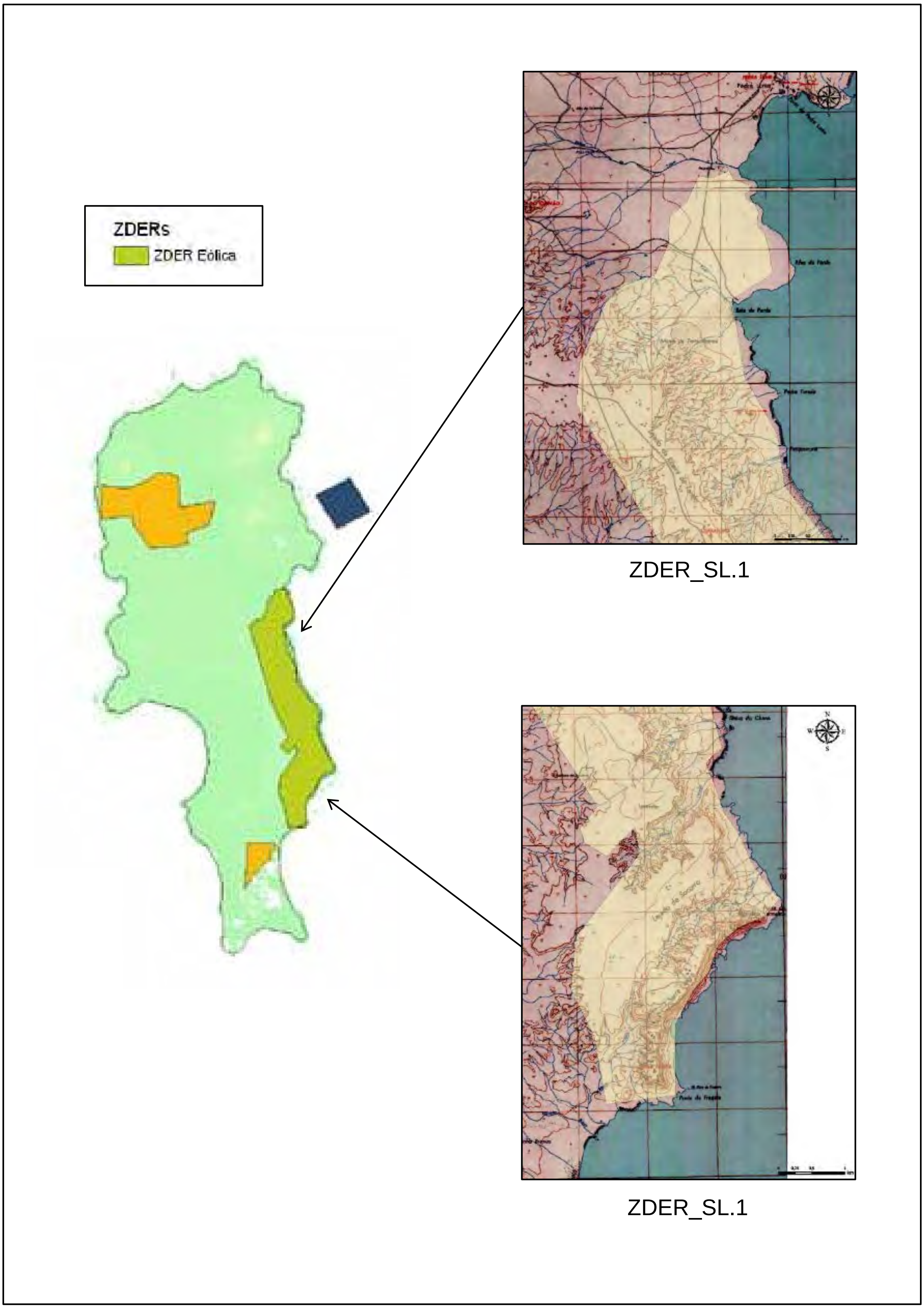
Figure 7.3-17 Wind-power generation development zones in São Vicente



Map of the entire island and the enlarged view of the wind-power generation development zones

Source: JICA Study Team based on the data provided by DGE

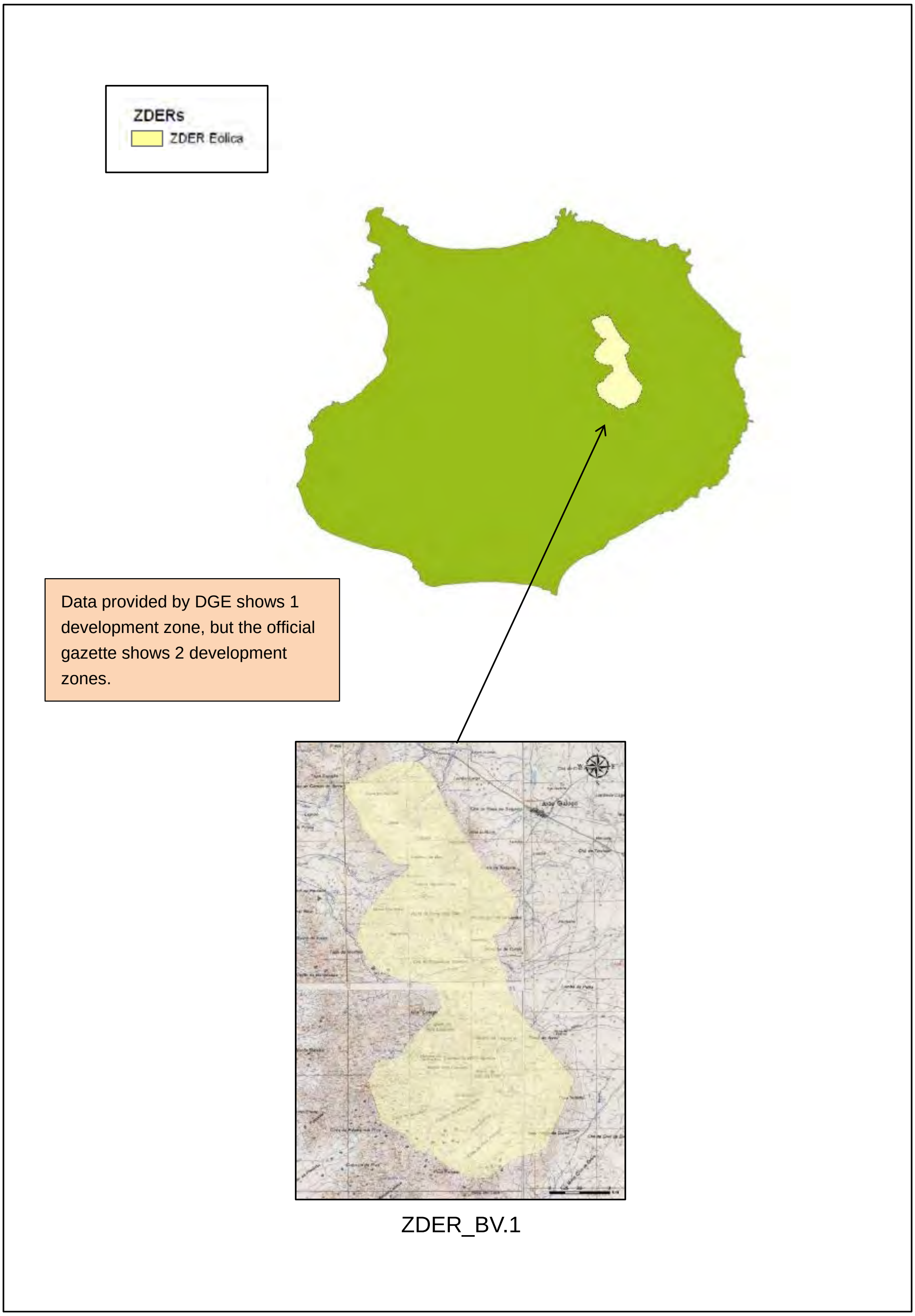
Figure 7.3-18 Wind-power generation development zones in São Nicolau



Map of the entire island: Cabo Verde 100% Renewable Energy Plan for 2020 (October 2013) •Enlarged view of the wind-power generation development zone

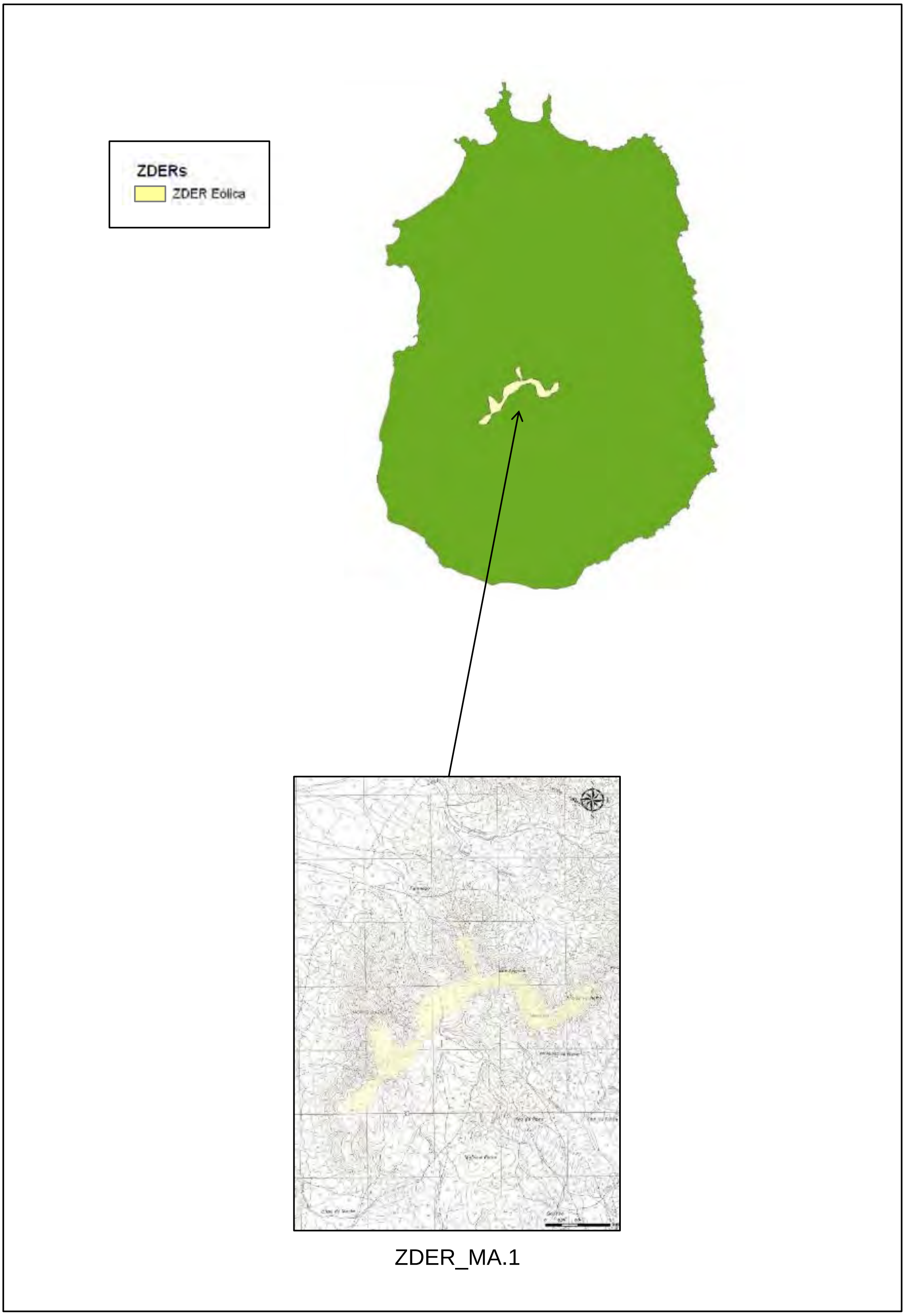
Source: JICA Study Team based on the data provided by DGE

Figure 7.3-19 Wind-power generation development zone in Sal



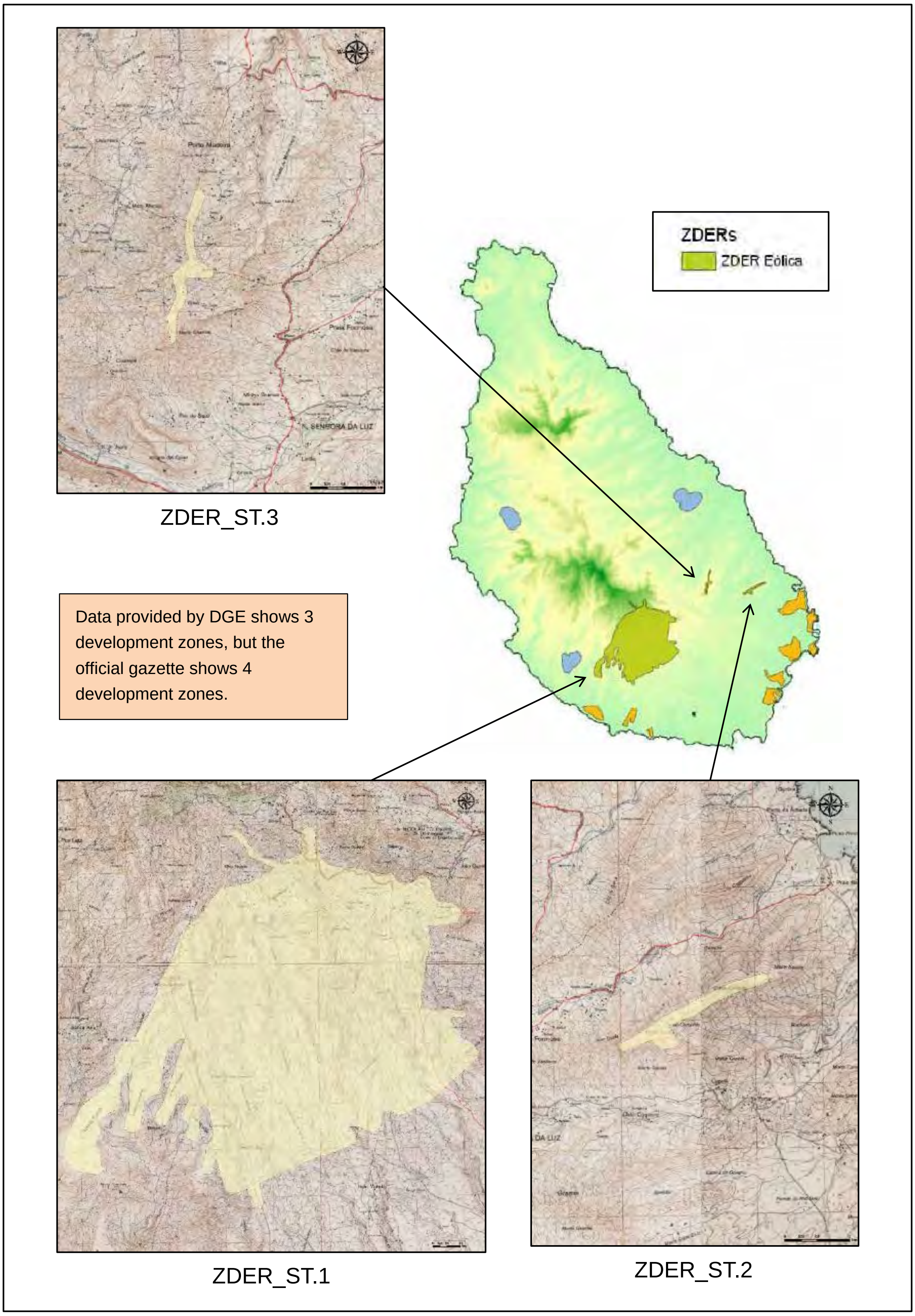
Map of the entire island and the enlarged view of the wind-power generation development zone
Source: JICA Study Team based on the data by DGE

Figure 7.3-20 Wind-power generation development zone in Boa Vista



Map of the entire island and the enlarged view of the wind-power generation development zone
Source: JICA Study Team based on the data provided by DGE

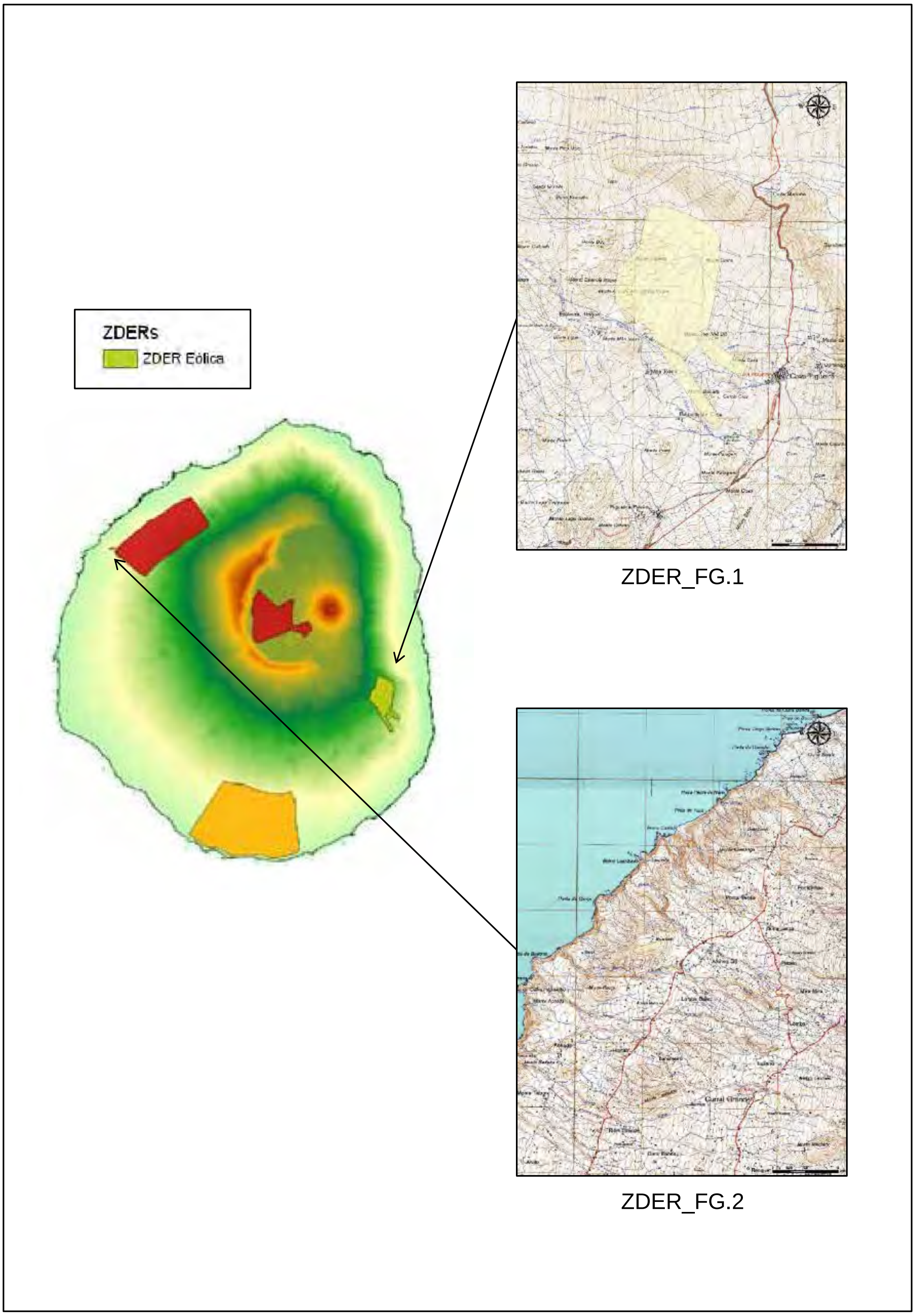
Figure 7.3-21 Wind-power generation development zone in Maio



Map of the entire island: Cabo Verde 100% Renewable Energy Plan for 2020 (October 2013) •Enlarged view of the wind-power generation development zones

Source: JICA Study Team based on the data provided by DGE

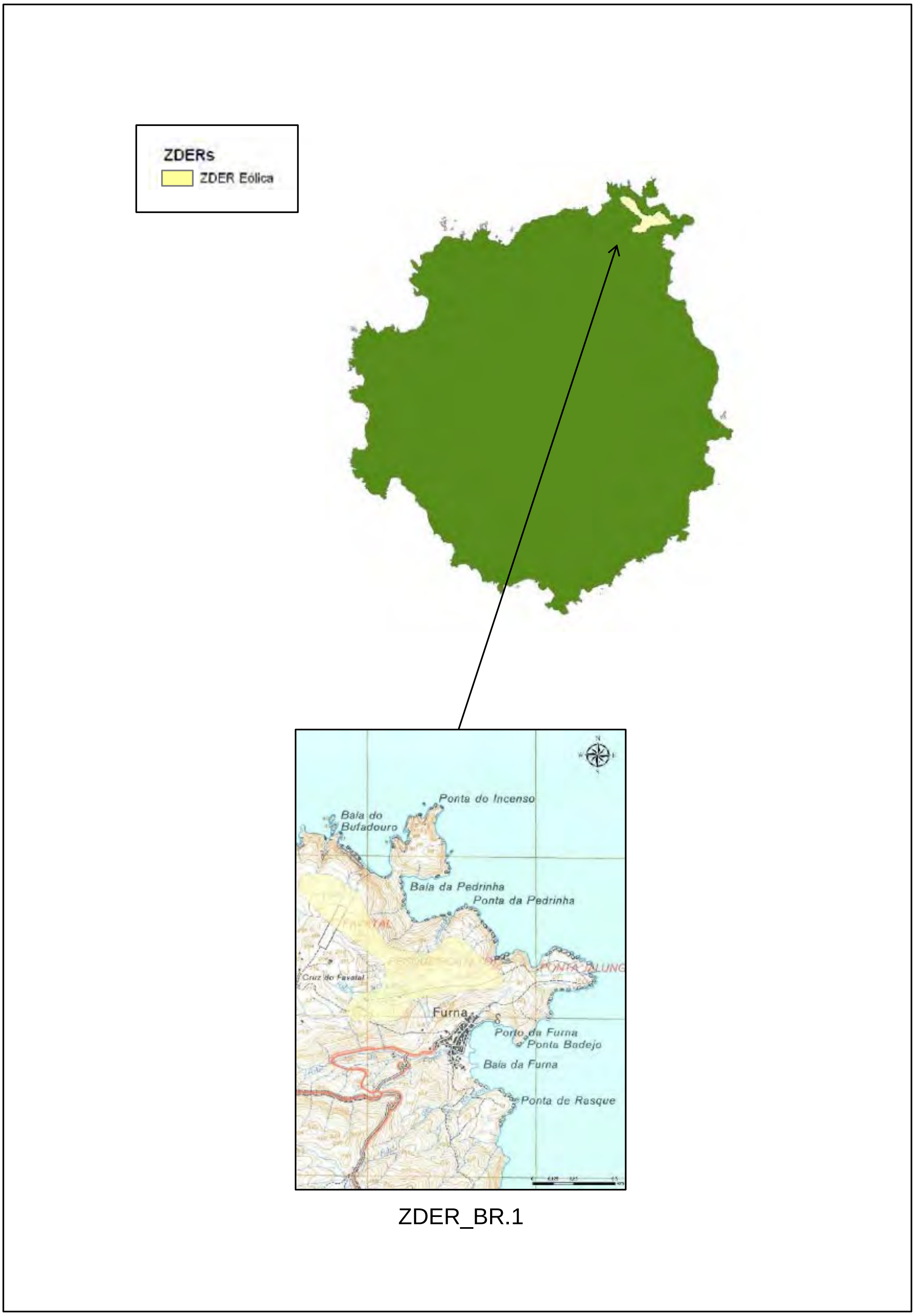
Figure 7.3-22 Wind-power generation development zones in Santiago



Map of the entire island: Cape Verde 100% Renewable Energy Plan for 2020 (October 2013) •Enlarged view of the wind-power generation development zones

Source: JICA Study Team based on the data provided by DGE

Figure 7.3-23 Wind-power generation development zones in Fogo



Map of the entire island and the enlarged view of the wind-power generation development zone

Source: JICA Study Team based on the data provided by DGE

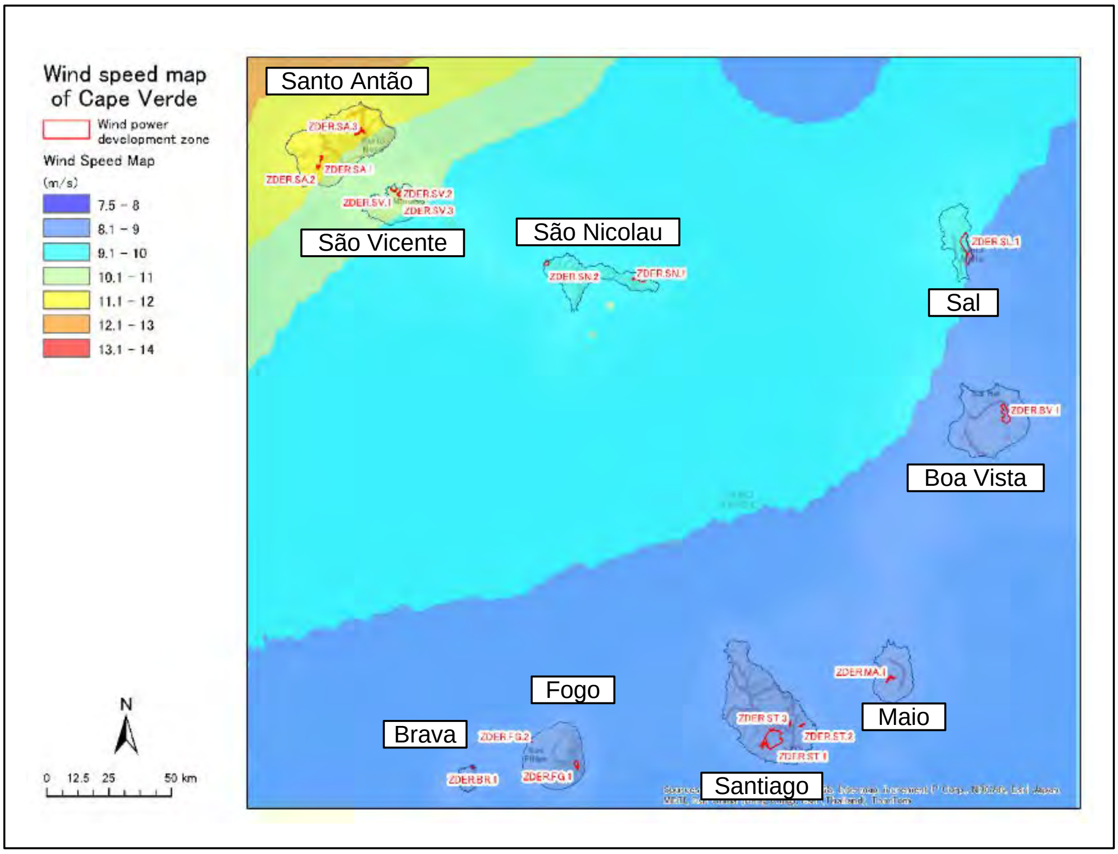
Figure 7.3-24 Wind-power generation development zone in Brava

(2) Evaluation of wind speed in the wind-power generation development zones

Cabo Verde has favorable wind conditions where average annual wind speed exceeds 8 m/s (ground height of 55 meters).

Figure 7.3-25 shows the map of average annual wind speed (2015) [ground height of 55 meters] based on the numerical prediction data.

Table 7.3-13 shows the list of wind-power generation development zones, provided by DGE, Which are shown in each island in Figure 7.3-25.



Source: JICA Study Team

Figure 7.3-25 Map of average annual wind speed (2015) [ground height of 55m] based on the numerical prediction data

Table 7.3-13 List of wind-power generation development zones provided by DGE

Name of island		Zone ID
1	Santo Antão	ZDER_SA.1
2		ZDER_SA.2
3		ZDER_SA.3
4	São Vicente	ZDER_SV.1
5		ZDER_SV.2
6		ZDER_SV.3
7	São Nicolau	ZDER_SN.1
8		ZDER_SN.2
9	Sal	ZDER_SL.1
10	Boa Vista	ZDER_BV.1
11	Maio	ZDER_MA.1
12	Santiago	ZDER_ST.1
13		ZDER_ST.2
14		ZDER_ST.3
15	Fogo	ZDER_FG.1
16		ZDER_FG.2
17	Brava	ZDER_BR.1

Source: JICA Study Team

7.3.7 Evaluation of Wind Power Potential in Each Island

As to the wind-power generation development zones indicated by DGE, we studied theoretical arrangement of windmills and calculated the number of windmills to be arranged as trial calculation of theoretical value. Next, as trial calculation of expected available quantity, we calculated the number of windmills that can be realistically arranged by taking into consideration the terrain slope angle and the offset distance from existing windmills.

Figure 7.3-26 shows the flow of evaluation of wind power potential in each island.

STEP 1

Trial calculation of theoretical value

- Theoretical arrangement in the development zone by ensuring the offset distance [10D (=520 m) × 3D (=156 m)] so as not to include a windmill in the wake area *1, by use of existing Cabeolica windmills (capacity per unit: 850 kW)
- Calculation of the number of units theoretically arranged

↓

STEP 2

Trial calculation of expected available quantity

- Evaluation of terrain slope angle of 10% or less *2 within the development zone (100 m mesh)
- Evaluation of offset distance of 520 m from the existing Cabeolica windmills (diameter of 52m × 10 times)
- As development zones in Santiago and Sal are wide, wind conditions are compared with those of the location of the existing Cabeolica windmills.
- Calculation of the number of units realistically

↓

Wind power potential

Note) *1:An area where an energy acquisition amount significantly decreases

*2:Rough standard of a large heavy machine's climbing ability

Source: JICA Study Team

Figure 7.3-26 Flow of evaluation of wind power potential in each island

(1) Trial calculation of theoretical value (STEP 1)

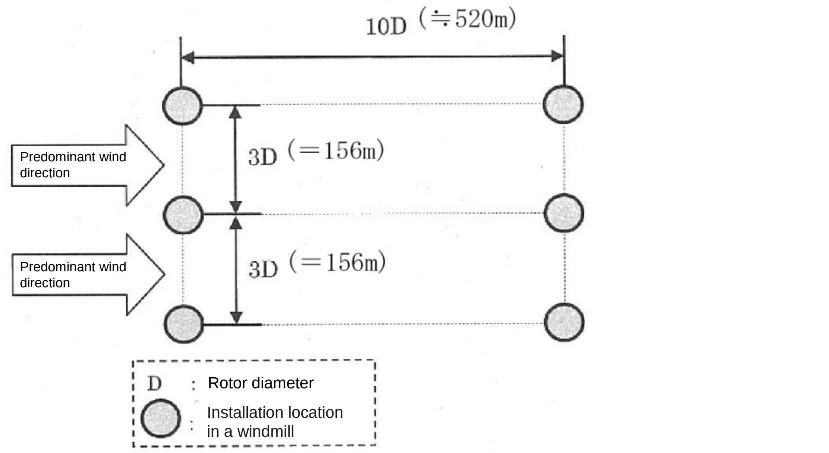
1) Requirements for studying theoretical arrangement

When installing two or more windmills, it is necessary to determine the arrangement of windmills by taking into consideration the prevailing wind direction in the area. An area located downwind from a windmill where wind conditions are disturbed is referred to as a wake area. If a windmill is installed in such an area, the energy acquisition amount significantly decreases. Experiments and actual measurements prove that the wake area ranges 3D (D: diameter of rotor) along the direction perpendicular to the wind direction and approximately 10D along the downwind direction.

Therefore, we studied temporary arrangement (theoretical arrangement) by taking into consideration the wake area in respect to the prevailing wind direction (northeast) in Cabo Verde.

By regarding the offset distance [520 meters (diameter of 52 meters × 10 times) × 156 meters (diameter of 52 meters × 3 times)] from the existing windmills (single-unit capacity of 850 kW) as a criterion, we studied theoretical arrangement of windmills in the wind-power generation development zone and calculated the number of units theoretically arranged. Table 7.3-14 shows the conditions for the study of theoretical arrangement of windmills.

Table 7.3-14 Conditions for the study of theoretical arrangement of windmills

	Conditions for study
Type of windmill	Maker: Vestas Model: V52-850 kW Rated output: 850 kW Diameter of rotor: 52 m Hub height: 55 m
Prevailing wind direction	Northeast
Offset distance from windmill	 When the prevailing wind direction is obvious

Source: "Guidebook for introducing wind-power generation" by the New Energy and Industrial Technology Development Organization, Japan (9th edition revised in February 2008)

2) Result of study of theoretical arrangement

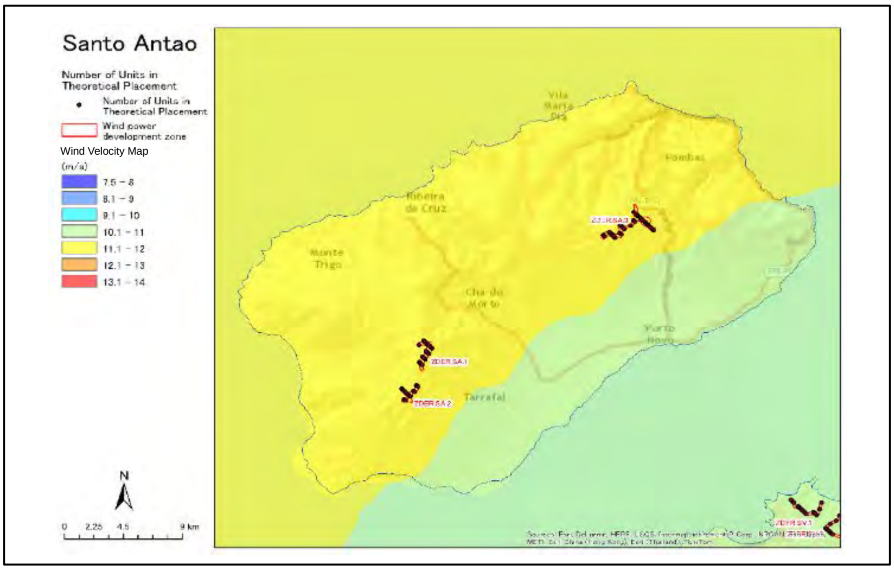
Table 7.3-15 shows the number of windmills theoretically arranged and the potential quantity.

Figure 7.3-27 to Figure 7.3-35 show the theoretical arrangement of windmills in the wind-power generation development zones in nine islands.

Table 7.3-15 Number of windmills theoretically arranged and the potential quantity

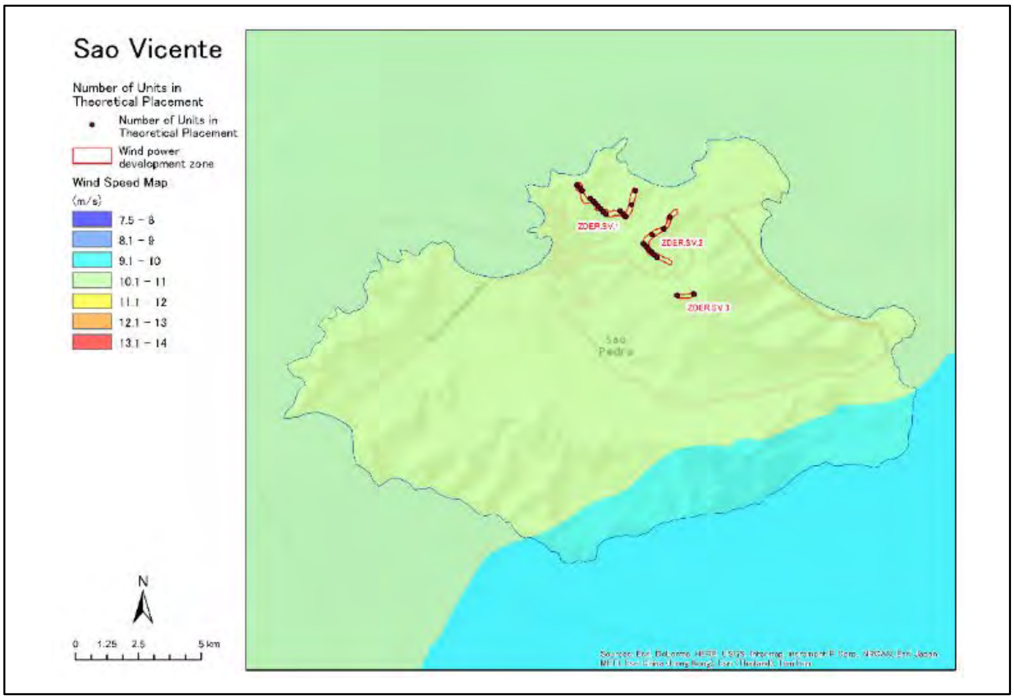
Island name	Zone ID	Zone area (km^2)	Theoretical number of windmills installed	Single unit capacity (kW)	Latent volume of reserves (MW)
Santo Antao	ZDER.SA.1	1.04	17	850	14.5
	ZDER.SA.2	0.64	13		11.1
	ZDER.SA.3	1.91	31		26.4
Sao Vicente	ZDER.SV.1	0.64	15		12.8
	ZDER.SV.2	0.53	9		7.7
	ZDER.SV.3	0.12	2		1.7
Sao Nicolau	ZDER.SN.1	3.15	48		40.8
	ZDER.SN.2	2.18	31		26.4
Sal	ZDER.SL.1	22.10	351		298.4
Boa Vista	ZDER.BV.1	1.36	202		171.7
Maio	ZDER.MA.1	1.71	23		19.6
Santiago	ZDER.ST.1	36.00	525		446.3
	ZDER.ST.2	0.52	9		7.7
	ZDER.ST.3	0.43	8		6.8
Fogo	ZDER.FG.1	2.90	45		38.3
	ZDER.FG.2	0.04	1		0.9
Brava	ZDER.BR.1	0.37	7		6.0
Total	—	75.64	1,337	—	1,136.5

Source: JICA Study Team



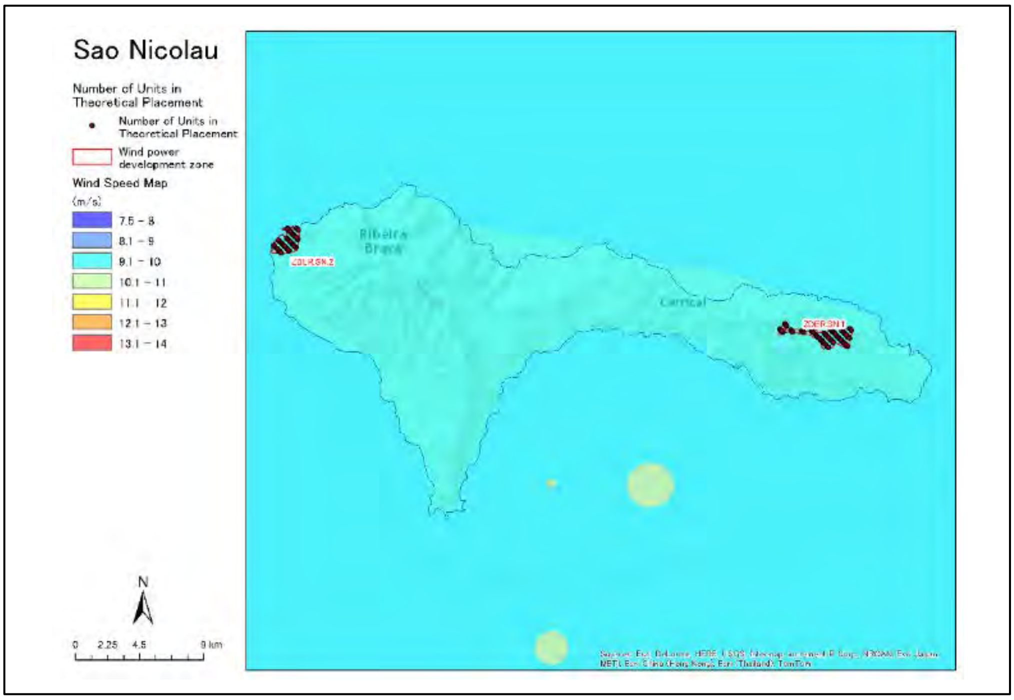
Source: JICA Study Team

Figure 7.3-27 Theoretical arrangement of windmills in the wind-power generation development zones in Santo Antão (development zone: 3 locations)



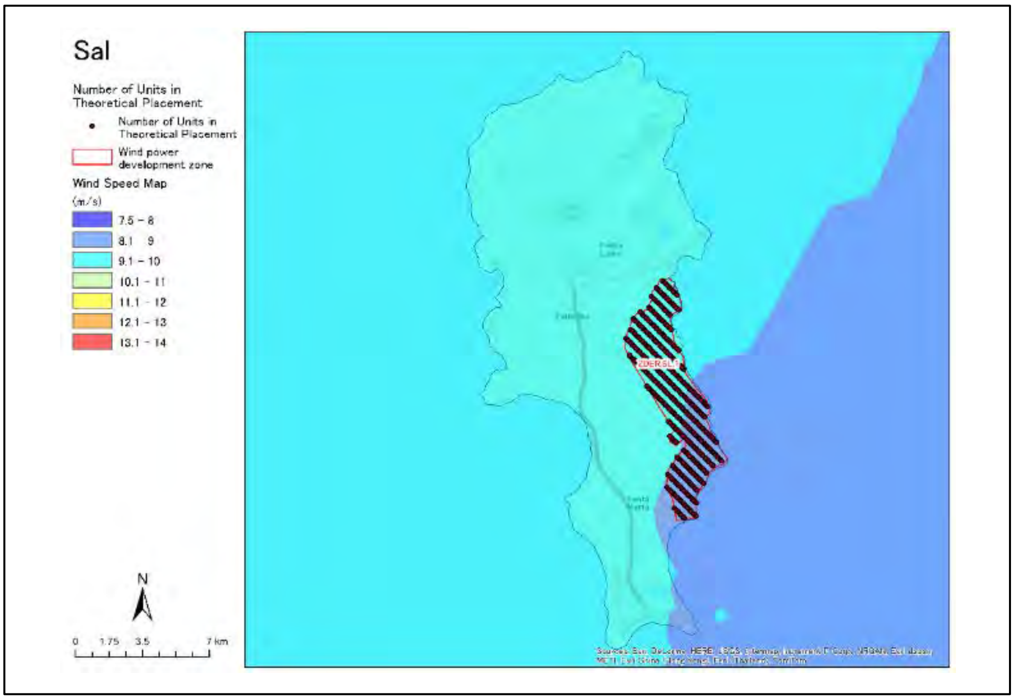
Source: JICA Study Team

Figure 7.3-28 Theoretical arrangement of windmills in the wind-power generation development zones in São Vicente (development zone: 3 locations)



Source: JICA Study Team

Figure 7.3-29 Theoretical arrangement of windmills in the wind-power generation development zones in São Nicolau (development zone: 2 locations)

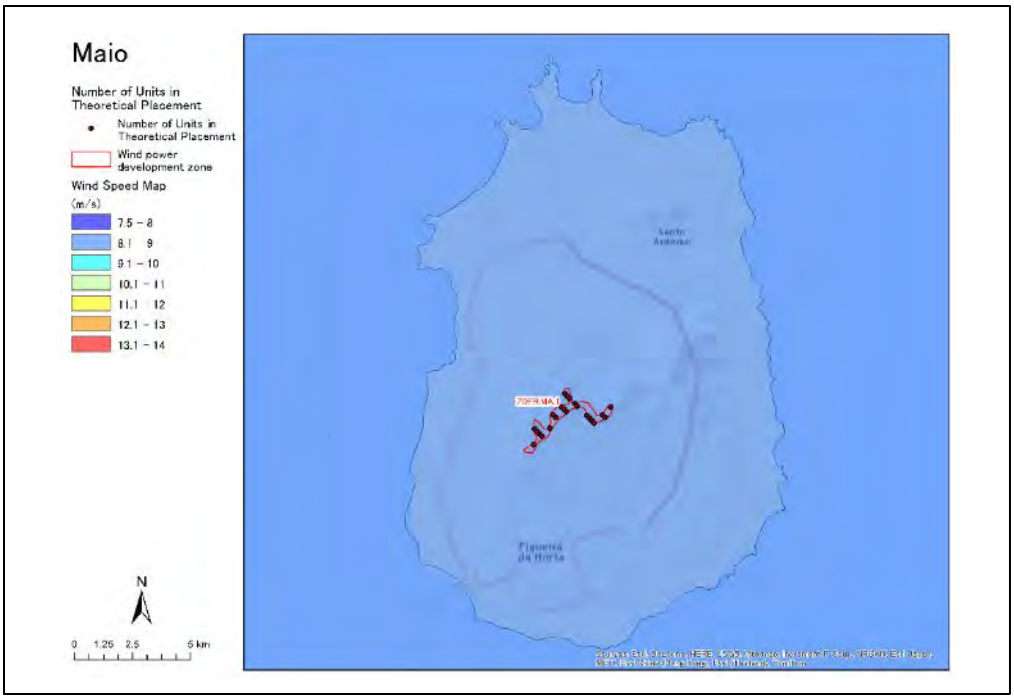


Source: JICA Study Team

Figure 7.3-30 Theoretical arrangement of windmills in the wind-power generation development zone in Sal (development zone: 1 location)

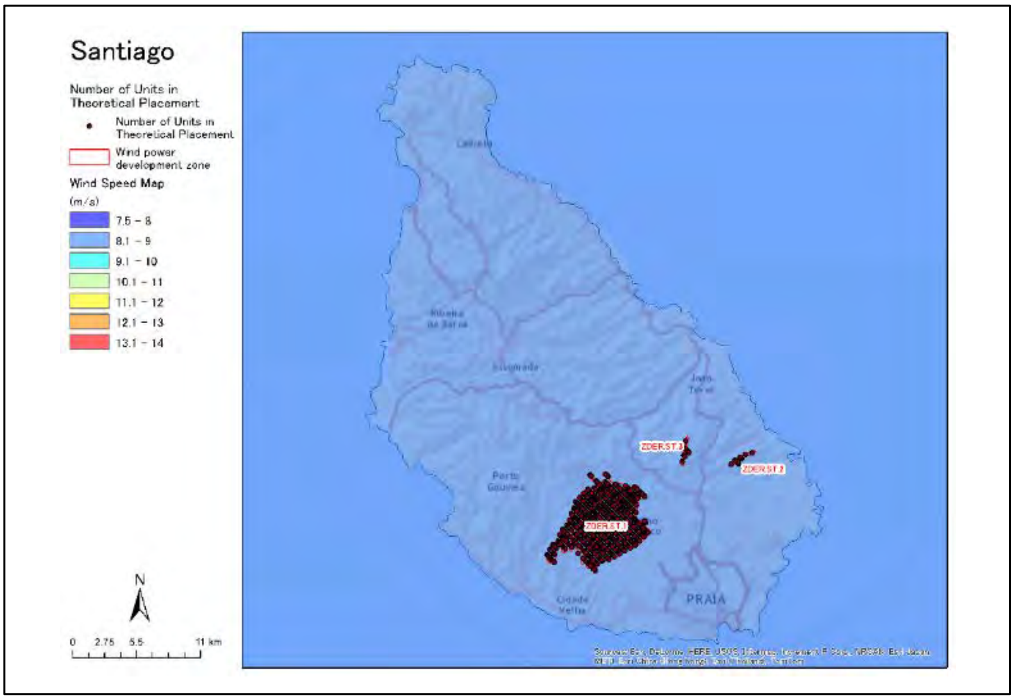
Source: JICA Study Team

Figure 7.3-31 Theoretical arrangement of windmills in the wind-power generation development zone in Boa Vista (development zone: 1 location)



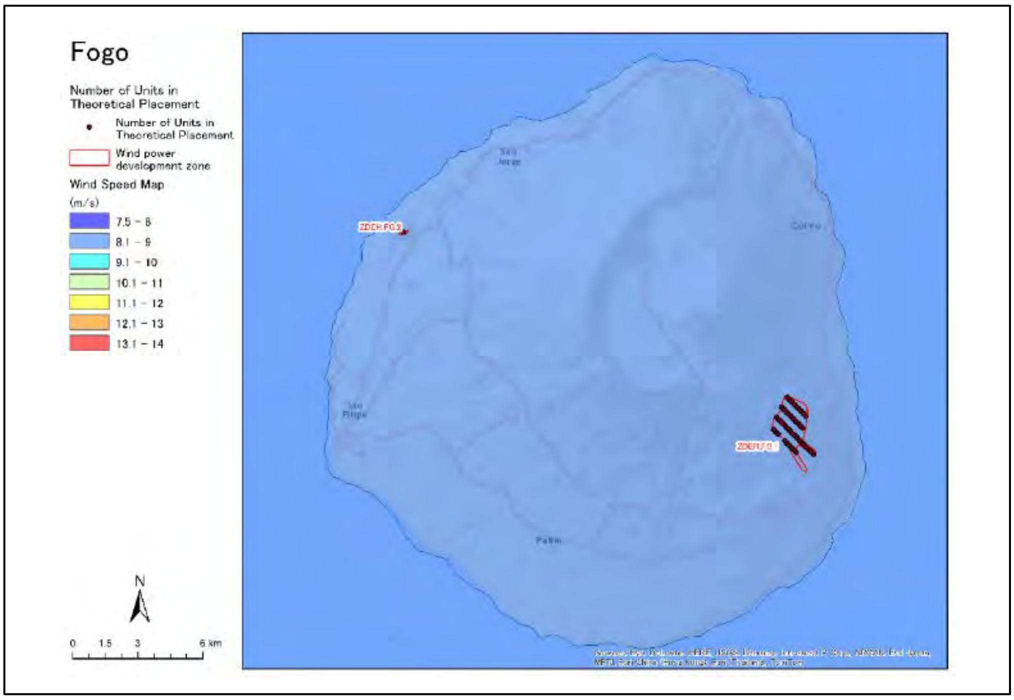
Source: JICA Study Team

Figure 7.3-32 Theoretical arrangement of windmills in the wind-power generation development zone in Maio (development zone: 1 location)



Source: JICA Study Team

Figure 7.3-33 Theoretical arrangement of windmills in the wind-power generation development zones in Santiago (development zone: 3 locations)



Source: JICA Study Team

Figure 7.3-34 Theoretical arrangement of windmills in the wind-power generation development zones in Fogo (development zone: 2 locations)

Source: JICA Study Team

Figure 7.3-35 Theoretical arrangement of windmills in the wind-power generation development zone in Brava (development zone: 1 location)

(2) Trial calculation of the expected available quantity (STEP 2)

Figure 7.3-36 shows the flow of trial calculation of the expected available quantity.

STEP 2-1

Analysis of the terrain slope angle of 10% or less (100m mesh)

↓

STEP 2-2

Analysis of the wake area [10D (=520 m)] related to the existing wind-power generation facilities (5 islands)
(Only facilities in Sal are in operation within the wind-power generation development zones)

↓

STEP 2-3

① Wind speed rank ② Turbulent intensity

Wind condition simulation for the prevailing wind direction (northeast) was performed by use of an unsteady, non-linear wind condition simulator (RIAM-COMPACT®) and the wind speed rank and turbulent intensity were analyzed (100m mesh)

③ Distance from 66kV Transmission Line and 20kV Transmission Line (hereafter, referred to as a power transmission line)

Based on the power transmission line GIS data provided by Electra, offset distance was analyzed.

Evaluation score=①×3+②×1+③×1

Evaluation items and evaluation points

Evaluation item	1 point	2 points	3 points	4 points	5 points
	Unsuitable for installation ←			→ Suitable for installation	
① Wind speed rank	0~0.25	0.25~0.5	0.5~0.75	0.75~1.0	1.0 or more
② Turbulent intensity	Over 0.20	0.20~0.15	0.15~0.10	0.10~ 0.05	0.05 or less
③ Distance from transmission line	20km or more	15~20km	10~15km	5~10km	Less than 5km

↓

STEP 2-4

Retrieval of windmills that have more points than the average evaluation points for the location of existing Cabeolica windmills (Santiago).

Retrieval of windmills that have more values than the average wind velocities for the Location of existing Cabeolica windmills (Sal).

↓

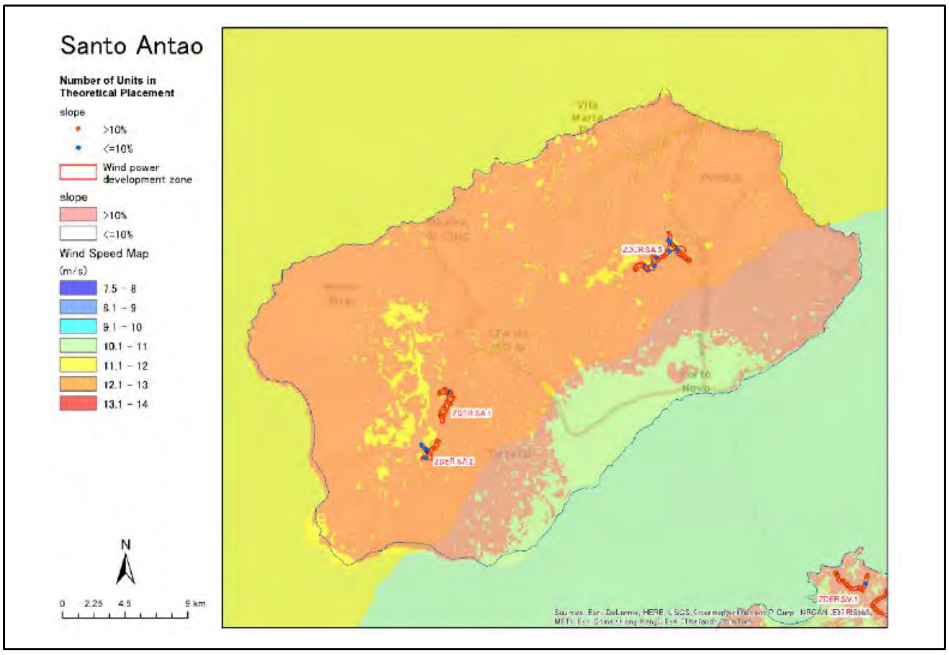
Expected available quantity

Source: JICA Study Team

Figure 7.3-36 Flow of trial calculation of the expected available quantity

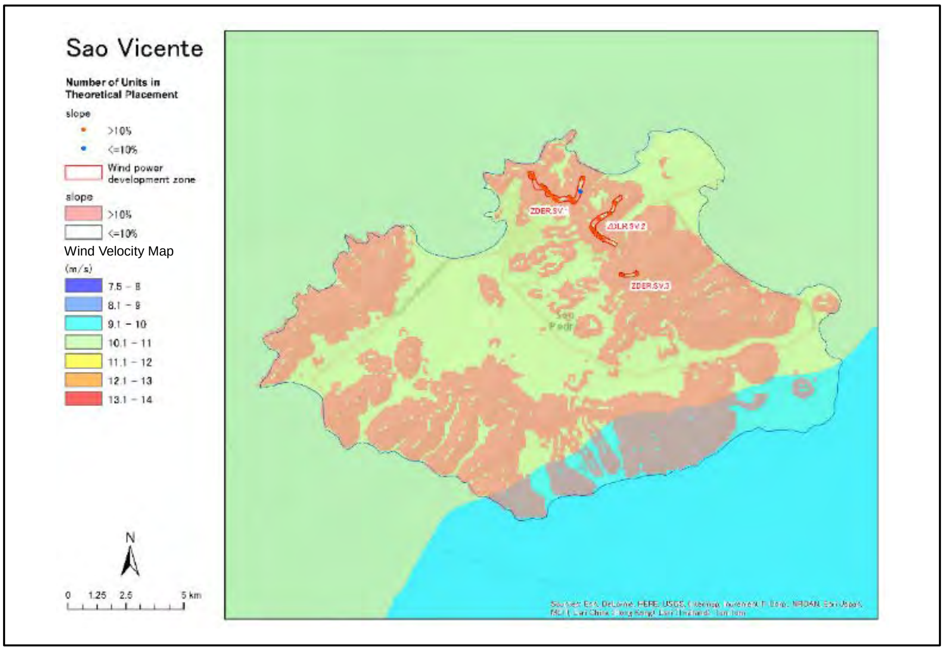
1) Evaluation of the terrain slope angle (STEP 2-1)

The terrain slope angle of 10% or less in the wind-power generation development zone was evaluated by use of 100m mesh. Figure 7.3-37 to Figure 7.3-45 show the terrain slope angle in the wind-power generation development zones in nine islands. As topographic data for evaluation was used SRTM (Shuttle Reader Topography Mission) 90m mesh evaluation data.



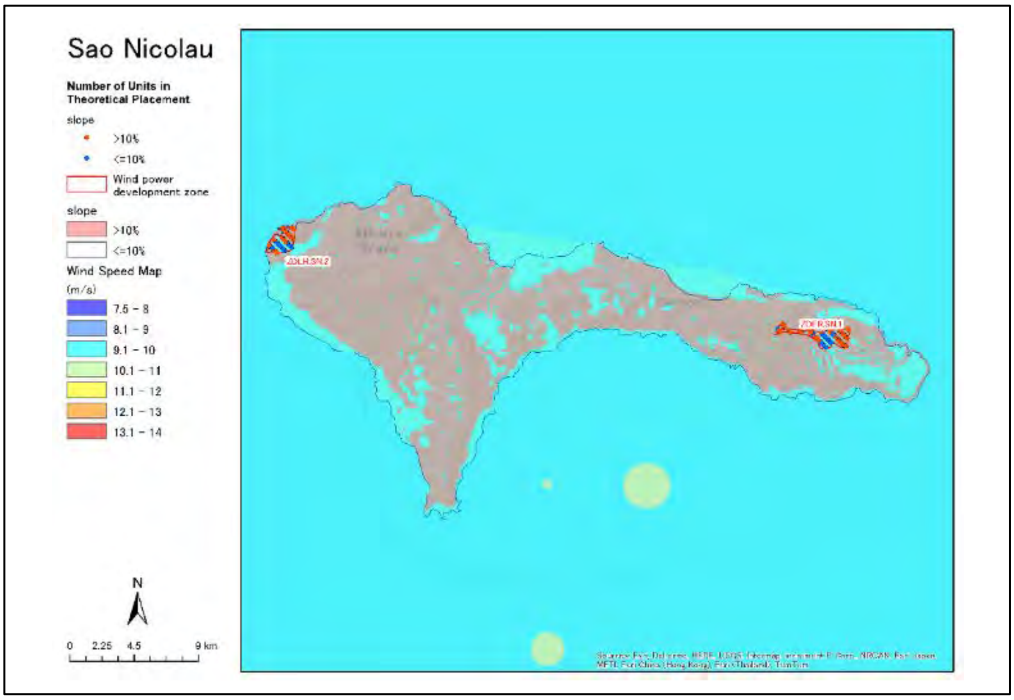
Source: JICA Study Team

Figure 7.3-37 Terrain slope angle in the wind-power generation development zones in Santo Antão



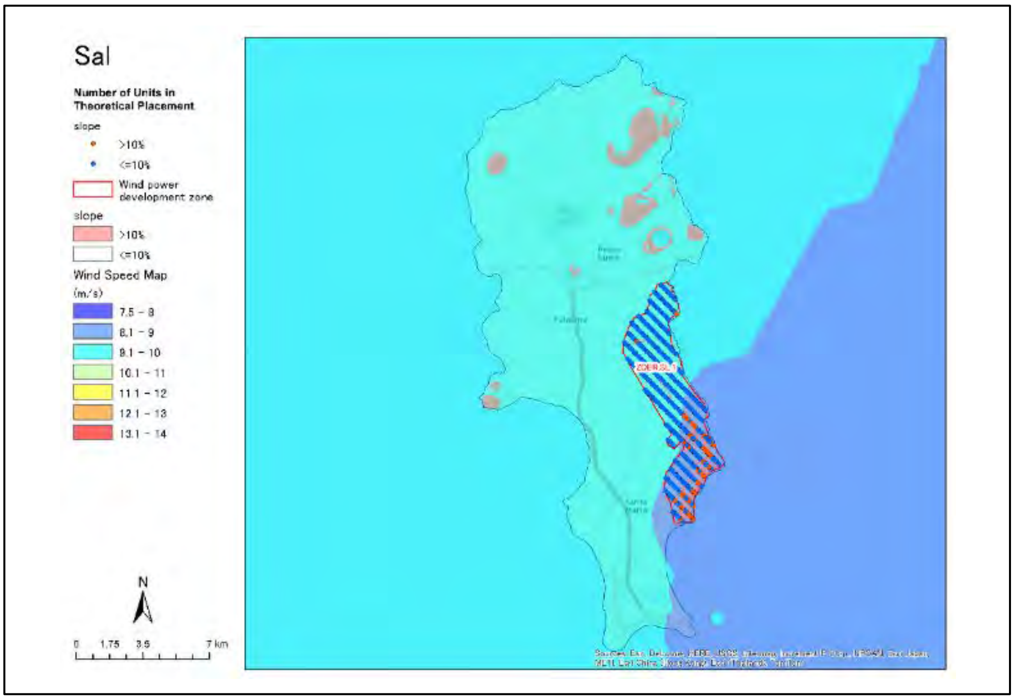
Source: JICA Study Team

Figure 7.3-38 Terrain slope angle in the wind-power generation development zones in São Vicente



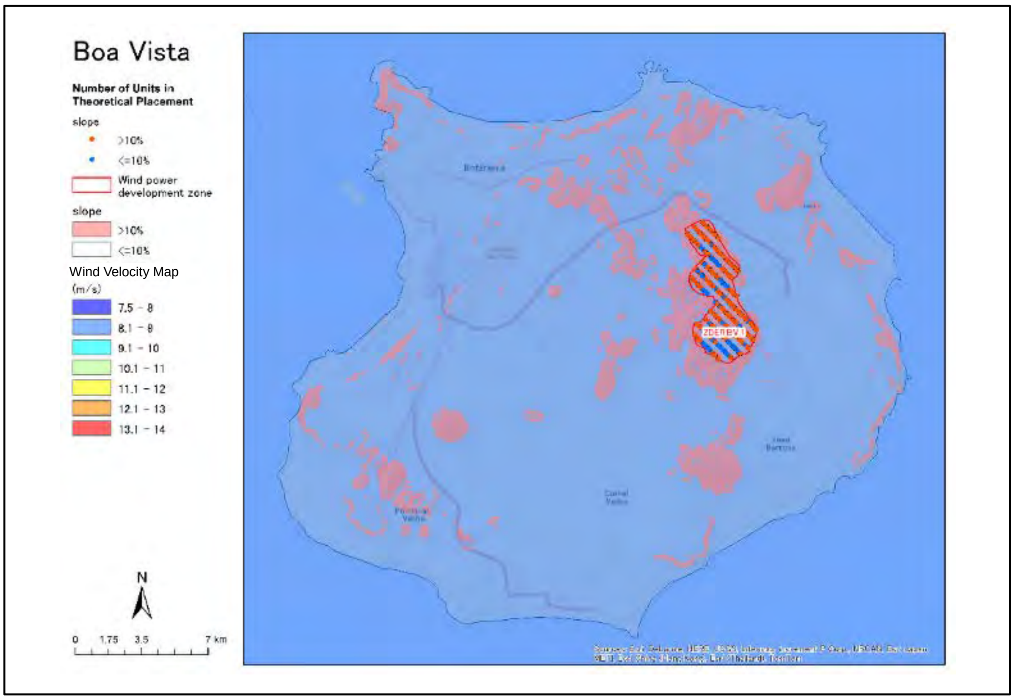
Source: JICA Study Team

Figure 7.3-39 Terrain slope angle in the wind-power generation development zones in São Nicolau



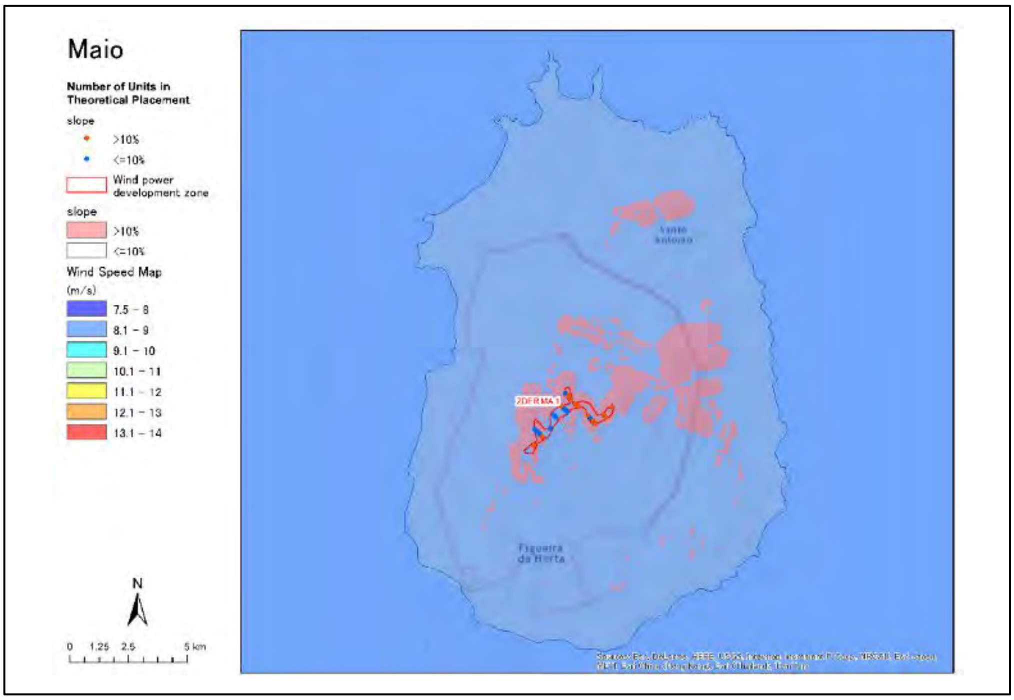
Source: JICA Study Team

Figure 7.3-40 Terrain slope angle in the wind-power generation development zone in Sal



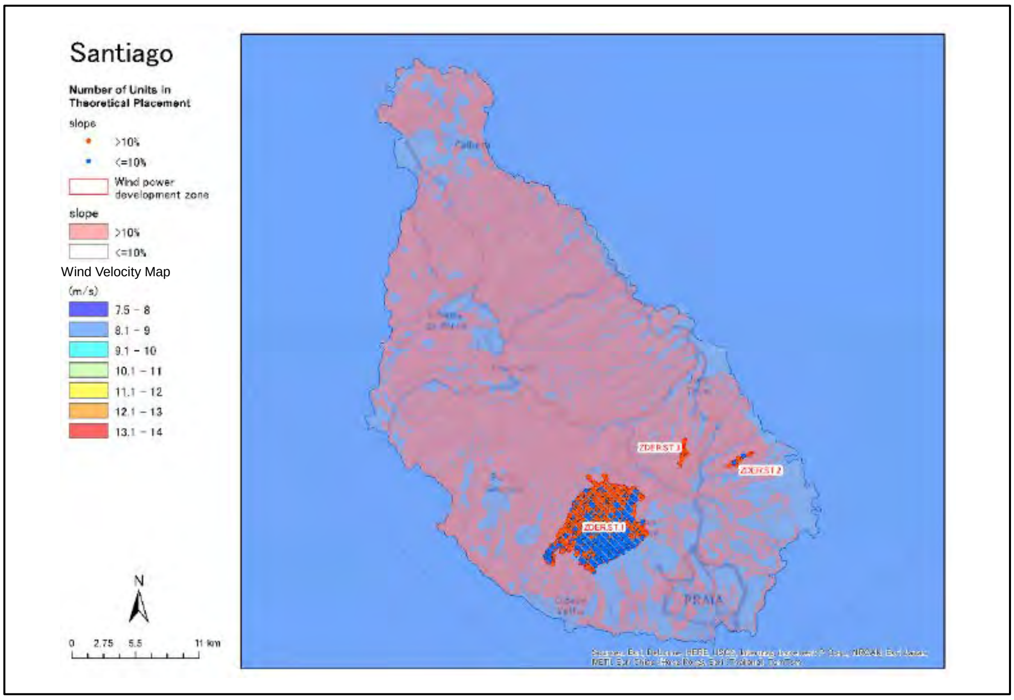
Source: JICA Study Team

Figure 7.3-41 Terrain slope angle in the wind-power generation development zone in Boa Vista



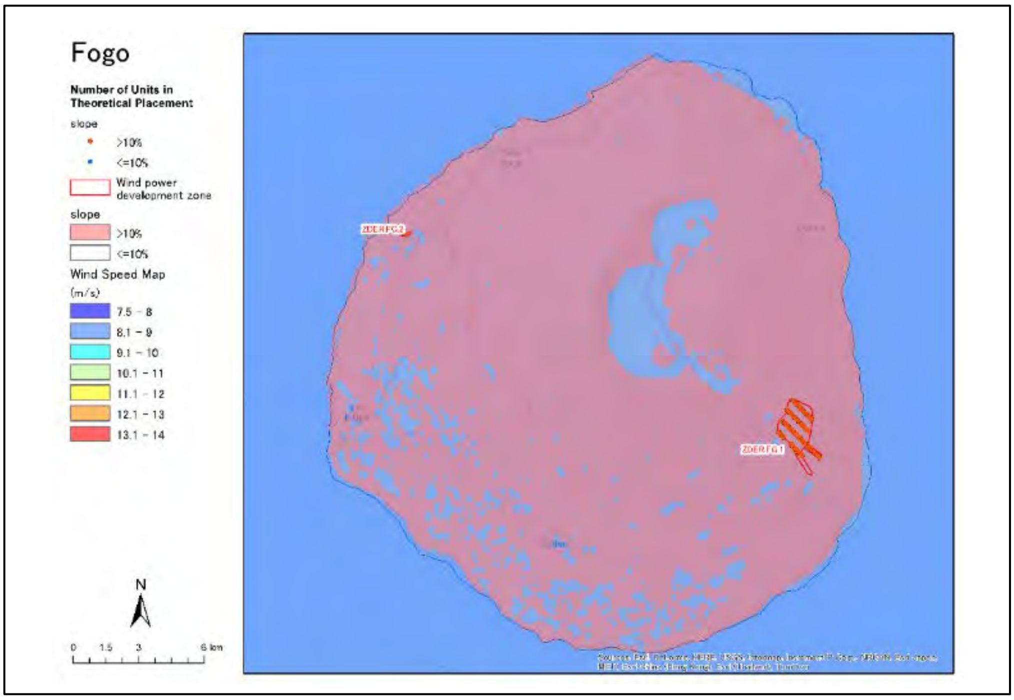
Source: JICA Study Team

Figure 7.3-42 Terrain slope angle in the wind-power generation development zone in Maio



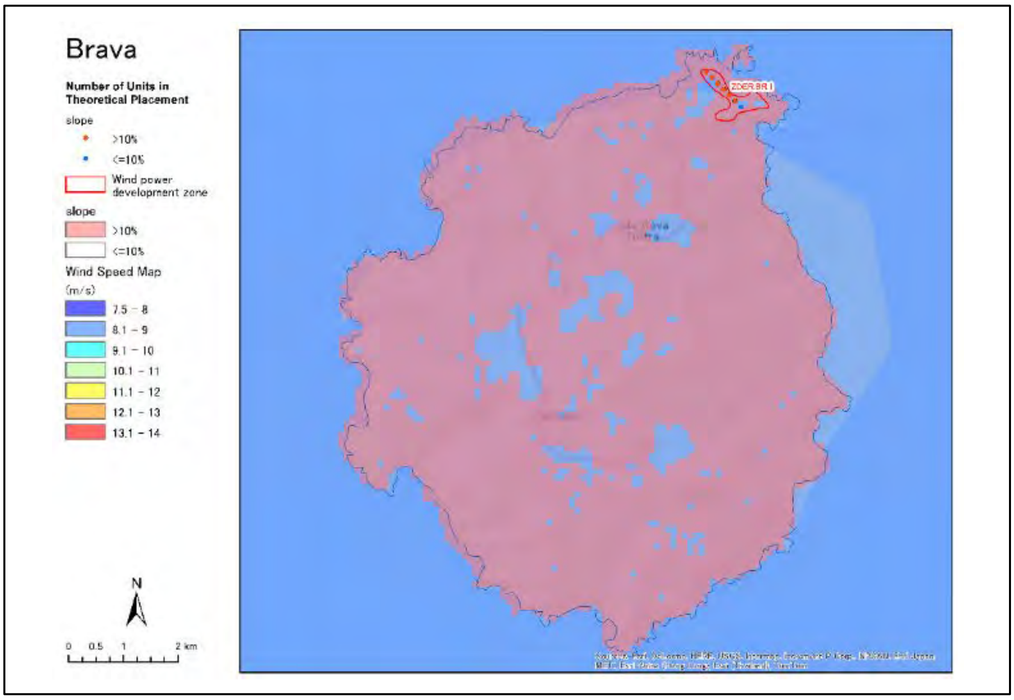
Source: JICA Study Team

Figure 7.3-43 Terrain slope angle in the wind-power generation development zones in Santiago



Source: JICA Study Team

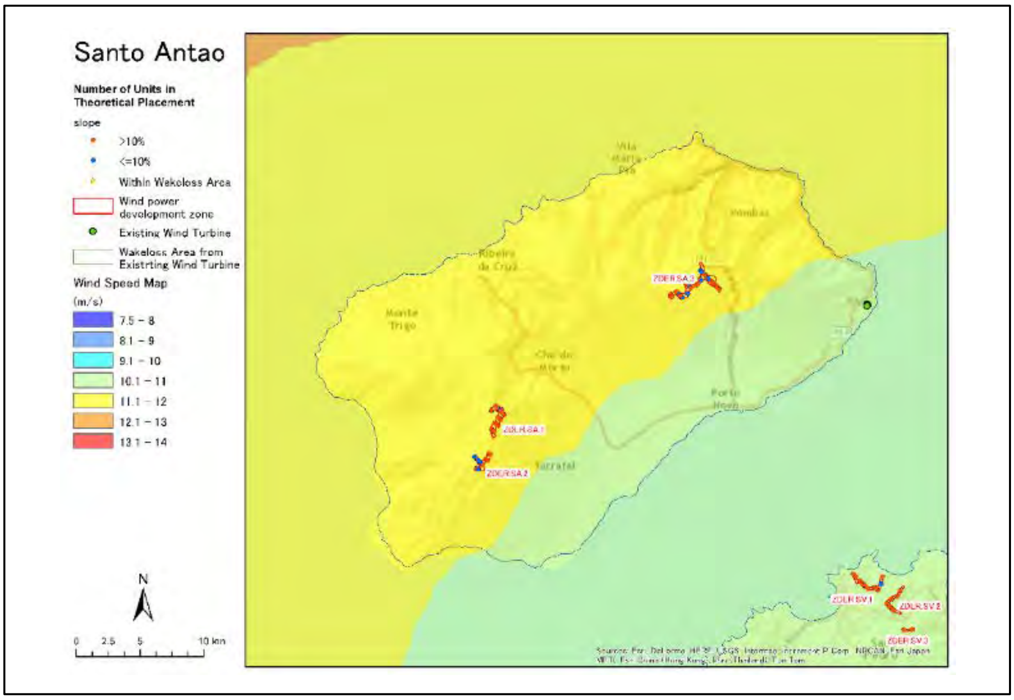
Figure 7.3-44 Terrain slope angle in the wind-power generation development zones in Fogo



Source: JICA Study Team

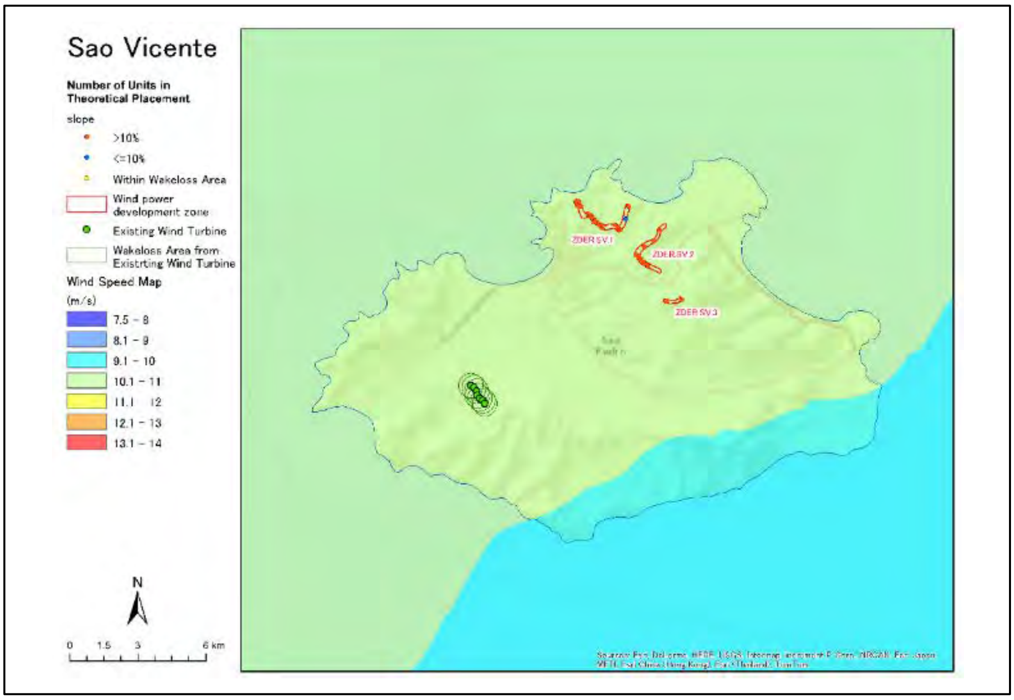
Figure 7.3-45 Terrain slope angle in the wind-power generation development zone in Brava

2) Offset distance from the arranged existing windmills (STEP 2-2)
   In Cabo Verde, wind-power generation facilities owned by two business operators (Cabeolica, Electric) of wind power IPP are in operation in five islands (Santo Antão, São Vicente, Sal, Boa Vista, and Santiago).
   Among them, only facilities in Sal are in operation within the wind-power generation development zones.
   Therefore, Figure 7.3-46 to Figure 7.3-50 show the offset distance between the existing windmills and the wind-power generation development zones in five islands.



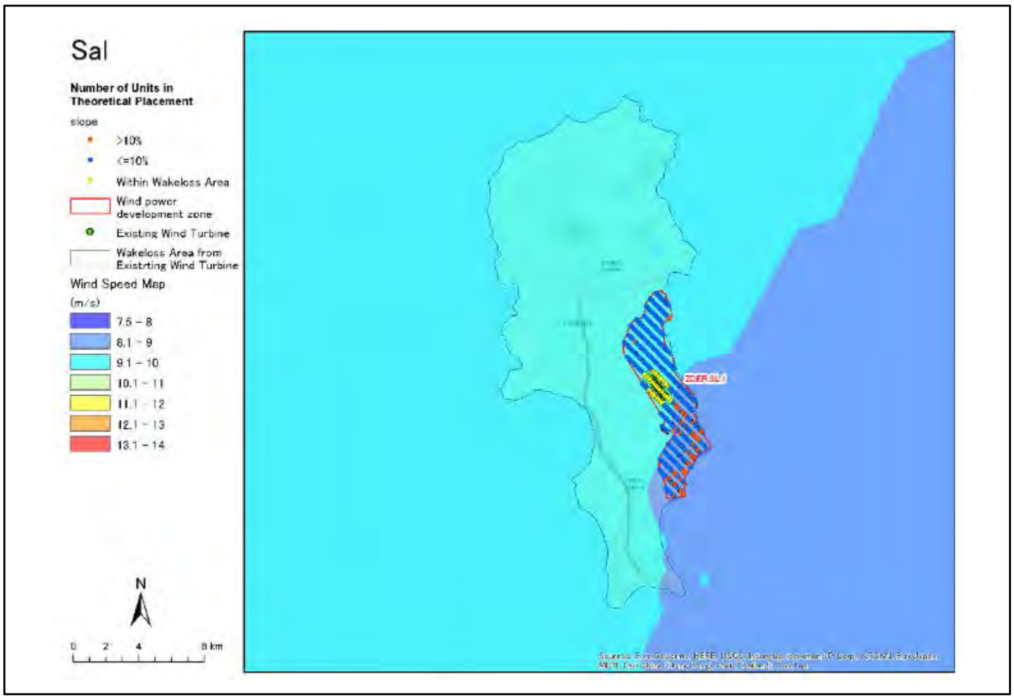
Source: JICA Study Team

Figure 7.3-46 Offset distance between the existing windmills and the wind-power generation development zones in Santo Antão



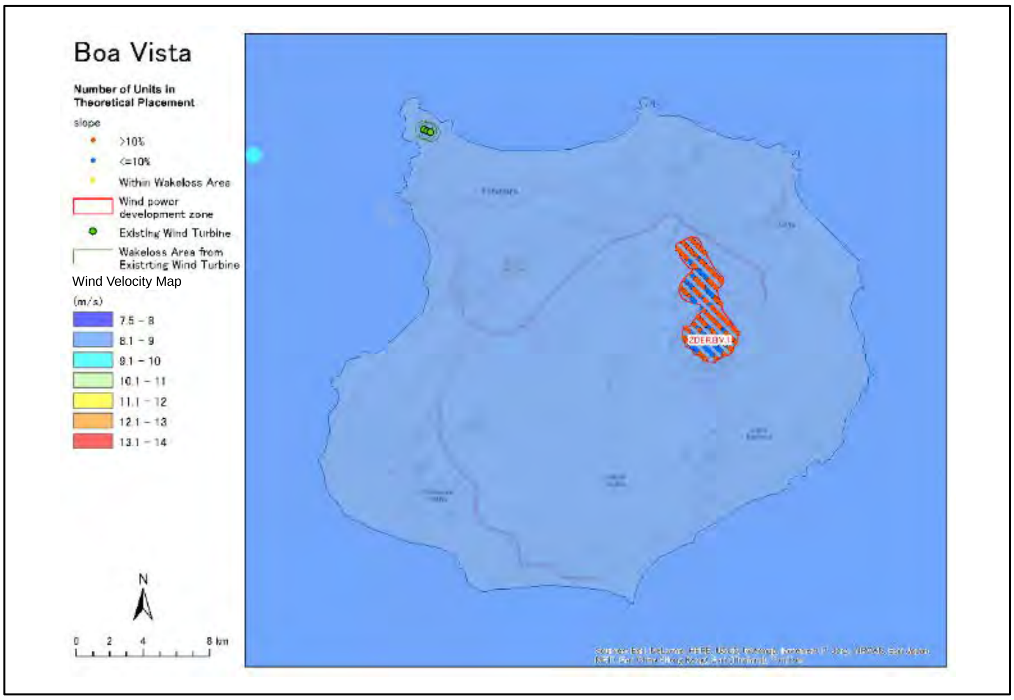
Source: JICA Study Team

Figure 7.3-47 Offset distance between the existing windmills and the wind-power generation development zones in São Vicente



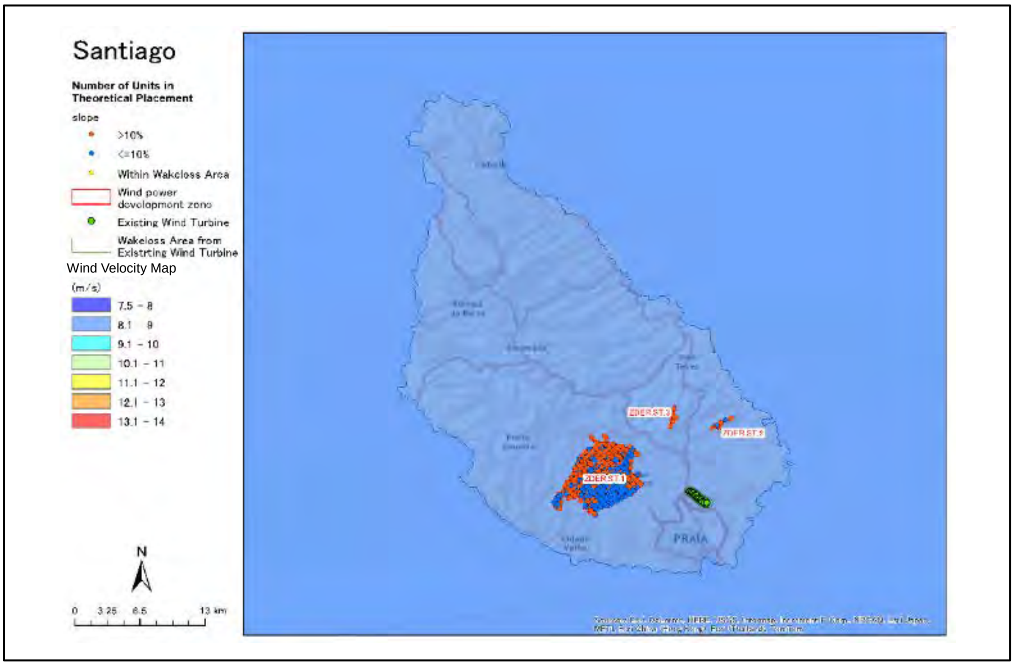
Source: JICA Study Team

Figure 7.3-48 Offset distance between the existing windmills and the wind-power generation development zone in Sal



Source: JICA Study Team

Figure 7.3-49 Offset distance between the existing windmills and the wind-power generation development zone in Boa Vista



Source: JICA Study Team

Figure 7.3-50 Offset distance between the existing windmills and the wind-power generation development zones in Santiago

3) Result of study of the windmill arrangement taking into consideration the terrain slope angle and the existing windmill wake area

As the result of study of the windmill arrangement, the potential quantity became "0" in two zones (SV.2, SV.3) in São Vicente, one zone (ST.3) in Santiago, and two zones (FG.1, FG.2) in Fogo.

This is because the terrain slope angle exceeds 10%.

Also, difference of the potential quantity became large in one zone (SL.1) in Sal and one zone (ST.1) in Santiago.

Table 7.3-16 shows the number of windmills arranged and the potential quantity taking into consideration the terrain slope angle and the existing windmill wake area.

Table 7.3-17 shows the comparison with the potential quantity of wind-power generation shown in the official gazette (February 2012) obtained from DGE.

Table 7.3-16 Number of windmills arranged and the potential quantity taking into consideration the terrain slope angle and the existing windmill wake area

Island name	Zone ID	Theoretical number of windmills	Theoretical number of windmills having an inclination angle of 10% or less	Number of windmills having an inclination angle of 10% or less, not included in the wakeloss of the existing windmills	Single unit capacity	Volume of reserve
Santo Antao	ZDER.SA.1	17	2	2	850	1.7
	ZDER.SA.2	13	6	6		5.1
	ZDER.SA.3	31	9	9		7.7
Sao Vicente	ZDER.SV.1	15	1	1		0.9
	ZDER.SV.2	9	0	0		0.0
	ZDER.SV.3	2	0	0		0.0
Sao Nicolau	ZDER.SN.1	48	16	16		13.6
	ZDER.SN.2	31	11	11		9.4
Sal	ZDER.SL.1	351	308	273		232.1
Boa Vista	ZDER.BV.1	202	53	53		45.1
Maio	ZDER.MA.1	23	10	10		8.5
Santiago	ZDER.ST.1	525	263	263		223.6
	ZDER.ST.2	9	2	2		1.7
	ZDER.ST.3	8	0	0		0.0
Fogo	ZDER.FG.1	45	0	0		0.0
	ZDER.FG.2	1	0	0		0.0
Brava	ZDER.BR.1	7	1	1		0.9

Source: JICA Study Team

Table 7.3-17 Comparison with the potential quantity of wind-power generation

Island name	Zone ID	Zone area (km^2)	This survey	Official gazette (December, 2012)
			Volume of reserve (MW)	
Santo Antao	ZDER.SA.1	1.04	1.7	11.1
	ZDER.SA.2	0.64	5.1	11.1
	ZDER.SA.3	1.91	7.7	12.8
Sao Vicente	ZDER.SV.1	0.64	0.9	10.2
	ZDER.SV.2	0.53	0.0	7.7
	ZDER.SV.3	0.12	0.0	2.6
Sao Nicolau	ZDER.SN.1	3.15	13.6	14.5
	ZDER.SN.2	2.18	9.4	1.32
Sal	ZDER.SL.1	22.10	232.1	38.4
Boa Vista	ZDER.BV.1	1.36	45.1	20.4
Maio	ZDER.MA.1	1.71	8.5	14.5
Santiago	ZDER.ST.1	36.00	223.6	96.9
	ZDER.ST.2	0.52	1.7	6.8
	ZDER.ST.3	0.43	0.0	6.0
Fogo	ZDER.FG.1	2.90	0.0	17.9
	ZDER.FG.2	0.04	0.0	1.7
Brava	ZDER.BR.1	0.37	0.9	6.0

Source: JICA Study Team

4) Analysis of evaluation points of Santiago and the evaluation of wind speed in Sal (STEPS 2-3 to 2-4)

We analyzed the evaluation points of Santiago where potential quantity difference was large and calculated the potential quantity.

Also, we calculated the potential quantity in Sal where potential quantity difference was also large, by taking into consideration the conditions for wind speed.

a. Evaluation of Santiago (ST.1)

(a) Evaluation requirements

Wind conditions simulation for the prevailing wind direction (northeast) was performed by use of an unsteady, non-linear wind condition simulator (RIAM-COMPACT®) and the wind speed rank map and the turbulent intensity map were created. The terrain data created based on the evaluation of the terrain slope angle was used for the wind condition simulation.

Furthermore, offset distance was analyzed based on the GIS data, provided by Electra, concerning the 66kV Transmission Line and the 20kV Transmission Line.

On the basis of those three elements, the 100 meter mesh evaluation point map was created.

Table 7.3-18 shows the evaluation items and evaluation points.

Figure 7.3-51 shows the conditions for wind condition simulation.
Figure 7.3-52 to Figure 7.3-54 show the wind speed rank map, turbulent intensity map, and the map of offset distance from the 66kV Transmission Line and the 20kV Transmission Line.
Figure 7.3-55 shows the evaluation point map.

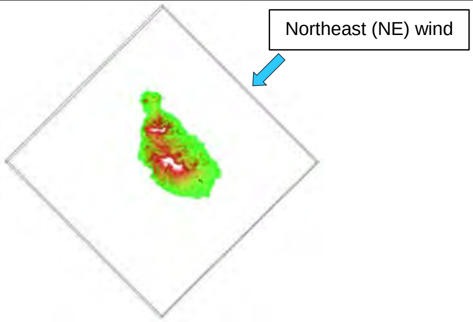
Table 7.3-18 Evaluation items and evaluation points

Evaluation item	1 point	2 points	3 points	4 points	5 points
	Unsuitable for installation ← → Suitable for installation				
① Wind speed rank	0~0.25	0.25~0.5	0.5~0.75	0.75~1.0	1.0 or more
② Turbulent intensity	Over 0.20	0.20~0.15	0.15~ 0.10	0.10~0.05	0.05 or less
③ Distance from 66 kV Transmission Line and 20 kV Transmission Line	20km or more	15~20km	10~15km	5~10km	Less than 5km

Note) Total evaluation points =①×3+①×1+③×1

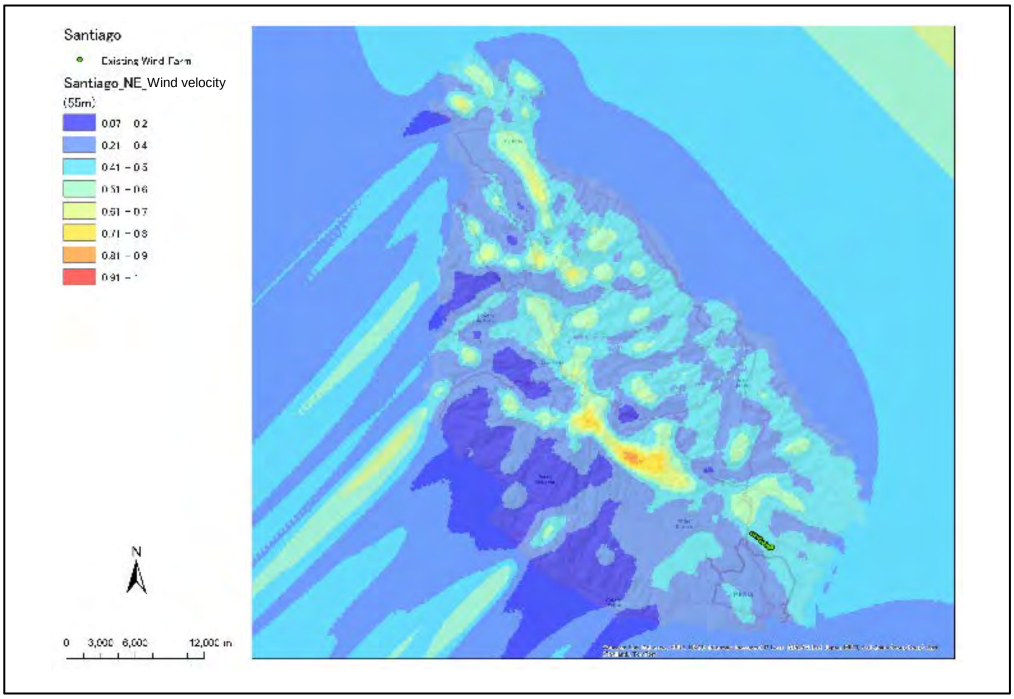
Source: JICA Study Team

- Wind direction: NE
- Horizontal direction area: 100 km × 100 km × 4km
- Number of meshes: 201 × 201 × 51 points (Approx. 2 million points)
- Wind speed: upper air 10 m/s (1/10 power law)
- Altitude difference: 1,180 m



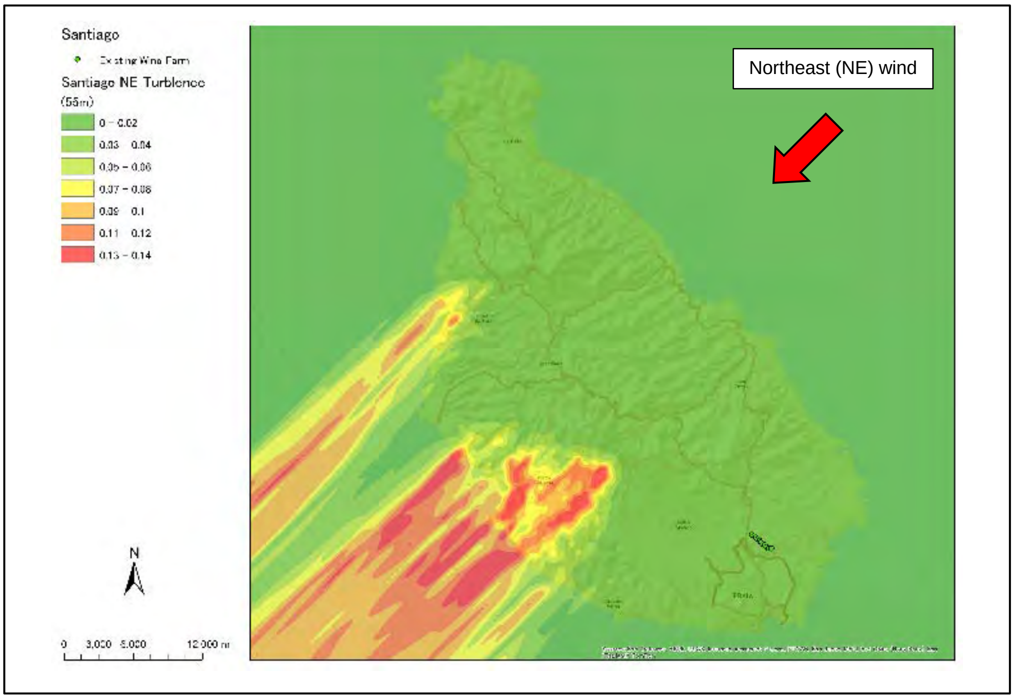
Source: JICA Study Team

Figure 7.3-51 Conditions for wind condition simulation



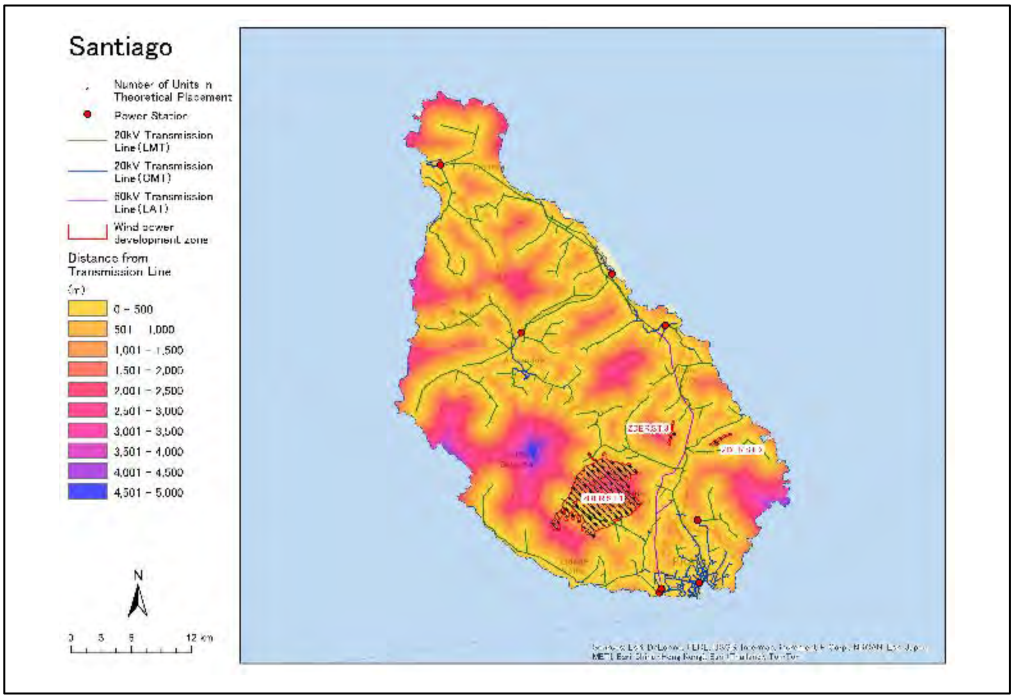
Source: JICA Study Team

Figure 7.3-52 Wind velocity rank map



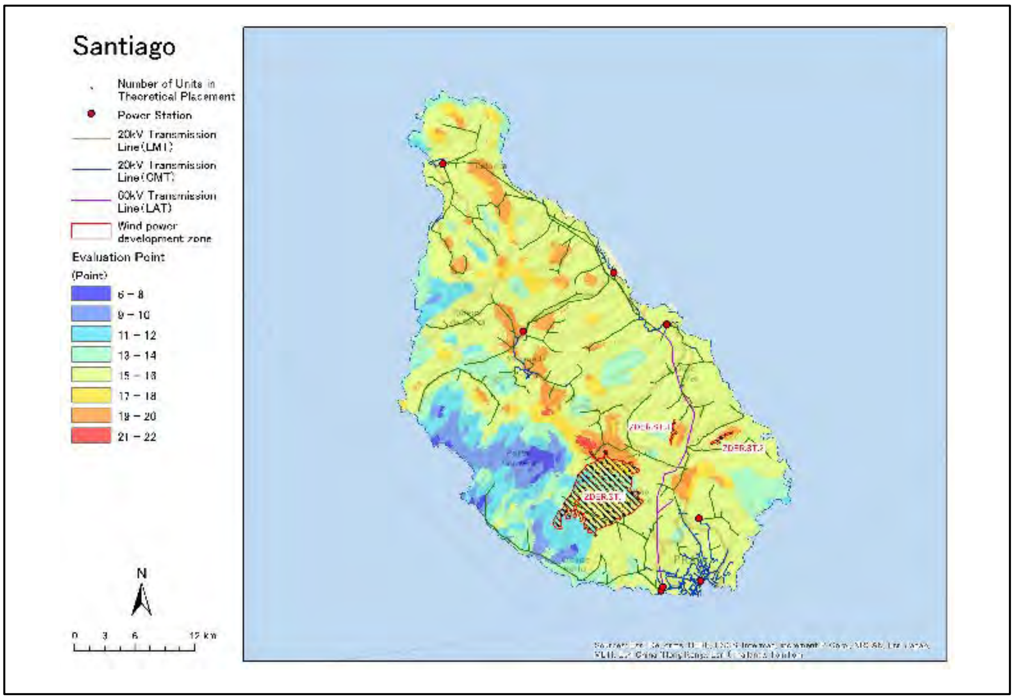
Source: JICA Study Team

Figure 7.3-53 Turbulent intensity map



Source: JICA Study Team

Figure 7.3-54 Map of offset distance from 66 kV Transmission Line and 20 kV Transmission Line



Source: JICA Study Team

Figure 7.3-55 Evaluation point map

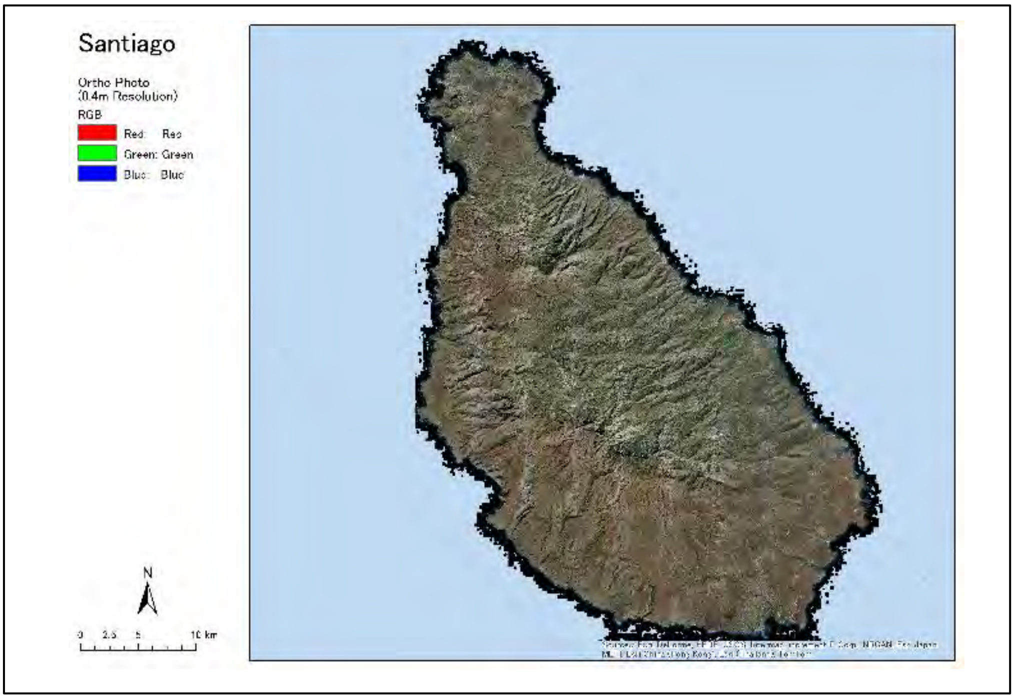
(b) Evaluation result

There are mountains on the northeast side of the zone (ST.1) where 263 windmills, each having capacity of 850 kW, are arranged. According to result of the evaluation, it was confirmed that wind speed decreases in the area downwind of the mountains when the northeast (NE) wind blows.

When regarding the average evaluation points (16 points) of Cabeolica's existing windmills (850 kW X 11 units) as a criterion, the number of windmills having the evaluation points of 16 points or more was 118 units.

Figure 7.3-56 shows an altitude map in which altitude data obtained from DGE has been diagrammatized.

Table 7.3-19 shows the evaluation point collection result for Cabeolica's windmill site. Figure 7.3-57 shows the histogram of the evaluation points.



Source: JICA Study Team

Figure 7.3-56 Altitude map of Santiago

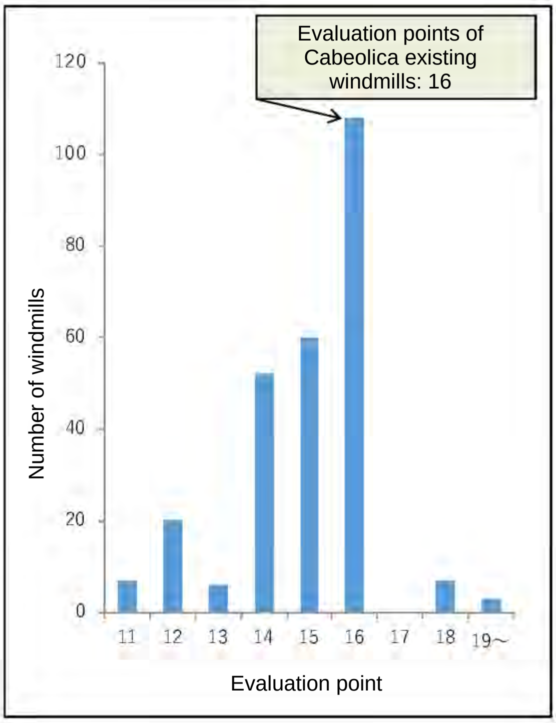
Table 7.3-19 Evaluation point collection result for Cabeolica's windmill site

Windmill No.	1	2	3	4	5	6	7	8	9	10	11	Total	Average
Point.	16	16	16	16	16	16	16	16	16	16	16	176	16

Source: JICA Study Team

Evaluation point	Number of windmills
11	7
12	20
13	6
14	52
15	60
16	108
17	0
18	7
19~	3
total	263

118 Cabeolica existing windmills have evaluation points of 16 or more.



Source: JICA Study Team

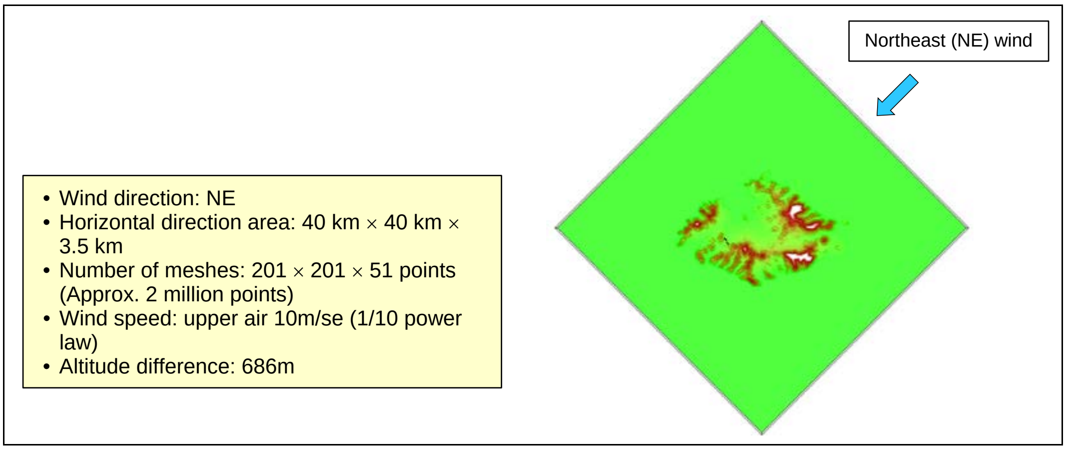
Figure 7.3-57 Histogram of the evaluation points

b. Evaluation of Sal (SL.1)
According to the 2015 wind condition map, it was confirmed that wind speed decreased by 1m/s on the south side of the zone (SL.1) where 273 windmills, each having a capacity of 850 kW, are arranged. Therefore, when regarding the wind speed of 9 m/s or more (the wind power potential identical to that in the location of Cabeolica's windmills) as a criterion, the number of windmills is 182.

5) Analysis of the evaluation points of São Vicente, Boa Vista, and Brava
Evaluation points of three islands were analyzed: São Vicente where the potential quantity of wind-power generation became 0.9MW, Boa Vista where future increase in demand is expected, and Brava which is a model case of 100% renewable energy on a small-scale demand.

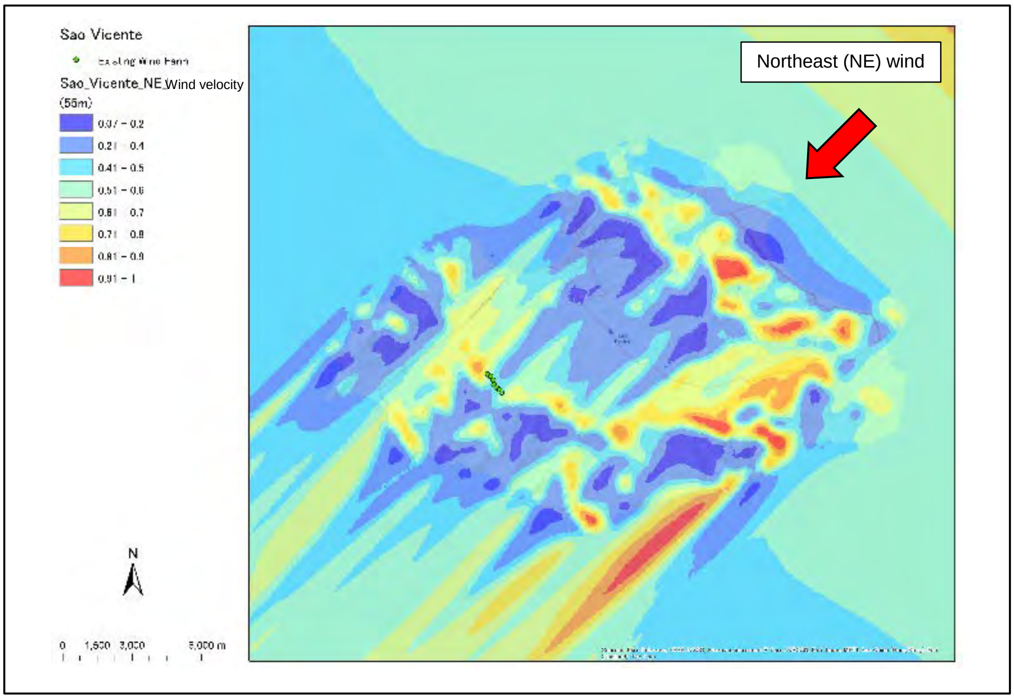
a. Evaluation of São Vicente

(a) Evaluation requirements
Evaluation requirements are the same as those for "a. Evaluation of Santiago (ST.1)."
Figure 7.3-58 shows the conditions for wind condition simulation.
Figure 7.3-59 to Figure 7.3-61 show the wind speed rank map, turbulent intensity map, and the map of offset distance from the 20 kV Transmission Line.
Figure 7.3-62 shows the evaluation point map.



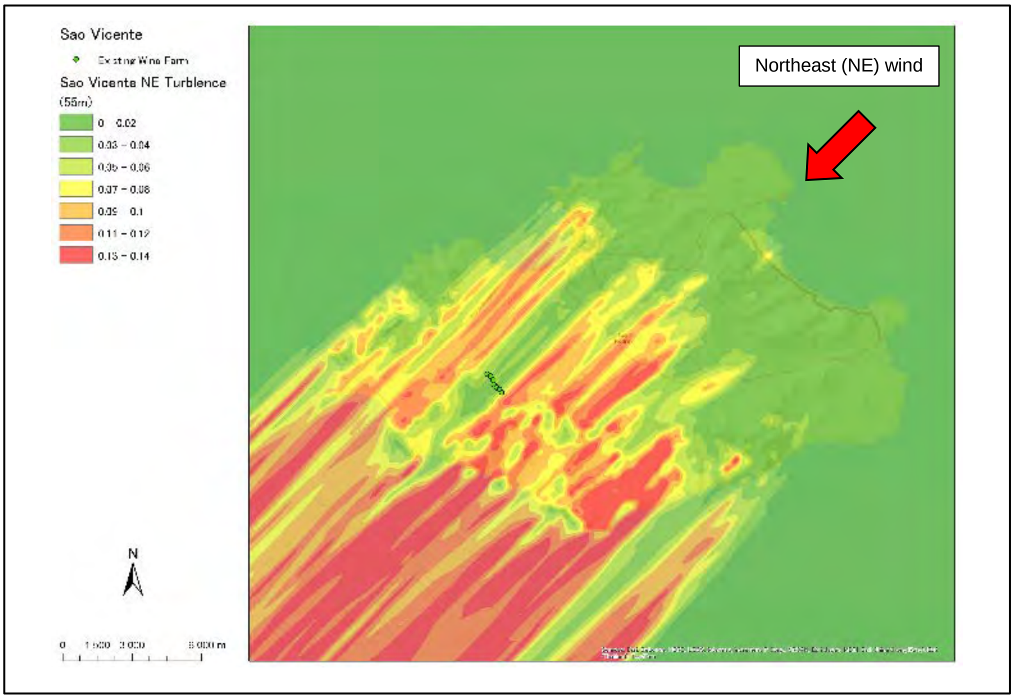
Source: JICA Study Team

Figure 7.3-58 Conditions for wind condition simulation



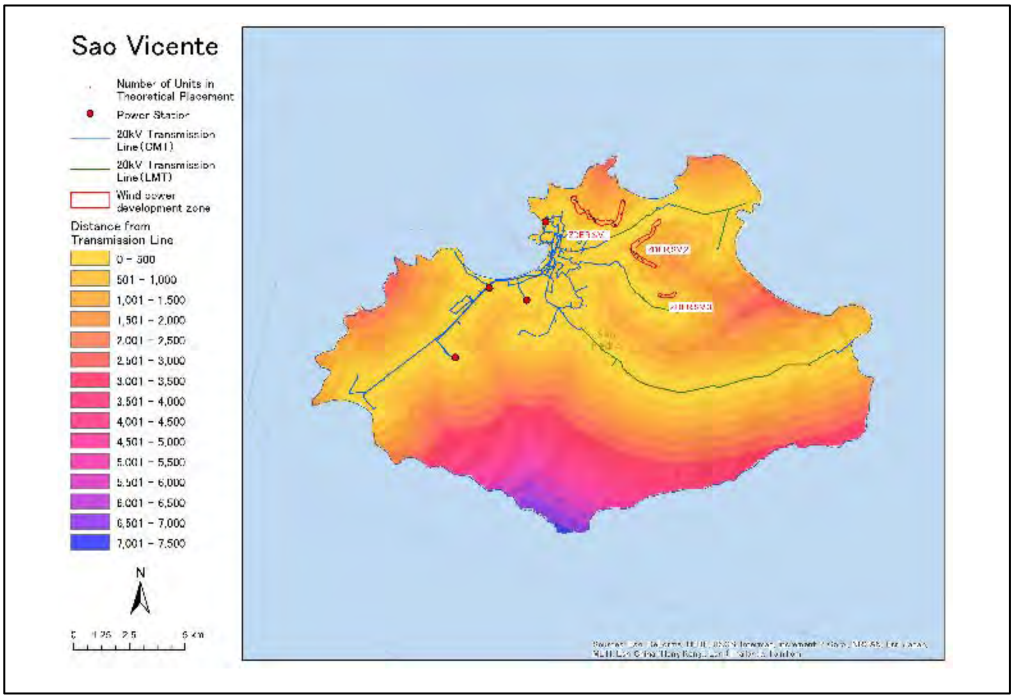
Source: JICA Study Team

Figure 7.3-59 Wind velocity rank map



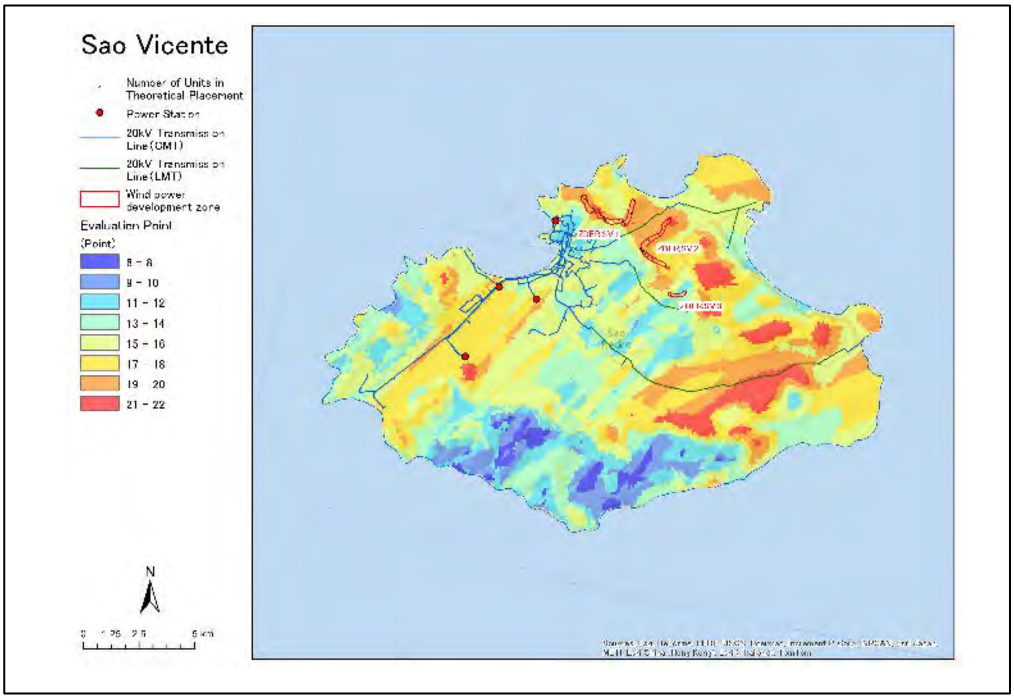
Source: JICA Study Team

Figure 7.3-60 Turbulent intensity map



Source: JICA Study Team

Figure 7.3-61 Map of offset distance from 20 kV Transmission Line



Source: JICA Study Team

Figure 7.3-62 Evaluation point map

(b) Evaluation result

The source of occurrence of the terrain turbulent flow is near the development zones in São Vicente.

Three development zones in São Vicente have the advantage of being close to power transmission lines. However, those zones are located where the terrain slope angle exceeds 10%. Therefore, when installing windmills in those zones, it is necessary to study and review in detail the arrangement of windmills.

b. Evaluation of Boa Vista

(a) Evaluation requirements

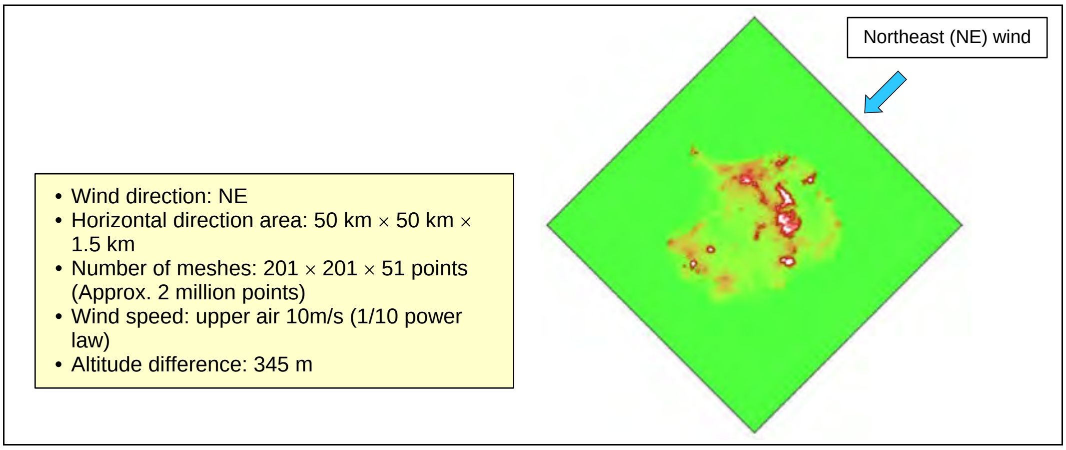
Wind conditions was simulated by use of an unsteady, non-linear wind condition simulator (RIAM-COMPACT®) and the wind speed rank map and the turbulent intensity map were created. On the basis of those two elements, the 100 meter mesh evaluation point map was created.

Figure 7.3-63 shows the conditions for wind condition simulation.

Table 7.3-20 shows the evaluation items and evaluation points.

Figure 7.3-64 to Figure 7.3-65 show the wind speed rank map and the turbulent intensity map.

Figure 7.3-66 shows the evaluation point map.



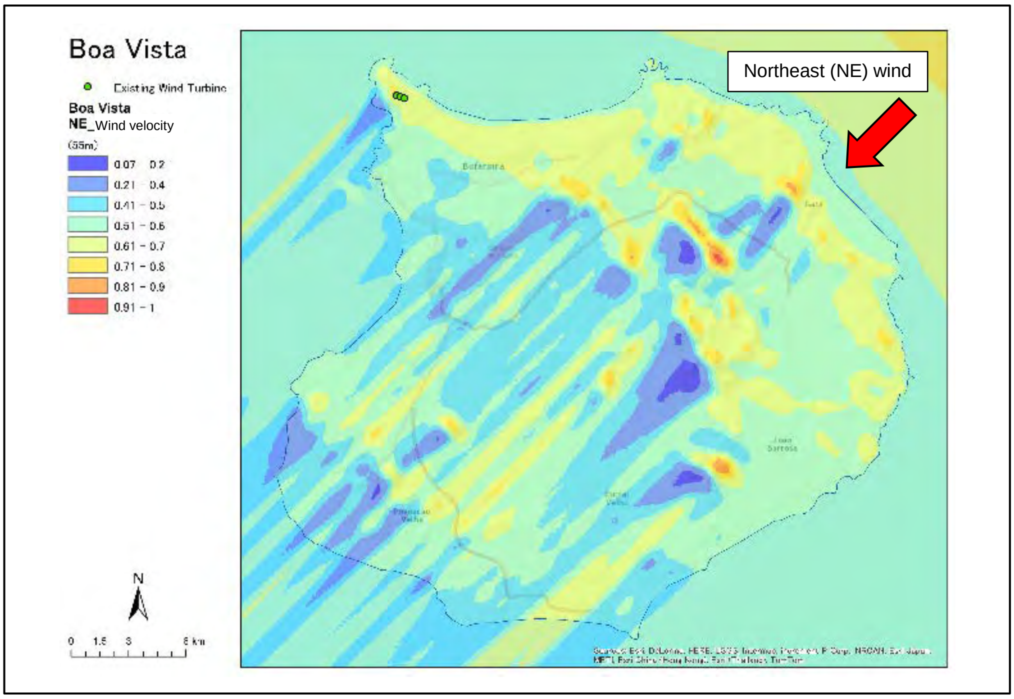
Source: JICA Study Team

Figure 7.3-63 Conditions for simulating wind conditions

Table 7.3-20 Evaluation items and evaluation points

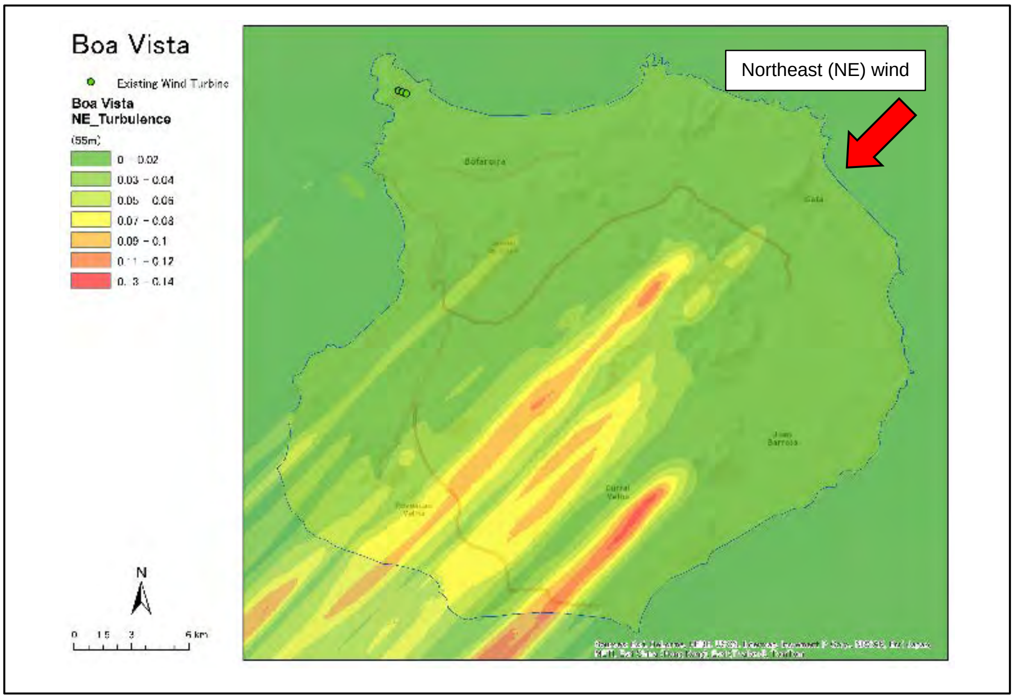
Evaluation item	1 point	2 points	3 points	4 points	5 points
	Unsuitable for installation ←				→ Suitable for installation
① Wind speed rank	0~0.25	0.25~0.5	0.5~0.75	0.75~1.0	1.0 or more
② Turbulent intensity	Over 0.20	0.20~0.15	0.15~0.10	0.10~0.05	0.05 or less

Source: JICA Study Team



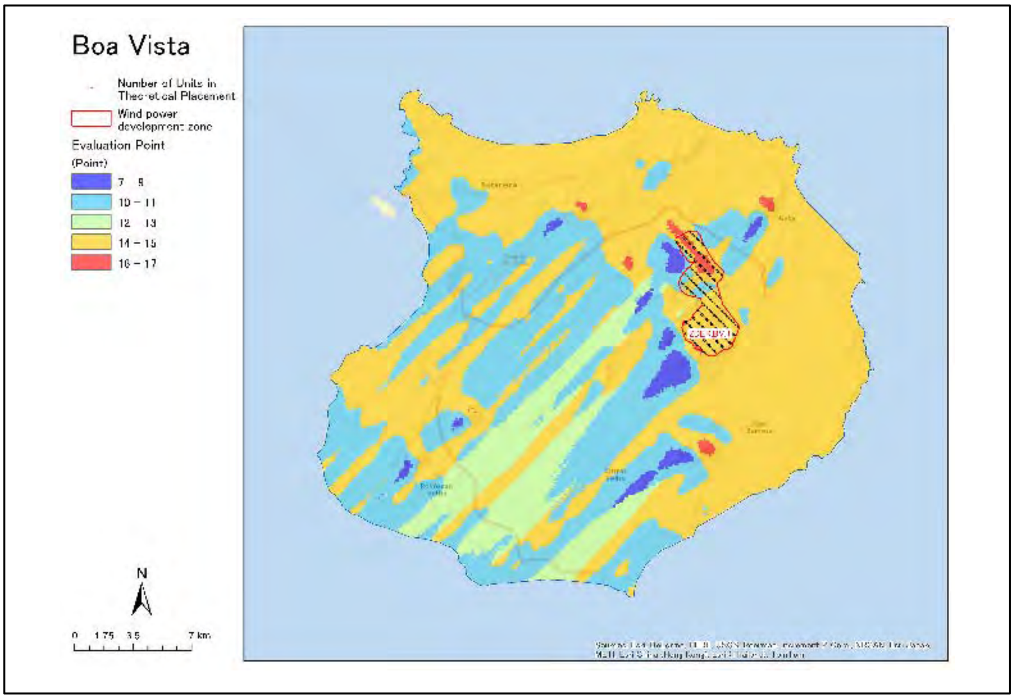
Source: JICA Study Team

Figure 7.3-64 Wind velocity rank map



Source: JICA Study Team

Figure 7.3-65 Turbulent intensity map



Source: JICA Study Team

Figure 7.3-66 Evaluation point map

(b) Evaluation result

The source of occurrence of the terrain turbulent flow is near the development zone in Boa Vista.

The development zone is located where the terrain slope angle exceeds 10%. Therefore, when installing windmills in the zone, it is necessary to study and review in detail the arrangement of windmills.

c. Evaluation of Brava

(a) Evaluation requirements

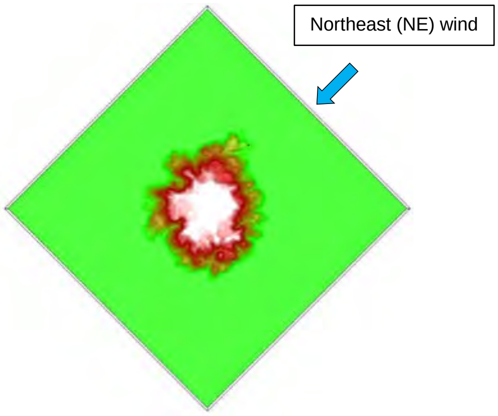
Evaluation requirements are the same as those for "d. Evaluation of Boa Vista."

Figure 7.3-67 shows the conditions for wind condition simulation.

Figure 7.3-68 to Figure 7.3-69 show the wind speed rank map and the turbulent intensity map.

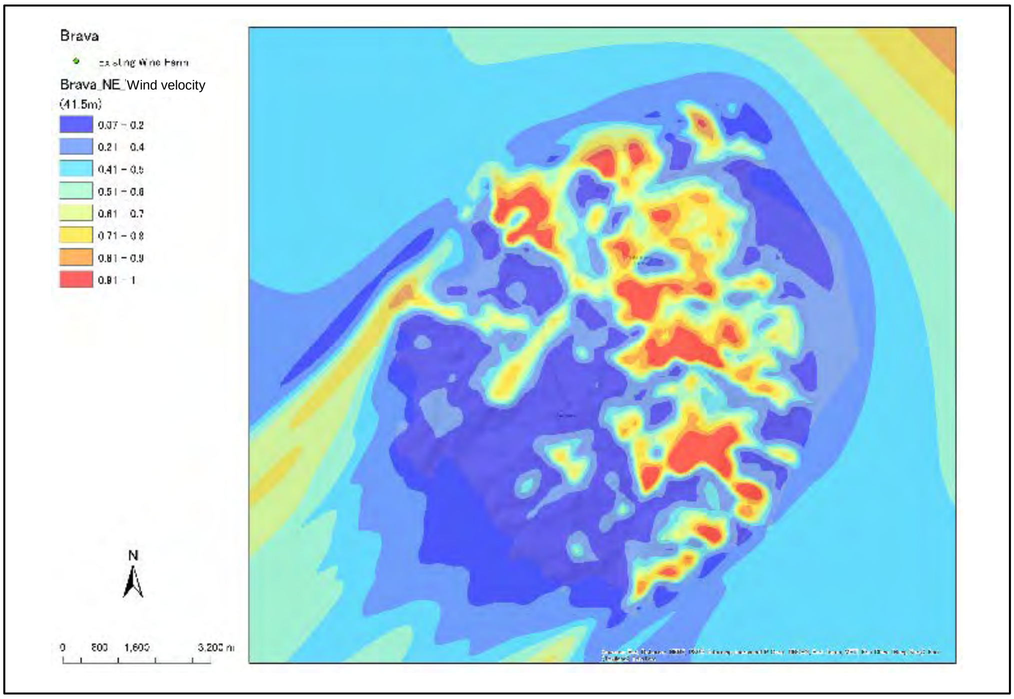
Figure 7.3-70 shows the evaluation point map.

- Wind direction: NE
- Horizontal direction area: 20 km × 20 km × 4.8 km
- Number of meshes: 201 × 201 × 51 points (Approx. 2 million points)
- Wind speed: Upper air 10m/s (1/10 power law)
- Altitude difference: 948 m



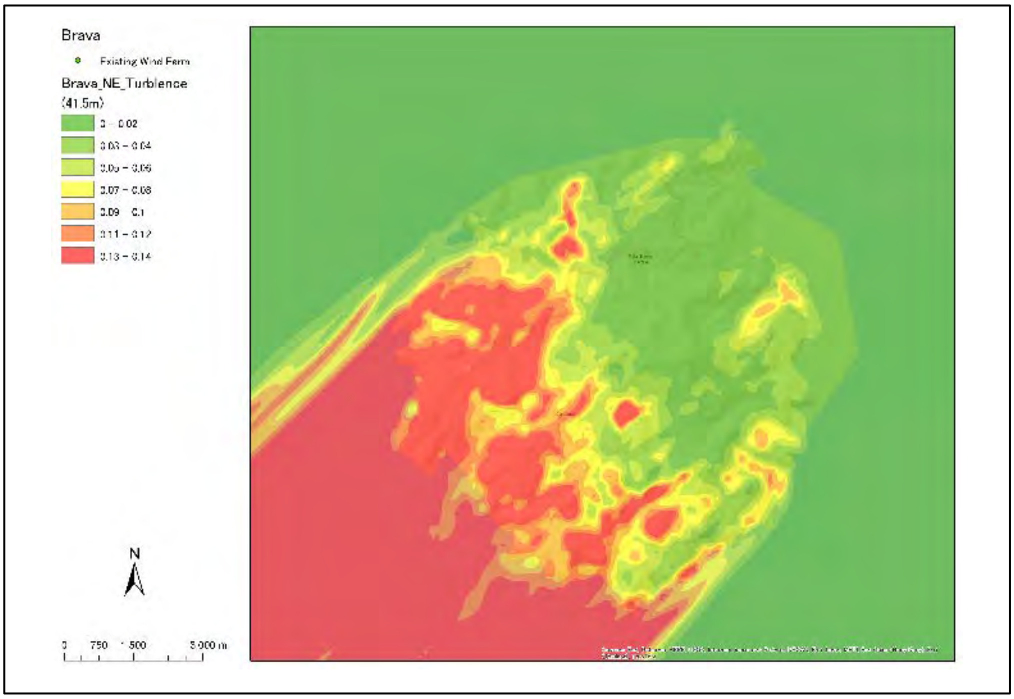
Source: JICA Study Team

Figure 7.3-67 Conditions for wind condition simulation



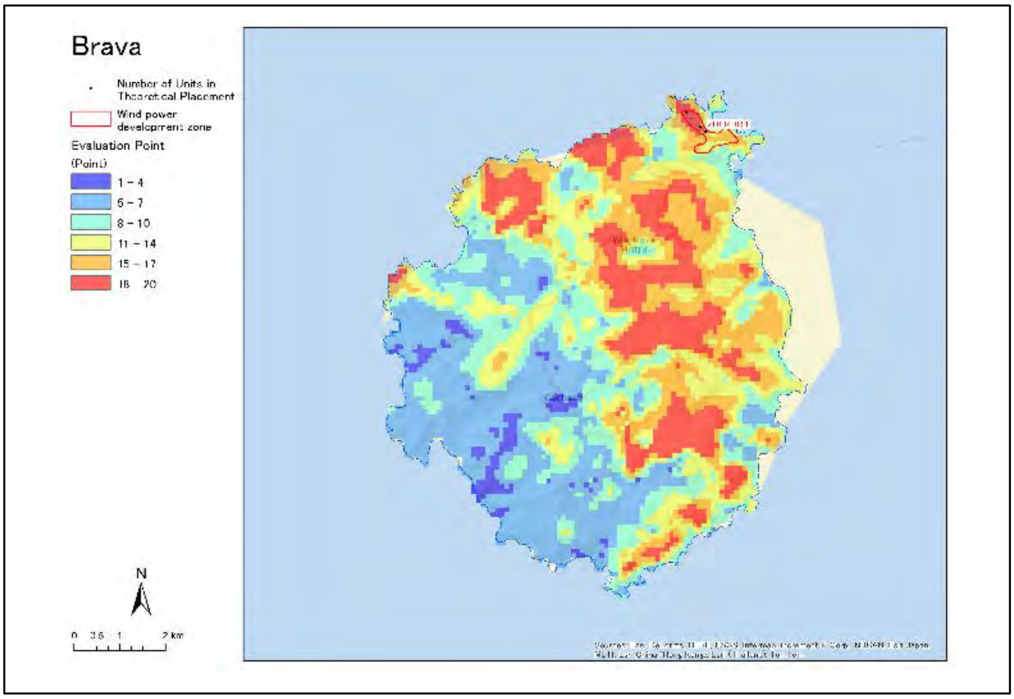
Source: JICA Study Team

Figure 7.3-68 Wind velocity rank map



Source: JICA Study Team

Figure 7.3-69 Turbulent intensity map



Source: JICA Study Team

Figure 7.3-70 Evaluation point map

(b) Evaluation result

The development zone in Brava is located where the terrain slope angle exceeds 10%. Therefore, when installing windmills in the zone, it is necessary to study and review in detail the arrangement of windmills.

6) Result of trial calculation of the expected available quantity

a. Result of trial calculation of the expected available quantity

Table 7.3-21 shows the result of trial calculation of the expected available quantity.

Table 7.3-21 Result of trial calculation of the expected available quantity

Name of island	Zone ID	STEP 1 Theoretical number of windmills	STEP 2-1 Theoretical number of windmills having slope angle of 10% or less	STEP 2-2 Number of windmills having slope angle of 10% or less and excluded from wake area of existing windmills	STEP 2-4 Number of windmills in ST.1 and SL.1 better wind conditions of location of Cabeolica's existing windmills	Single-unit capacity (kW)	Potential quantity (MW)
Santo Antão	ZDER.SA.1	17	2	2	2	850	1.7
	ZDER.SA.2	13	6	6	6		5.1
	ZDER.SA.3	31	9	9	9		7.7
São Vicente	ZDER.SV.1	15	1	1	1		0.9
	ZDER.SV.2	9	0	0	0		0.0
	ZDER.SV.3	2	0	0	0		0.0
São Nicolau	ZDER.SN.1	48	16	16	16		13.6
	ZDER.SN.2	31	11	11	11		9.4
Sal	ZDER.SL.1	351	308	273	182		154.7
Boa Vista	ZDER.BV.1	202	53	53	53		45.1
Maio	ZDER.MA.1	23	10	10	10		8.5
Santiago	ZDER.ST.1	525	263	263	118		100.3
	ZDER.ST.2	9	2	2	2		1.7
	ZDER.ST.3	8	0	0	0		0.0
Fogo	ZDER.FG.1	45	0	0	0		0.0
	ZDER.FG.2	1	0	0	0		0.0
Brava	ZDER.BR.1	7	1	1	1		0.9
Total	—	1,337	682	647	411	-	349.4

Note) [shaded]: Development zone where STEP 2-4 was implemented

Source: JICA Study Team

b. Considerations

Considerations are described below:

Table 7.3-22 shows the comparison of potential quantity based on this investigation and the data provided by DGE.

- As the development zones in Santo Antão, São Vicente, Maio, Santiago, Fogo, and Brava have large topographical relief (more than 10%), the potential quantity in this investigation was lower than the data provided by DGE. Specifically, when installing windmills in the development zones in São Vicente and Fogo, it is considered necessary to study and review in detail the arrangement of windmills.
- The potential quantity in Sal became four times the data provided by DGE. As a large-scale development of recreational facilities is scheduled near the development zone in Sal, evaluation from an environmental perspective including noise impact is considered necessary.

Table 7.3-22 Comparison of potential quantity based on this investigation and data provided by DGE

Name of island	Zone ID	Area of zone (km^2)	This investigation	Data provided by DGE
			Potential quantity (MW)	
Santo Antão	ZDER.SA.1	1.04	1.7	11.1
	ZDER.SA.2	0.64	5.1	11.1
	ZDER.SA.3	1.91	7.7	12.8
São Vicente	ZDER.SV.1	0.64	0.9	10.2
	ZDER.SV.2	0.53	0.0	7.7
	ZDER.SV.3	0.12	0.0	2.6
São Nicolau	ZDER.SN.1	3.15	13.6	14.5
	ZDER.SN.2	2.18	9.4	1.32
Sal	ZDER.SL.1	22.10	154.7	38.4
Boa Vista	ZDER.BV.1	1.36	45.1	20.4
Maio	ZDER.MA.1	1.71	8.5	14.5
Santiago	ZDER.ST.1	36.00	100.3	96.9
	ZDER.ST.2	0.52	1.7	6.8
	ZDER.ST.3	0.43	0.0	6.0
Fogo	ZDER.FG.1	2.90	0.0	17.9
	ZDER.FG.2	0.04	0.0	1.7
Brava	ZDER.BR.1	0.37	0.9	6.0
Total	—	75.64	349.60	279.92

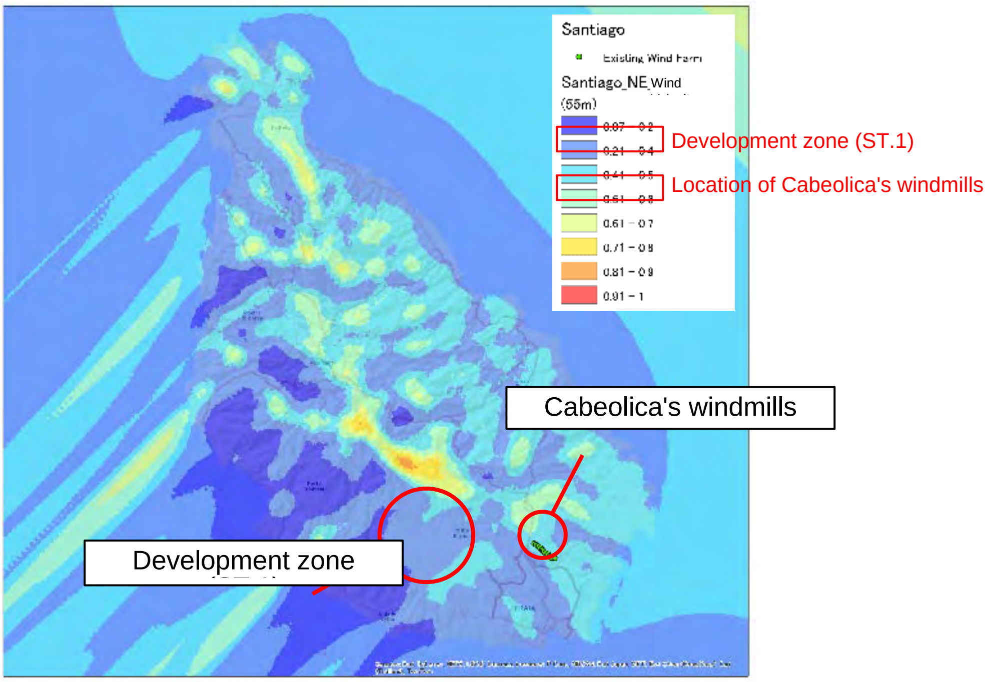
Source: JICA Study Team

7) Future issues of potential evaluation of the wind-power generation development zones

As mainstream windmills have a single-unit capacity of 2MW or more, and materials and equipment for the windmill have grown in size, confirmation of transportation conditions is important. As the windmills become larger, when building windmills, it is necessary to perform low-cost road construction and foundation construction to ensure economic efficiency. However, it was not possible to study and discuss more realistic and detailed arrangement of windmills because only data of the development zones was provided for this investigation, and GIS data concerning land features and roads could not be obtained. As the result of the simulation of northeast wind (main wind direction) in the development zone (ST.1) in Santiago, it was found that wind speed decreased due to topographical features of the mountains located on the northeast side of the development zone. There are some locations where terrain slope is steep in the specified wind-power generation development zones. Therefore, it is necessary to confirm whether road construction and site development construction are possible by using detailed topographical data. It is also necessary to simulate wind conditions and analyze the wind conditions including disturbance of wind.

In the future, when investigating the introduction of wind-power generation facilities in the wind-power generation development zones, it is important to study and discuss detailed windmill arrangement plan from the perspective of civil engineering work and wind conditions.

Figure 7.3-71 shows the speed distribution (mean field) at the height of 55 meters above ground.



Source: JICA Study Team

Figure 7.3-71 Speed distribution (mean field) at the height of 55 meters above ground

7.4 Collaboration between Diesel and Wind Power Generation

Electra (Santiago, São Vicente, Sal islands) and AEB (Boa Vista island) accept wind electricity under a long-term power selling agreement (PPA) with Cabeolica, monitors the power system status (the power demand, available diesel electricity, voltage, and frequency) and the wind firm status (the wind speed, wind direction, electricity output, and voltage), and utilizes wind electricity output forecasts.
PPA includes a purchase guarantee provision (Take or Pay) that defines the obliged purchase amounts and prices.

7.4.1 Basic Operation Rules

Electra and AEB, under PPA, can control the output and power factor of the Cabeolica wind firm from Electra power plants. Wind electricity output control and the basic operation of diesel generators are as follows.

- The electric power generation in energy-saving mode satisfies 30% of the demand forecast.
- The mega solar output forecast is deducted from the wind electricity.
- To address output decrease in energy-saving mode, diesel generators cover 50% of the energy-saving electric power generation. Specifically, use a number of diesel generators that have the reserve capacity or output margin accounting for 50% of the energy-saving power generation so that diesel generation accounts for 70% of the demand forecast.
- Currently the minimum output of diesel power generation is 50%.

The above is the basic operation but the actual energy-saving electric power generation may sometimes be around 50%.

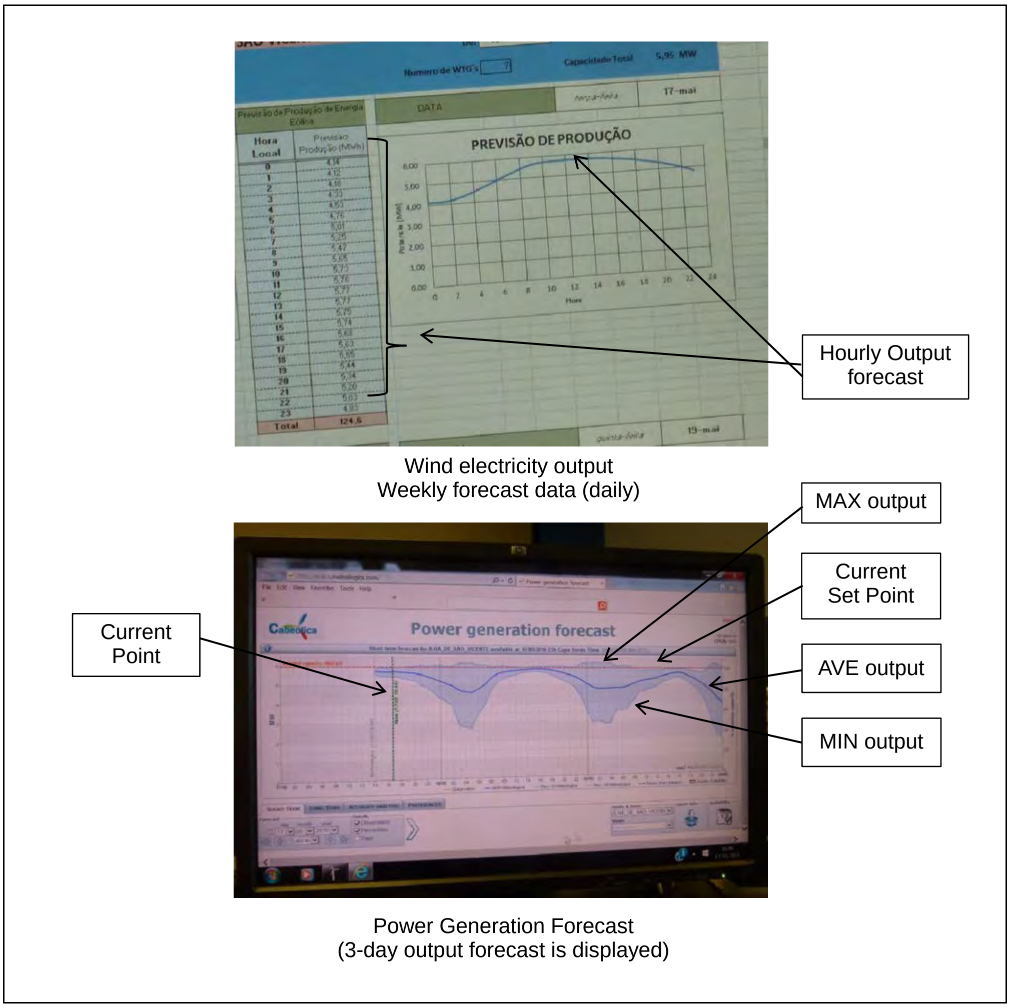
7.4.2 Operation Status

The Cabeolica wind electricity output is controlled by Electra and AEB power plant operators by setting the output upper limit (Set Point) every hour from a remote monitoring device (general-purpose computer) based on the wind electricity output forecasts provided by Vestas that is in charge of maintenance of the Cebeolica wind firm facilities.

(1) Utilizing the wind electricity output forecast system

Vestas sends the wind electricity output weekly forecast (hourly data) every week to the remote monitoring devices in Electra and AEB power plants. Electra and AEB plan weekly power generation based on this forecast. Furthermore, they check 15-day wind electricity forecast data provided by Vestas every 3 days to review their power generation plans such as the wind electricity output rate against the demand before the relevant operation day.
They also set/check every hour or change in an emergency the wind electricity output upper limit (Set Point) in view of the demand status, wind changes, and other wind electricity output forecast data.
For the wind electricity output upper limit (Set Point), the facility capacity (kW) based output, average (AVE) output, and minimum (MIN) output can be usded but they virtually use the AVE output.

Figure 7.4-1 shows the wind electricity output forecast system that is regularly updated by Vestas.



Wind electricity output
Weekly forecast data (daily)

Power Generation Forecast
(3-day output forecast is displayed)

Figure 7.4-1 Wind electricity output forecast system

(2) Operating status of the Palmaregio Power Plant (Santiago)

1) Setting status of the wind electricity output upper limit (Set Point)

Based on the results of our visiting the power plants and interviews on March 9, 2016, the operational ratio between the diesel electricity output and wind electricity output was 7:3. As described later in 10.2, the output of the Santiago wind firm facilities need not be restricted for operation. Therefore, the operation of diesel generators was said to account for 85 to 95%.

At the time of our visiting the wind firm, the wind electricity output upper limit was set to the rated output 9.35 MW but due to less wind speeds, 5.0 to 7.5 MW outputs were accepted.

The frequency variable range shown on the power plant monitoring device was 49.08 to 50.08 Hz at the time of our visit. This is within the operational target range (49.0 to 51.0 Hz) set by Electra.

Based on the load curve results by power source as of March 8, 2016, the wind electricity output exceeded 9.0 MW and accounted for one third of the power demand in some hours, indicating that wind electricity was accepted as possible for operation. The wind electricity output was not restricted in Santiago in 2015.

Figure 7.4-2 shows the load curve by power source.

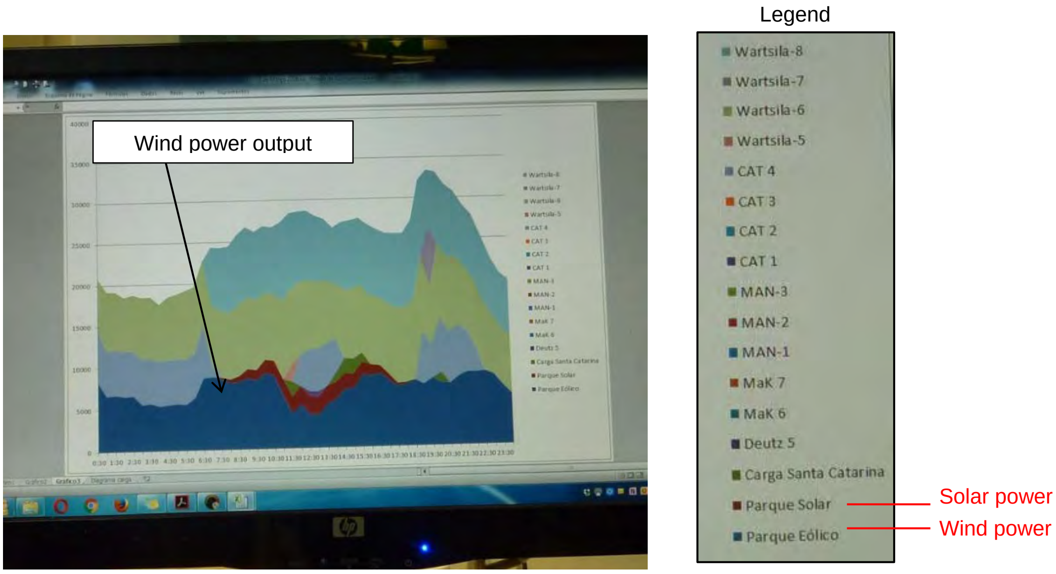


Figure 7.4-2 Load curve by power source (March 8, 2016)

2) Acceptance status of wind electricity

The Palmaregio Power Plant does not restrict the Cabeolica wind electricity output and thus all the wind electricity is accepted.

In February 2016, the HFO diesel power generation costs (variable costs) were 7.5 euro/kWh while the wind electricity selling price was 15 euro/kWh. Currently Electra accepts costly wind electricity as possible under the PPA purchase guarantee provision (Take or Pay) while fuel prices remain low.

(3) Operation status of the Lazareto Power Plant (São Vicente)

1) Setting status of the wind electricity output upper limit (Set Point)

The Lazareto Power Plant accepts wind electricity up to 50% of the demand (kW) provided that wind conditions are stable at high levels. In this case, it decreases the operational reserve diesel capacity from 50% to 40% to address the wind electricity variation (surplus) and the demand variation (shortage).

At the time of our visit, the wind electricity output upper limit was 4.5 MW (Rating: 5.95 MW).

The Lazereto Power Plant power generation plans and daily operation reports indicated that in some cases the wind electricity output ratio against demand was approximately 50% (kW base).

Also we confirmed that the operational reserve diesel capacity at the same hour was lowered to approximately 12%. We can infer from these cases that Cabo Verde has stable wind

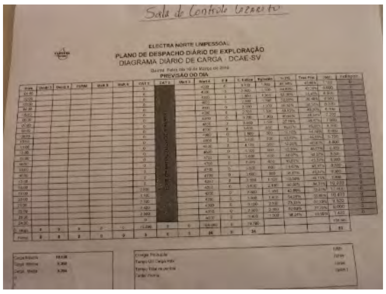
conditions and its stable wind electricity outputs are on the base power source level.
At about 4PM on March 10, 2016, we confirmed with the monitoring device that the frequency at the wind electricity feeder exit was kept around 50 Hz. The wind speed was 13 m/s and wind conditions were good. The wind electricity output was restricted to 4.5 MW and remained stable for operation.
Table 7.4-1 and Figure 7.4-3 show the operation plans and results of Lazareto Power Plant (March 10, 2016).
Figure 7.4-4 shows Lazareto Power Plant's monitoring devices (frequency, voltage, power factor).

Table 7.4-1 Operation plans and results of Lazareto Power Plant (March 10, 2016)

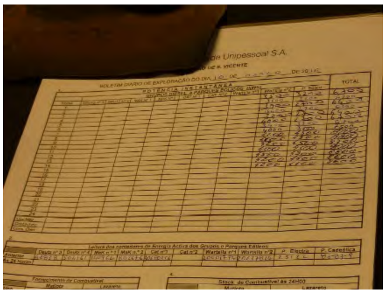
	Planned value (kW)						Performance record (kW)		
	War3	Wind power generation	Reserve	%RG	TaxaPen.	Total	War3	Wind power generation	Reserve
1	4000	3100	1300	41.94%	43.66%	7100	3500	3200	6700
2	4000	2900	1300	44.83%	42.03%	6900	3500	3200	6700
3	4000	2500	1300	52.00%	38.46%	6500	3700	2700	6400
4	4000	2500	1300	52.00%	38.46%	6500	3600	2700	6300
5	4000	2300	1300	56.52%	36.51%	6300	3700	2700	6400
6	4000	2700	1300	48.15%	40.30%	6700	4000	2700	6700
7	4000	3200	1300	40.63%	44.44%	7200	3400	3300	6700
8	4300	3600	1000	27.78%	45.57%	7900	4000	3500	7500
9	4700	3600	600	16.67%	43.37%	8300	4200	4500	8700
10	4800	3800	500	13.16%	44.19%	8600	4300	4500	8800
11	4800	3900	500	12.82%	44.83%	8700	4200	4500	8700
12	4800	4100	500	12.20%	46.07%	8900	4500	4500	9000
13	4800	4100	500	12.20%	46.07%	8900	4500	4300	8800
14	4700	3600	600	16.67%	43.37%	8300	4200	4400	8600
15	4700	3600	600	16.67%	43.37%	8300	4200	4400	8600

• War3: Rated output 5,520 (kW), available output 5,300 (kW) [War3 + reserve]
• Wind power generation: Rated output 5,950 (kW), [single unit capacity 850kW × 7 units]
• %RG: [War3 reserve output (kW)/planned output of wind power generation] × 100 (%)
• TzxaPan: [planned output of wind power generation (kW)/overall output (kW) × 100 (%)]

Source: Electra Lazaret Power Plant



Power Generation Plans



Daily Operation Reports

Figure 7.4-3 Operation plans and results of Lazareto Power Plant (March 10, 2016)

Wind electricity feeder exit
(frequency, voltage)

System power factor

Figure 7.4-4 Lazareto Power Plant's monitoring devices (frequency, voltage, power factor)

2) Acceptance status of wind electricity

Electra said its achievement rate of the purchase guarantee amount was 80% in January, 115% in February, 109% in March, and 112% in April (the achievement rate can be adjusted for 3 months). Electra would be obliged to pay an indemnity to Cebeolica under PPA if it could not achieve the wind electricity purchase guarantee amount. Therefore, it takes various measures to achieve the purchase guarantee amount while decreasing the diesel power generation costs. For example, in the first half of every month, it continues single operations of its main HFO diesel generators (Wartsila, etc) while not operating costly diesel reserve generators (LFO types), purchasing more wind electricity, and restricting the wind electricity output to secure an approximately 10% reserve capacity of wind electricity.

(4) Operating status of the Palmeira Power Plant (Sal)

1) Setting status of the wind electricity output upper limit (Set Point)

At about 2PM on March 14, 2016, the wind electricity output in Electra Palmeira Power Plant was restricted to 2 MW (rating: 7.65 MW), and 1.0 to 2.0 MW was provided by the wind firm.

2) Yearly acceptance status of wind electricity

Electra said its achievement rate of the purchase guarantee amount was 80% in January, 115% in February, 109% in March, and 112% in April (the achievement rate can be adjusted for 3 months).

(5) Operation status of AEB Chavez Power Plant (Boa Vista)

1) Setting status of the wind electricity output upper limit (Set Point)

In the morning on May 23, 2016, the wind electricity output was restricted to 1.2 MW (rating: 2.55 MW), and constant outputs of 1.2 MW were provided by the wind firm.

2) Acceptance status of wind electricity

AEB had the following to say about the wind electricity acceptance status of Boa Bista.

- PPA regarding wind power generation was made and entered into between Electra and Cabeolica, and there is no direct contract between AEB and Cabeolica.
- AEB pays Electra for wind electricity purchase and Electra makes settlement with Cabeolica. AEB has recently accepted more wind electricity than the purchase guarantee amount (Take or Pay) because it does not have enough power sources.
- In some hours, its wind electricity acceptance rate exceeded 60% (output base). Even in the light load winter period (January and February), the Set Point was around the rated value exceeding the wind condition forecasts.

7.4.3 Issues of Accepting Wind Electricity under Purchase Guarantee (Take or Pay) Type PPA

After researching in Electra power plants that accept Cabeolica wind electricity, we discuss with Electra (São Vicente) the diesel and wind collaboration and issues under the Take or Pay provision of PPA. We confirmed the provisions of the PPA in person but did not request a copy of it considering confidentiality.

(1) Contents of PPA and diesel power generation costs

1) PPA

- Cebolica wind power generators are running on 4 islands (Santiago, São Vicente, Sal, Boa Vista) but only one PPA has been made between Electra and Cabeolica.

2) Wind electricity purchase guarantee amount and achievement

- The wind electricity purchase guarantee amounts for up to 2034 are defined by PPA, and Electra has established power supply plans based on these amounts.
- If the purchase guarantee amount is not satisfied, the electricity fees for the purchase guarantee amount must be paid. Electra so far has achieved the amount and has not paid any penalty fees.
- Electra's operation aims to achieve the purchase guarantee amount within the first half of each month to avoid shortfall at month-end.

3) Wind electricity selling prices

- The price at which Cabeolica sells wind electricity to Electra is in principle fixed until 2034 under the initial PPA. The electric price calculation formula includes the base tariff to vary incrementally from opening of business. The purchase costs are adjusted up to the yearly upper limit 3.5%. Fuel cost variation is not related to this "3.5%". The "3.5%" value is a fixed yearly value irrelevant to inflation and fuel costs. This value is applied to all the 3 intervals (basic price, discount tiers 1 and 2).
- The following table shows electricity selling prices between Electra and Cabeolica.

Table 7.4-2 Electricity selling prices between Electra and Cabeolica

	Interval 1	Interval 2	Interval 3
	20 months after the COD	60 months after Interval 1	After Interval 2
Base Tariff, EURO/kWh, Santiago, São Vicente and Sal	0.12360	0.11928	0.12000
Base Tariff, EURO/kWh, Boa VIsta	0.12360	0.12300	0.12000

Source: Interview with Electra

4) Modification of the original PPA

- According to Electra, it modified the PPA with the consent of Cabeolica. For example, Sal did not achieve its purchase guarantee amount for several months in a row since the start of its operation, and Electra understood that it was clearly difficult for it to satisfy the target values defined under the contract. Therefore the target purchase amount for Sal under PPA was moved to that for Santiago.
- Electra can pay for the purchase guarantee amount on 3-month basis. If it fails to achieve the amount for the first month, it will pay a penalty fee at the end of the first month. If it fails to achieve the amount for the second month, it will pay a penalty fee at the end of

the second month. If it is to achieve the 3-month amount at the end of the third month, the differential amount will be settled. Adjustment and settlement should be made in each quarter (March, June, September, December). For example, the amount is not achieved at the end of March, there will be no settlement. This adjustment was not included in the original PPA.

- Three-month base retroactive settlement items were amended after conclusion of PPA. Yearly settlement was also discussed but currently not accepted due to the accounting bases of some Cabeolica foreign investors home countries.

5) Diesel power generation costs

Generally, using more wind electricity can reduce fuel consumption of diesel power generation, but does not necessarily reduce the costs of Electra because the diesel fuel price has been at low levels recently. Electra had this to say about the current diesel power generation costs.

- The HFO diesel variable cost is approximately 7 escudos/kWh at lowest due to the low price of crude oil. With fixed costs such as equipment costs added, the total costs are 19 to 20 escudos. Expenses and labor costs are not induced in the fixed costs.

(2) Current issues regarding accepting more wind electricity

In Cabo Verde, Cabeolica started to operate its wind firm in Santiago in October 2011 and now their wind power generation facilities with the total of 25.5 MW capacity are running properly on 4 islands (Santiago, São Vicente, Sal, Boa Vista)

The Cabeolica wind firm keeps its availability at a 95% or higher levels and contributes to energy saving thanks to good wind conditions and the availability guarantee contract with Vestas.

Meanwhile, the Electra power plants accept as much wind electricity as possible from Cabeolica based on their own judgment, not based on the basic rules regarding the wind firm output settings and the number of diesel generators, while putting priority on the electricity quality and system stability. As the background of such constant (not exceptional) operation, we investigated and confirmed that Electra and Cabeolica made and entered into the purchase guarantee type (Take or Pay) PPA.

Electra and AEB power plants always monitor their wind electricity output upper limit (Set Point) relevant to the system status. Especially in São Vicente and Sal, we confirmed that approximately 40% of electricity was restricted for system stability.

We also confirmed that Electra and Cabeolica discuss amending the PPA to achieve the purchase guarantee amount according to the operating status of each island.

Cabo Verde has put forth energy saving policies but facilitating energy saving, establishing operating procedures for stabilizing systems, and establishing appropriate profit sharing and agreements to accept further IPP partners are still big issues for the country.