SOLARGIS

INTEGRATION OF RENEWABLE ENERGIES FOR DECENTRALIZED ELECTRICITY PRODUCTION IN REGIONS OF EUROPEAN UNION AND DEVELOPING COUNTRIES

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C. Monteiro, V. Miranda

INESC - Instituto de Engenharia e Sistemas de Computadores

INTEGRATION OF RENEWABLES IN CAPE VERDE

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Acknowledgments

A report of this scope and size involves the work of many people. That is why we would like to express our gratitude towards those who made this work possible. In the first place, we would like to thank ELECTRA - Empresa Pública de Electricidade e Água, for their colaboration related with the data retrievement. We would also like to thank other institutions such as IICT AT&C, Internel and FEUP.

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1. GENERAL INFORMATION ON THE COUNTRY AND REGION

1.1 GEOGRAPHY

Cape Verde, officially known as Republic of Cape Verde (República de Cabo Verde) is an archipelago situated 600 km west of Dakar in Senegal. The archipelago occupies 63000 km^2 of ocean and 4030 km^2 of land with 965 km of coastline. It is formed by 10 islands and 7 islets, divided in two groups: the *Sotavento* group and the *Barlavento* group. The capital is the city of Praia in the island of Santiago.

The archipelago of Cap Verde is essentially of volcanic origin. The orography of the archipelago was modelled by volcanic activity and strong erosion in certain periods. Some islands, like Santiago, show a very complex orography with a very steep and rocky landscape. Some islands have a flat landscape like, for example, Sal.

The archipelago is situated in a area of arid climate, the South-Saelian, extending from the Atlantic to the Red Sea. Rainfall is scarce and highly irregular. In certain places of the archipelago, rainfall is sometimes null for the period of one year, even for several years. It may also happen that, during one day, rainfall is equivalent to several months of rainfall. Consequently, rivers have a very irregular flow, sometimes even torrential. The year is basically divided in two distinct periods: the dry season, from October to June, is also the coolest; the wet season, from July to September, is the hottest period.

The climatic characteristics derive from the conjunction of three main elements:

- The dominant northeast wind, blowing for ten months, from October to July, superimposed to the masses of air from the Canary islands. This leads to a situation of high stability in wind speed and direction.

- The Atlantic monsoon, blowing from S-SW, from the end of July to the beginning of October. This is a wet wind, bringing some rain, but is blocked by an inter-tropical barrier.

- The Harmattan, coming from Africa is a dry, hot wind, blowing sometimes in January and December. It carries dust and sand from the Sahara, contributing for lower insulation levels in the eastern part of the islands.

The archipelago has not an uniform climate. The eastern islands: Sal, Boa Vista, Maio and Santiago are the closest to Africa and have higher temperatures than the western islands. Even within each island, the climatic conditions vary, with well-defined microclimates, function of altitude and exposure. The small valleys sheltered from the Harmattan, are invaded by fog causing humidity, favorable to the development of vegetation and agriculture, while eastern slopes are clearly drier.

For 20 years, statistics have been revealing a considerable decrease in rainfall. It is possible to notice considerable differences from island to island in rainfall levels and temperatures. Even in the same island, differences are relevant, as function of the altitude.

The severe erosion problems in Cape Verde are due deforestation, in order to gain supplementary agricultural land, to fuel distilleries or even to cook. Another reason for erosion are strong winds allied to occasional torrential rainfall.

In mountain areas, vegetation depends on exposure: slopes exposed to dry winds are arid, while the ones exposed to Atlantic winds are wet and covered with vegetation and trees, sometimes even forests at a certain altitude.

The archipelago, situated in the crossing of African, European and American routes, is a transplantation land and only 1/6 of the species are native. The most common cultures are: wine, fruit trees (orange, lemon, figs, apples), sugar cane, sisal, papaya, rice, cotton, corn, manioc, tobacco, coconut, coffee, banana, and some oleaginous species. Cape Verde has just 20 km2 of irrigated land, on a total of 4030 km^2, being 9% of agricultural land, 6% grassland, and 85% is not used.

1.2 POPULATION

Total population in 1994 was estimated in 423120, half of which living in rural areas. In the last few years we have been witnessing a phenomenon of urban concentration due to drought and low quality of life in rural areas. Some data on Cape Verde:

Population growth: 3.01% (4.5% in urban areas)

Birth rate : 46.23 per 1000 inhabitants

Mortality rate: 9.04 per 1000 inhabitants

Emigration rate: 7.07 per 1000 inhabitants

Infant mortality rate: 57.7 per 1000 living births

Fertility rate: 6.32 children per woman

The official language of Cape Verde is Portuguese, spoken by half of the population. The language spoken in the whole country is Creole (Crioulo), a language based mainly on Portuguese and several African dialects.

School is obligatory for children under 15 years of age. However, children and adolescents spend most of their time in water transportation, the most important problem in Cape Verde. It is assumed that 67% of the water that falls in Cape Verde evaporates, while 20% flows on the surface and is wasted, and only 13% reaches underground levels. Of 23 millions of m^3 of water used in Cape Verde 3/4 come from underground sources and 1/4 from desalinization.

1.3 ECONOMY

Since 1989, the economy of Cape Verde is in a difficult situation. Inflation reaches 10% per year, external trade has a chronic deficit and repayment of the debt is quite problematic. Economy is oriented to the tertiary sector, where commerce, transportation and public services represent 60% of GNP. Even if 60% of the population lives in rural areas, agriculture represents only 29% of GNP. The fishing sector represents 4% of the GNP. Cape Verde is heavily dependent on imported food (around 90%). It is important to notice that imports represents 80% of GNP, while exports represent only 2%. Some economic indices:

GNP - 209 million ECU

GNP growth: 3.3%

Per Capita GNP - 819 ECU

Inflation rate: 8.9%

Unemployment rate: 35%

Exports: 4.08 million ECU

Imports: 171 million ECU

1.4 ENERGY SECTOR

The Electric Systems in Cape Verde are reduced, essentially, to the islands of S. Vicente and Santiago. ELECTRA (Public company of Electricity and water of Cape Verde) is responsible for the three main networks: the network of Praia, in the island of Santiago, supplying energy just to this city; the network of S. Vicente, supplying energy practically to the whole island; and the network of Sal, supplying energy to the whole island. The total annual energy production is around 60 GWh, composed by 30% domestic, 15% industry, 20% in desalination, 15% commerce and services, 10% power losses and 10% in public services.

The networks in Cape Verde have, until recent times, been supplied by small Diesel and heavy fuel plants. This situation was altered in 1989 in the island of S. Vicente, where 10 wind generators of 30 kW were installed, reaching an average annual energy production of 1.17 GWh. However, due to lack of maintenance, all these machines are, presently, out of service. In 1994, 3 wind farms were installed in these 3 islands with a total capacity of 2.4 MW. Presently wind energy represents 15% of total electrical energy consumption. It is in progress a feasibility study developed by RIS∅, using the model for performance assessment of WINSYS power systems for the expansion of the existing 3 wind farms, and considering the possibility of installing another 3.6 MW.

The following table presents some data concerning the 3 main networks in Cape Verde.

	Sal	**Mindelo**	**Praia**
Diesel capacity (MW)	3	11	9
Total power system load (MWh)	7	30	30
Desalinization capacity load (kW)	310	2250	3400
Diesel fuel type	gasoil	heavy fuel	gasoil
Diesel fuel consumption (t)	1500	5300	6300
Diesel fuel expenses (kECU)	340	800	1400
Nominal medium voltage grid (kV)	13.8 and 6.3	6.3	15
Installed wind Turbine Capacity (kW)	2 x 300	3 x 300	3 x 300
Interconnecting cable	3x95mm^{2}Cu	3x95mm^{2}Cu	3x95mm^{2}Cu
Interconnecting cable Voltage (kV)	13.8	20	15
Interconnecting Distance (km)	1.5	11.5	6.7
Avg. wind speed at hubheight (m/s)	7.8	11.6	8.6
Wind energy production (MWh)	1700	5000	3000
Wind turbine availability inc. grid %	93.5	92.5	99
wind turbine capacity factor %	35	68	41
wind energy penetration %	24	19	11
levelized fuel prod. costs (ECU/kWh)	0.055	0.050	0.045
level. wind prod. costs (ECU/kWh)	0.056	0.031	0.050
Wind farm expansion (kW)	600	1200	1800

Table 0.1 Electrical characteristics of Cape Verde.

The consumer energy prices has uniform values for all systems explored by ELECTRA, and approximately 0.15 ECU/kWh. Urban load growth is approximately 4% per year, with a forecast of 5% for the next decade. Two load forecast studies have been performed for two different scenarios (excluding desalination):

	High Scenario(MWh)			**Low Scenario(MWh)**		
Year	**Sal**	**Mindelo**	**Praia**	**Sal**	**Mindelo**	**Praia**
1995	6904	24757	31557	5283	24107	29758
2000	9998	32763	44992	6537	29593	38612
2005	13376	42313	63568	8542	36905	52660
2010	19454	55149	93303	12499	47588	77612

Table 0.2 Load forecast for the main islands in Cape Verde.

When planning the production system of Cape Verde, renewable forms of energy are viewed through two different perspectives. On one hand, ELECTRA intends to maximize wind power penetration in order to delay the construction of conventional power plants, for which there are no financial means. On the other hand, ELECTRA intends to move forward with a comprehensive electrification process, on the whole island of Santiago, based on small isolated systems. It is important to notice that, in countries like Cape Verde, the electrification process is extremely slow due to low and disperse consumption. This makes this process almost unfeasible, especially in the first years. Presently, there is no regulation or legislation for connecting independent producers to the network. However, there are some cases of independent producers connected to the network without any type of frequency regulation. This is the case of some hotels, that at the same time, are responsible for the maintenance of the systems.

Besides ELECTRA's networks, there are in Cape Verde some other smaller networks maintained by municipalities. In spite of the effort of these municipalities to supply energy to their inhabitants, it is possible to notice that load levels are not reaching forecasted values, which leads the municipalities to invest only in the center of the most important villages. Even in these places, levels of consumption are extremely weak, which leads the operators only to supply energy on peak hours. For these type of systems there is no uniformization of energy prices.

In Cape Verde there has been a set of initiatives in the area of renewable sources of energy, in order to increase the use of these type of energy, one of the most important resources of the country.

Cape Verde is a member of CILSS, CDEAO ,CRES and CRAT, all African organizations that approach serious water and energy problems. Cape Verde, one of the countries with the best wind and solar resources, has always been sensible to the use of renewable forms of energy. In this manner, it is not surprising the ambition of Cape Verde of becoming a development center and showcase of renewable energy technologies for West Africa.

Some political changes in 1991 lead to the disappearing of the institutional structure responsible for a large part of the initiatives promoted during the 80s. To fill this institutional void, the government is building the National Institute of Energy with the purpose of developing support programs for the use of renewable forms of energy. The people in charge of this project alerted to the need of economic, technologic and informative support in order to build a structure able to develop, stimulate and assess several initiatives regarding the integration of renewable energy.

The renewable forms of energy used are: biomass, biogas, wind power, and solar power. Geothermal resources have not been used so far, due to the need of localization of eventual sources and assessment of their potential.

In order to minimize the use of fossil fuel and considering the fundamental role of renewable energy as an alternative and solution for the enormous energy problems of Cape Verde, there has been some applied experiences in energy production, water pumping and desalination.

1.4.1 WIND ENERGY

Hybrid W/D systems, due to the isolated characteristics of certain load agglomerates (especially in the island of Santiago), may have a special place in the electrification of small villages, presently supplied by Diesel systems. Some examples of these applications are present in three villages of Santiago: Santa Catarina, Assomada and Tarrafal. However, due to the complexity of these systems and the absence of capable technical support for maintenance, the vast majority of these systems are out of service or being remodeled for connection to small existing networks.

One of the most important application of wind power in Cape Verde is water pumping. High costs of operating pumps based on conventional fuel lead to the dissemination of pumping systems based on wind power. One curious aspect of these type of systems is the need to extend a cable from the wind turbine to the pumping station because, in general, the wells are situated in places of little wind.

In several villages there is no potable water to be pumped and in some islands the water available is not enough to satisfy the needs of the population. Furthermore, the costs of water transportation are too high for both municipalities and population. So, wind power systems have been used to feed desalination systems based on electrodialysis and inverse osmosis, in spite of the relative unsuccessfulness of this last method in Cape Verde.

1.4.2 SOLAR ENERGY

The use of solar panels is limited to some private uses, mainly in lighting. This fact is not related to the lack of solar resources, for Cape Verde has average insulation around 5 kWh m^{-2} day^{-1}. The main problem comes from the non-existence of commercial support that makes these systems economically attractive. The government, in cooperation with the University of Massachusetts, has presently a plan for the electrification of 5000 isolated houses. One interesting aspect is the replacement of wind powered pumping systems, used in irrigation and reaching the end of their useful life, by photovoltaic systems. This is necessary due to the negative consequences of low wind periods on cultures.

1.4.3 CONSTRAINTS

From a global view on the situation of renewable forms of energy in Cape Verde we may see that this country has experimented several attempts to integrate RE in the last 20 year. However, different types of problems lead to worst than expected results in some of these projects. We may refer some primordial problems:

- lack of specialized technicians for project planning
- lack of commercial support, able to supply equipment at reasonable prices and assure its maintenance.
- shortage of financial resources to support existing experimental projects.
- developing technologies with several technical problems and little resources to solve them.
- ambitious projects, with obscure or incorrectly defined objectives and not often adapted to the reality of Cape Verde.
- bad project management: lack of coordination among the participators in the project and lack of funds for maintenance of equipment after project conclusion.

1.4.4 FUTURE PERSPECTIVES

In spite of Cape Verde being one of the countries in the world with a largest wind power penetration, one must notice that the value of renewable energy used is still very low. Renewable forms of energy appear as the solution, directly or through external factors, for the needs and problems of the country: electricity, water, deforestation, child labor, urban concentration, etc. Considering the dispersion and isolation of the population, the low levels of energy consumption and the need for rural electrification, a strong effort must be made in order not to waste another opportunity for renewable forms of energy. In Cape Verde, renewable energy does not only represent ecological or marginal benefits - it is the most appropriate solution, and this is what we intend to prove with the SOLARGIS project.

1.5 STUDIED REGION

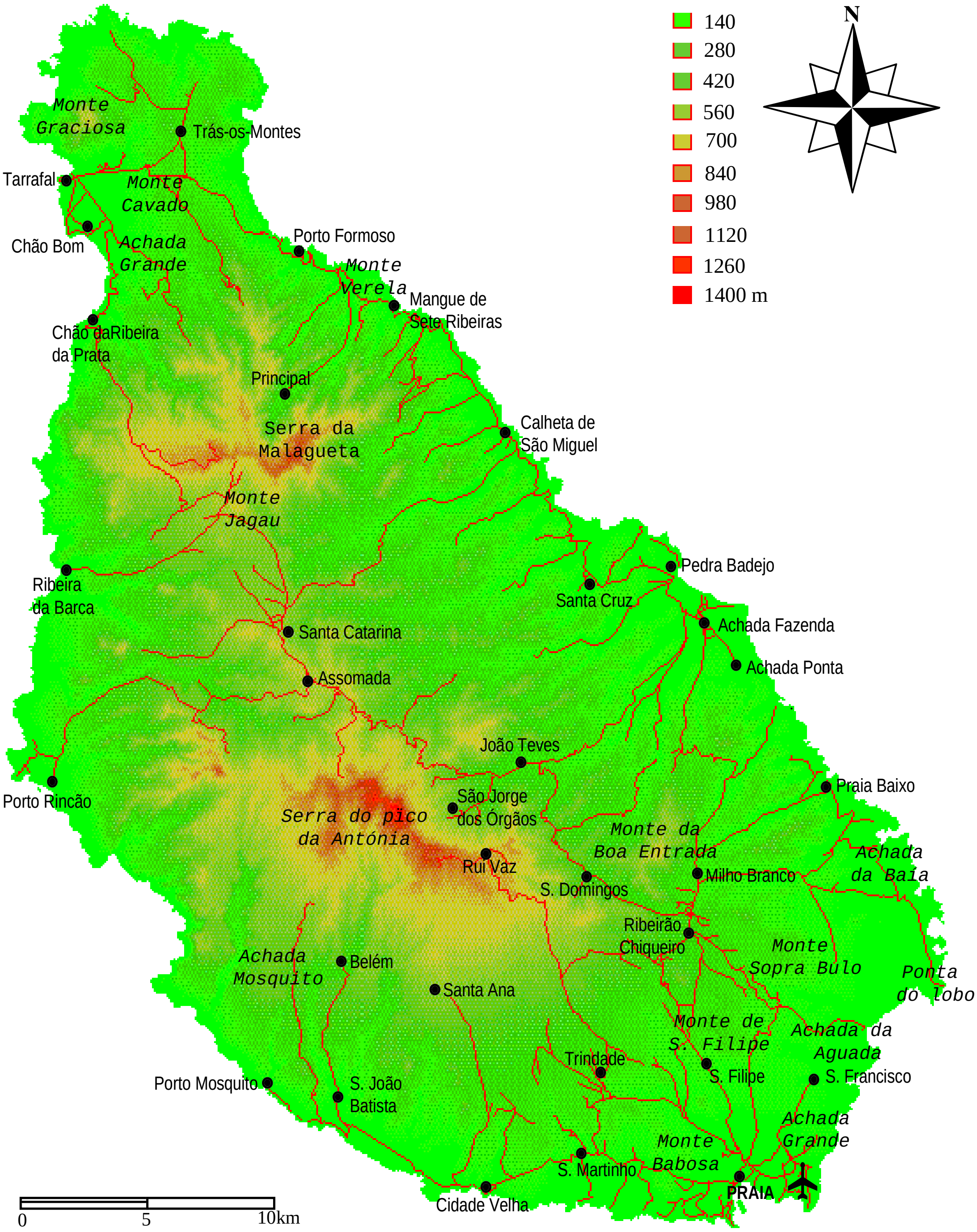


Table 0.3 Studied region (Santiago)

In the beginning of SOLARGIS, it was our intention to apply the developed methodologies to the islands of Santiago, S. Vicente and Sal. However, unexpected difficulties in obtaining data lead to the necessity of concentrating all our efforts in the island of Santiago.

The island of Santiago was the region chosen for the application of the methodologies developed in the project SOLARGIS. We have chosen this island for several reasons: it is the largest and most populated island in the archipelago; more than 50% of the population lives in rural isolated areas, without electric energy; it is an island with a very complex orography, which makes it very heterogeneous in terms of solar and wind resources; there are a large number of small isolated networks; the electrification process is still in the first stages; the population is dispersed along the whole island which allow us to take advantage of GIS; the essential geographical data for the calculation was gathered on schedule. We also believe that the results of the project might prove to be very advantageous for the development of the island.

The island of Santiago with its 991 km^2 is the largest island in the archipelago. The maximum height of the island is 55 km and the width 29 km. The island is essentially mountainous. From north to south, parallel to the coastline there are several mountain ranges. The highest point is *Pico da Antónia* (1392 m), but several other peaks reach 1000m: *Serra da Malagueta* - 1063m. The coastline is sharp and characterized by cliffs in the west coast. The east coast is considerably smoother. Like the other islands in the archipelago, Santiago has volcanic origin, but the volcanic elements were severely eroded, opening valleys and deep canyons.

In spite of being relatively small, the island of Santiago has not an uniform climate. Being orientated, longitudinally, SO - NE, it presents a favorable exposure to NE winds that, in high places, bring a certain humidity. For that reason it is noticeable that the eastern part of the island is more humid. This part of the island is also affected by the harmattan that brings dust and sand from the Sahara desert. The S-SE flank (meridional) of the island is drier due to lower altitudes. The N-NW flank has lower average altitude but is more humid than the S-SE flank due to its exposure to NE winds. The W-SW flank benefits from its complex orography, conditioning the existence of microclimates in small valleys protected by the central mountain ranges.

Santiago is the most populated island in the archipelago with its 175000 inhabitants, including 60000 in the capital, Praia. Agriculture takes an important place: the cultivated land in Santiago represents half of all agricultural land in Cape Verde. Fishing employs around 2000 people and concentrates in the fishing harbors of Praia, Pedra Badejo and Tarrafal.

Administratively, Santiago is divided in four municipalities: Praia, Santa Catarina, Santa Cruz e Tarrafal.

1.5.1 ENERGY SECTOR

Of 175000 inhabitants in Santiago, only 75000 have electrical supply. ELECTRA is in charge of the operation of the network of Praia, supplying 55000 consumers. Apart from this network, there are around 8 other small isolated networks, operated by municipalities.

The power plant in Praia is constituted by 4 groups with the following nominal capacities: 1560 kW, 2514 kW and 2x2650 kW. These groups operate directly over a 15 kV busbar and are prepared to work on Gasoil or heavy fuel, but presently are operating on Gasoil. Internal fuel prices are settled by the government of Cape Verde.

From 1985 until recent days, in Ponta d'Água (Praia), there were two 55kW wind turbines in operation, with an average annual energy production of 187 MWh. In 1994, three 300 kW wind turbines started operation. These generators are located in *Monte de S. Filipe*. This project is part of the first phase of a plan to integrate wind power in the electric networks of Cape Verde. The second phase of this plan includes the integration of another six 300 kW wind turbines. It has not been possible the installation of turbines with higher nominal power due to lack of conditions for the installation of the towers. Studies performed by the Ris∅ National Laboratory, considering the internal return rate, the annual production costs and the control systems presently used, show that it is not advisable to have a wind farm with an installed capacity higher than 3MW. Presently, the penetration of wind power in the network of Praia is around 11%. The objective is to reach 25% with the second phase generators in operation. The wind farm is connected to the network through an underground, 6.7 km 3X95 mm^2 Cu cable. The first phase resulted on a decrease on the power factor in the power plant, increase in frequency excursions, and voltage fluctuations of over 2%.

Scattered throughout the island there are some small isolated networks, managed by the municipal governments and whose characteristics are a product of the solutions and opportunities found to satisfy the basic needs of the municipalities. We will describe some of these networks:

- In *S. Domingos* we find a degraded 3 km long LV network supplying around 200 consumers. There are two 50 kVA generators supplying energy from 18:00 until 24:00.
- In *S. Jorge* there are two 80 kVA and one 150 kVA generator supplying energy to some domestic consumers, one hotel and one pumping system. The network is composed by one LV output and two MV (10 kV) outputs.
- In *Pedra Badejo* there are two 82 kVA and one 60 kVA generators supplying in LV 160 consumers during peak hours. Around 4 km from Pedra Badejo, there are three 155 kVA generators and two biogas 50 kVA generators supplying a 3 km, 20 kV, MV network.
- In *Assomada* there are 800 consumers supplied by a W/D system composed by one 250 kVA and one 125 kVA generator, associated to a 40 kVA wind generator. These consumers are supplied through a 5 km LV network, considerably degraded.

- In *Ribeira da Barca*, a fishermen village, there is a LV network extending to the whole village. However due to the bad conditions of the existing network no power is supplied to village homes and, only 2 industrial freezers are supplied by the plant.
- In *S. Catarina*, there is a W/D system, composed by a 52 kVA Diesel generator and a 55 kVA wind generator, feeding a battery system through a AC-DC-AC system. The system is connected to a network supplied by existing Diesel generators. Its maintenance has been problematic due to insufficient technical support.
- In *Tarrafal* there is a W/D system with two Diesel generators (175 and 90 kVA) and one wind turbine of 55 kVA. The system supplies around 400 consumers and one pumping system through one LV output and two MV outputs. Also here, there are maintenance problems related to lack of technical support.
- There has been a project to supply the *Cidade Velha* with a PV system, but it was abandoned due to aesthetic considerations.

Besides these applications, there are several others, smaller, that supply isolated pumping systems, desalination plants and domestic consumption.

Table 1.4 shows some results relating to load forecast for the next 15 years in the main villages in the island of Santiago.

	High Scenario(MWh)				**Low Scenario(MWh)**			
Year	**Praia**	**Santa Cruz**	**Santa Catarina**	**Tarrafal**	**Praia**	**Santa Cruz**	**Santa Catarina**	**Tarrafal**
1995	27538	662	1472	843	27538	662	1472	843
2000	41995	1167	2777	1343	36295	1020	2456	1190
2005	59173	1636	4040	1845	49446	1467	3349	1672
2010	86448	2214	5057	2420	72462	2024	4324	2228

Table 0.4 Load forecast for Santiago

2. SOLARGIS ANALYSIS

2.1 INTRODUCTION

We present here the results of the Solargis methodology applied at a full regional scale on Cape Verde region. The Solargis analysis is intended to help decision makers for the integration of renewable energy systems in decentralized electricity production. All the technical and economical parameters can be changed in order to define a scenario. The power of the GIS is then used to compute regional statistics on the results. Running different scenarios is very useful to test the robustness of a decision.

Two separate integration schemes are considered:

1. Rural electrification with stand alone or hybrid systems. Small photovoltaic or wind turbine stand alone systems represent a good solution for providing lighting, radio and TV electricity to isolated houses. With a larger power, hybrid wind diesel generators might be used to pre-electrify villages which are not yet connected to the main grid.
1. Grid connected Wind and PV farms.

For each study, a code has been developed on Arc-Info. The next chapter describes the input data used in these codes: solar, wind, population.

2.2 DATA SOURCES

2.2.1 SOLAR MAP

The mean global irradiation in on horizontal plane is calculated in ten meteorological stations using measured monthly mean global horizontal irradiation data. A value is then interpolated in each pixel.

To compute global irradiation in horizontal plane, we assume that:

1. the choice of the panel angle is equal to the mean latitude of the region (15°)
1. the albedo has a fixed value of 0.2
1. the panel is south oriented.

As it is noticeable in Fig. 2.1 the N-NE side has lower global radiation values due to NE winds. We may also observe the effects of the shades near some water lines and in mountain areas, namely in *Serra da Malagueta* and *Serra do Pico da Antónia*.

The island has several small valleys with characteristic micro-climates. However, the interpolation modules developed are only able to detect these micro-climates if the density of meteorological stations is sufficient to cover these small areas. This way, we can only detect shades and some climatic differences between the N-NE and S-SW sides.

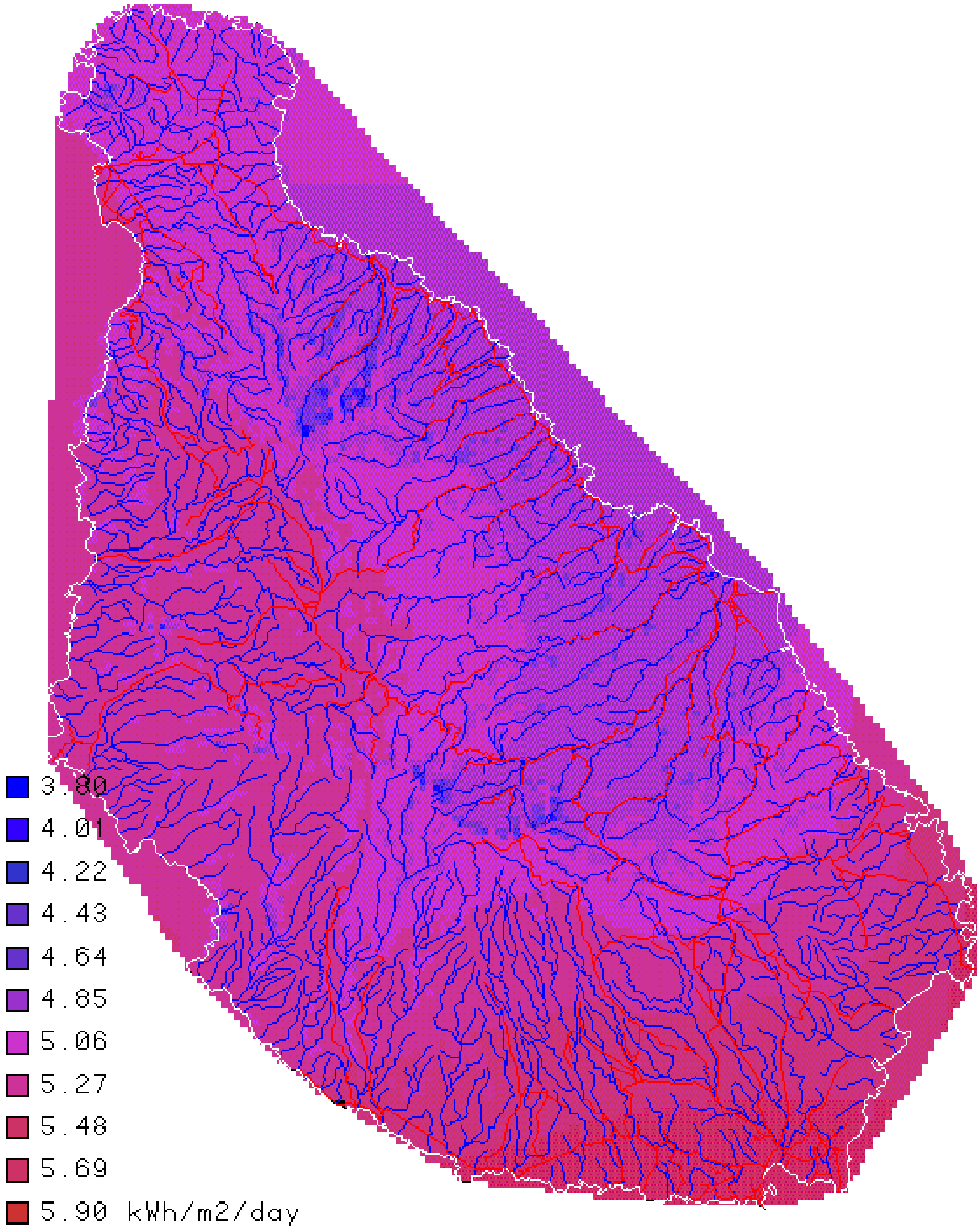


Figure 2.1 Global radiation grid, water lines (blue), roads (red).

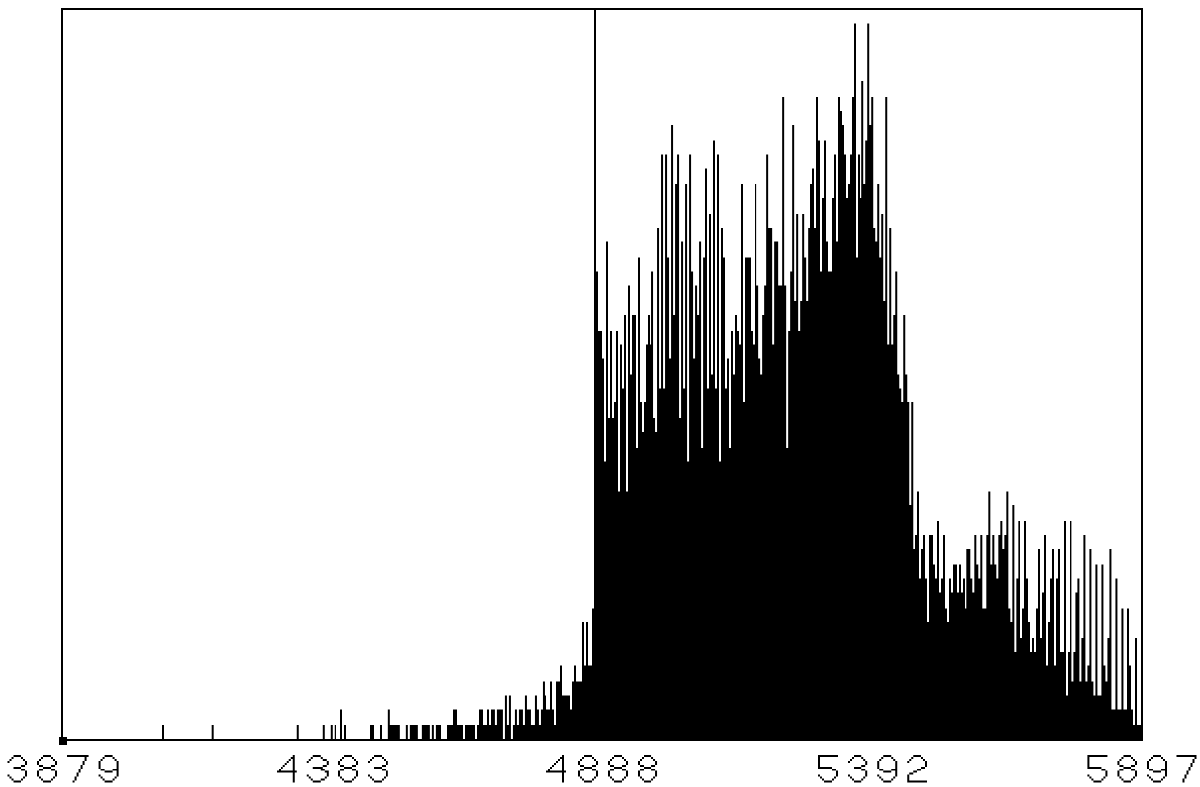


Figure 2.2 Annual global radiation grid histogram (Wh/m^2/day)

Figure 2.2 shows that the most common radiation values range between 4900 and 5500 Wh/m^2/day. In this histogram we may observe the efficiency of the interpolation method, for we may detect places with low global radiation values due to shading effects.

2.2.2 WIND MAP

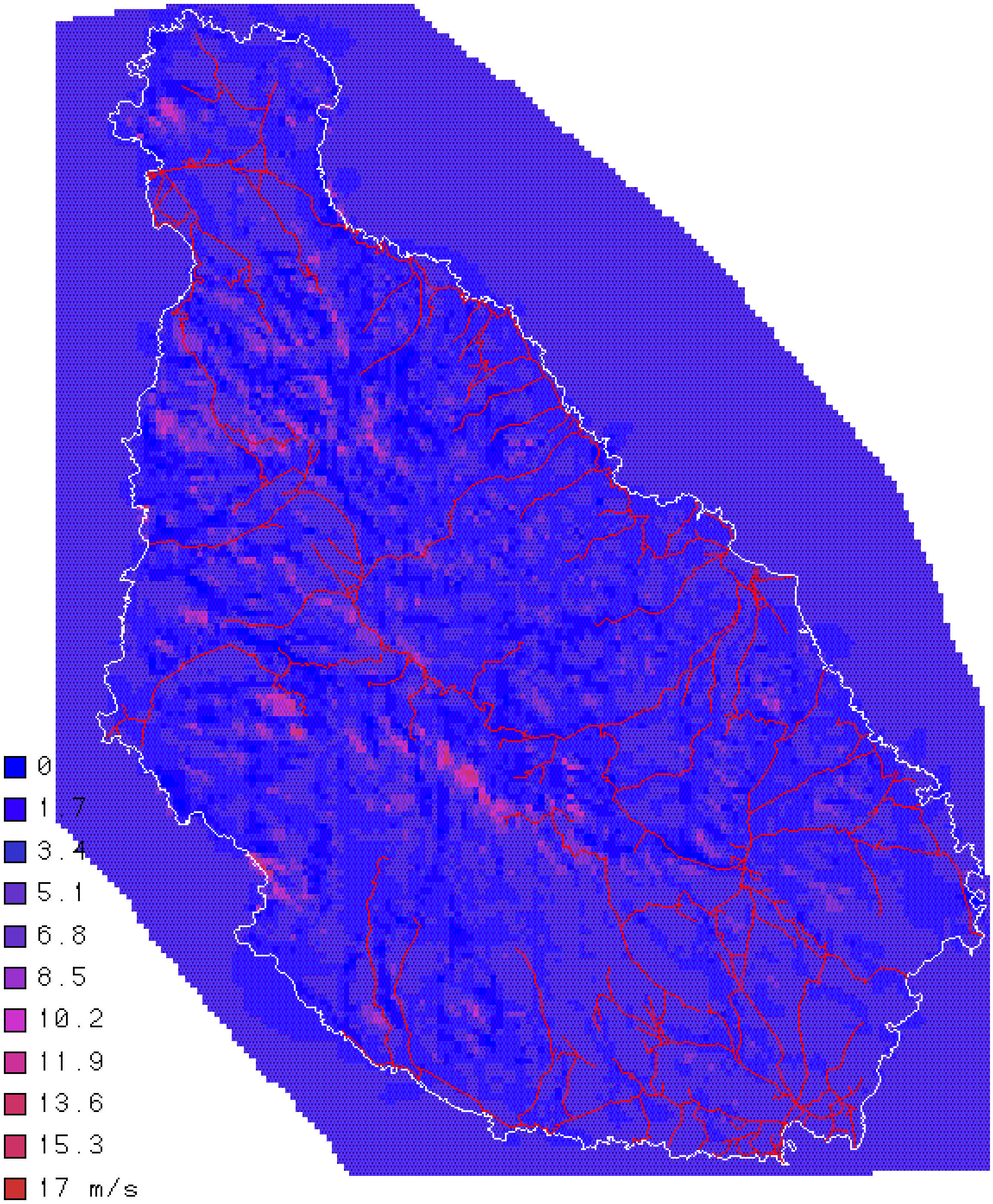


Figure 2.3 Wind grid, roads (red)

The wind grid was calculated with the aid of *WASP* software. For this purpose we used data gathered during the last 30 years in Praia meteorological station. The measurements relate to monthly frequencies, with 3 daily measurements, and average wind speed distributed by 8 different directional sectors, being 90% of the measurements registered on NE direction. The results have been confirmed with measurements of the last six months in *S. Filipe* wind farm, 7 km from the city of Praia. For a height of 30 m, the following parameters for the Weibull distribution were registered: A= 9.5 m/s, k=3.3.

For wind grid calculation we used a land digital model with a 50 m resolution. We also used a obstacle map composed by the existing buildings around the station. The wind grid was calculated with a 250 m resolution for an height of 10 m and class 2 rugosity (z_0 = 0.0001 for sea; z_0 = 0.05 on the ground).

We may observe high wind speed in mountain peaks, in some central plateaus as well as in some zones exposed to predominant NE winds. These zones may reach an annual average wind speed of about 14 m/s. Due to complex orography, average wind speed varies considerably from place to place. Although *WASP* software is not the most adequated for mountain regions, we concluded that the results coincide with measurements performed in some points and also with qualitative descriptions made by people with some experience in local wind observation.

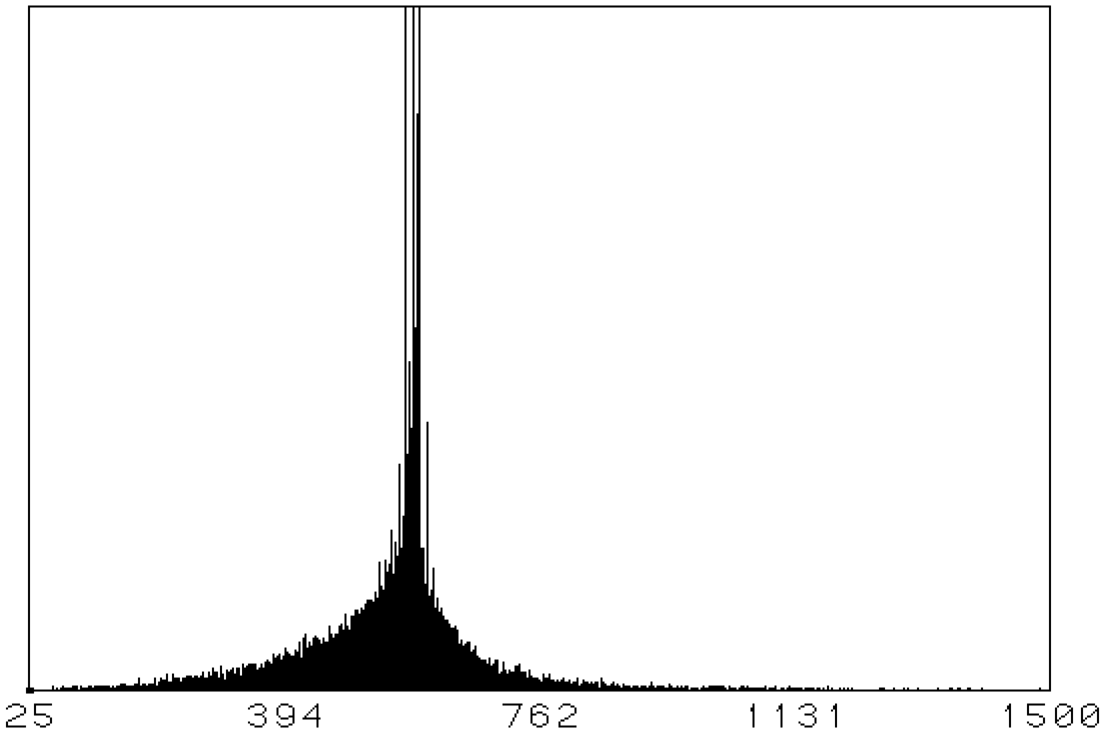


Figure 2.4 Wind speed grid histogram (m/s) (x100)

Wind speed values range from 2.5 to 15 m/s. However, Figure 2.4 shows that the most common value for the island is around 6 m/s. Another curious factor relates to the asymmetry that we may notice in the histogram, with a higher frequency of values under 6 m/s than above.

2.2.3 ELECTRIC GRID AND POPULATION

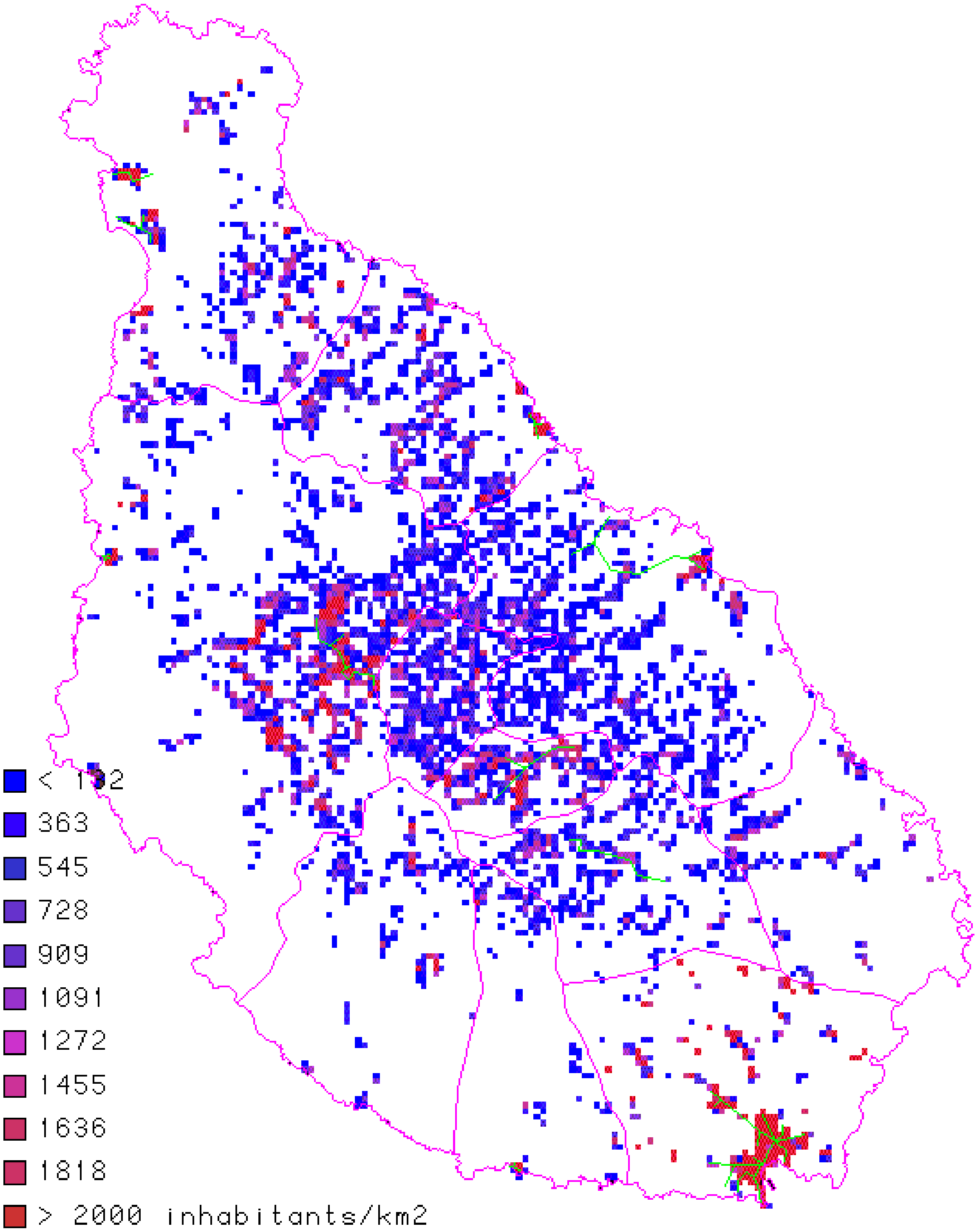


Figure 2.5 Population Grid , administrative boundaries (pink), electric grid (green**)**

Network layout is based on information from the local utility. The information represented on the map is not very precise, being useful only for the localization of the electrified area.

As it was referred in 1.5.1, in Santiago there is a main network explored by ELECTRA, feeding the city of Praia. The power station in Praia is constituted by four groups with rated power of 1560, 2514 and 2X2650 kW. These groups operate over a single 15 kV busbar.

Besides this network, there are some smaller networks explored by municipalities as described in the previous chapter.

The localization of the potential electrical demand proceeds in two steps:

1. Localize the potential consumers
1. Quantify their need for electricity

The data available about population respect only to each administrative region.

From the digitalization of 1:25000 maps we were able to detect houses and to build the associated database. After, we estimated population density, by distributing the population in each region according to house size and density.

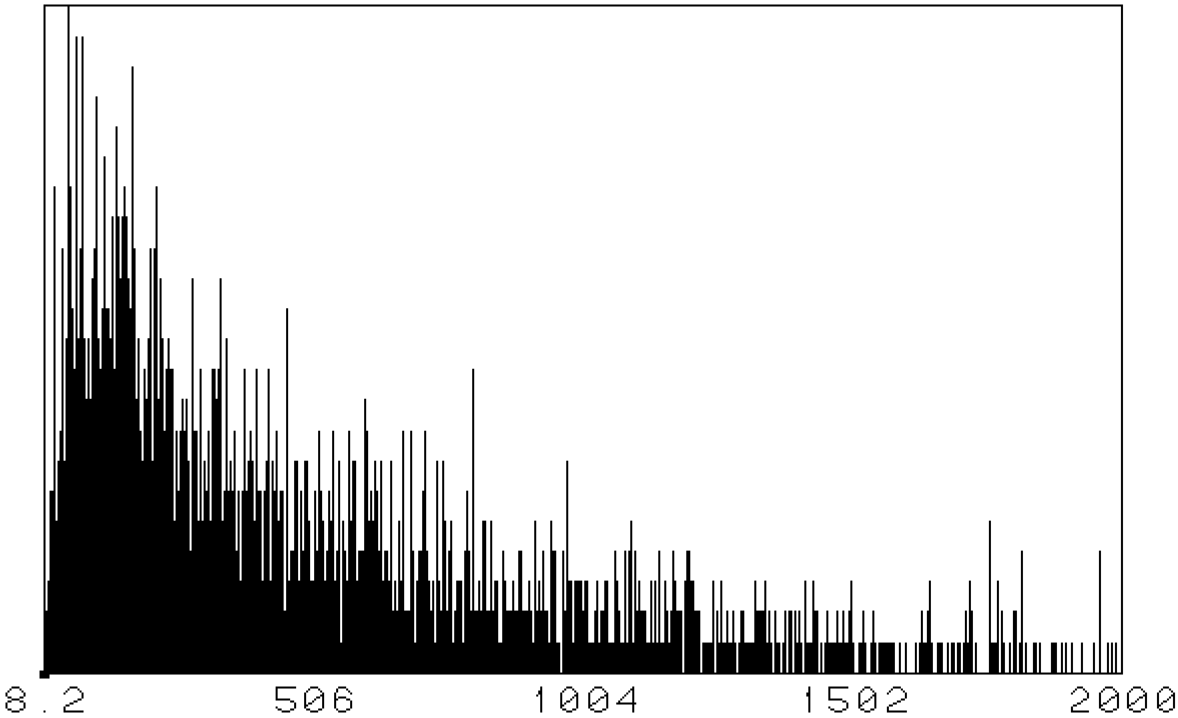


Figure 2.6 Population grid histogram (inhabitants/km^2)

The histogram shows that, in most inhabited areas, the density is rather low, around 100 inhabitants per km^2. In the smallest villages, density reaches values of around 1500 inhabitants/km^2. The resolution for population grid is 250 m, delimiting in a precise manner the inhabited areas. The lowest values in the histogram represent pixels (250X250) with only one or two isolated houses.

2.3 REGIONAL POTENTIAL FOR RENEWABLE TECHNOLOGIES

2.3.1 GRID CONNECTED SYSTEMS

2.3.1.1 Wind power plants

The methodologies applied in this regional study are described on the project hand book. For this study we have considered the characteristics shown in the following table. The methodology automatically calculates the number of cables to be installed function of voltage drop limits and electrical characteristics.

Resistance	0.627 Ohm/km
Reactance	0.381 Ohm/km
cosphi	1
Drop Voltage Limit	5 %
Electric Line annual costs	1500 ECU/km
Connection annual costs	3660 ECU
Road cost	40000 ECU/km
Generator+Internals cost	135000 ECU/MW (1996) 90450 ECU/MW (2010)
Discount rate	8 %

Table 2.1 Input data for grid connected analysis

In this analysis we only considered the scenarios for 1996 and 2010. The scenario for 2010 differs only in the costs for the generators, considered to be 30% lower.

Scenario	**Description**
Scenario 1	1 MW per km^2 in 1996
Scenario 2	4 MW per km^2 in 1996
Scenario 3	1 MW per km^2 in 2010
Scenario 4	4 MW per km2 in 2010

Table 2.2 Scenarios

In order to facilitate the observation of the maps, we considered and mapped the places with a LEC (Levelized Electric Cost) lower than 0.2 ECU/kWh, which is the maximum value to be considered in the legend of the maps.

For the calculations we assumed the following:

- The resolution is equal to 1 km^2 per grid element.
- wind speed for each pixel is the average speed of the respective 16 250X250m grid elements.
- We have excluded grid elements corresponding to inhabited areas.
- We have excluded grid elements corresponding to the airport.
- We have excluded grid elements corresponding to inclinations over 10%.

2.3.1.1.1 *Wind power plants LEC maps*

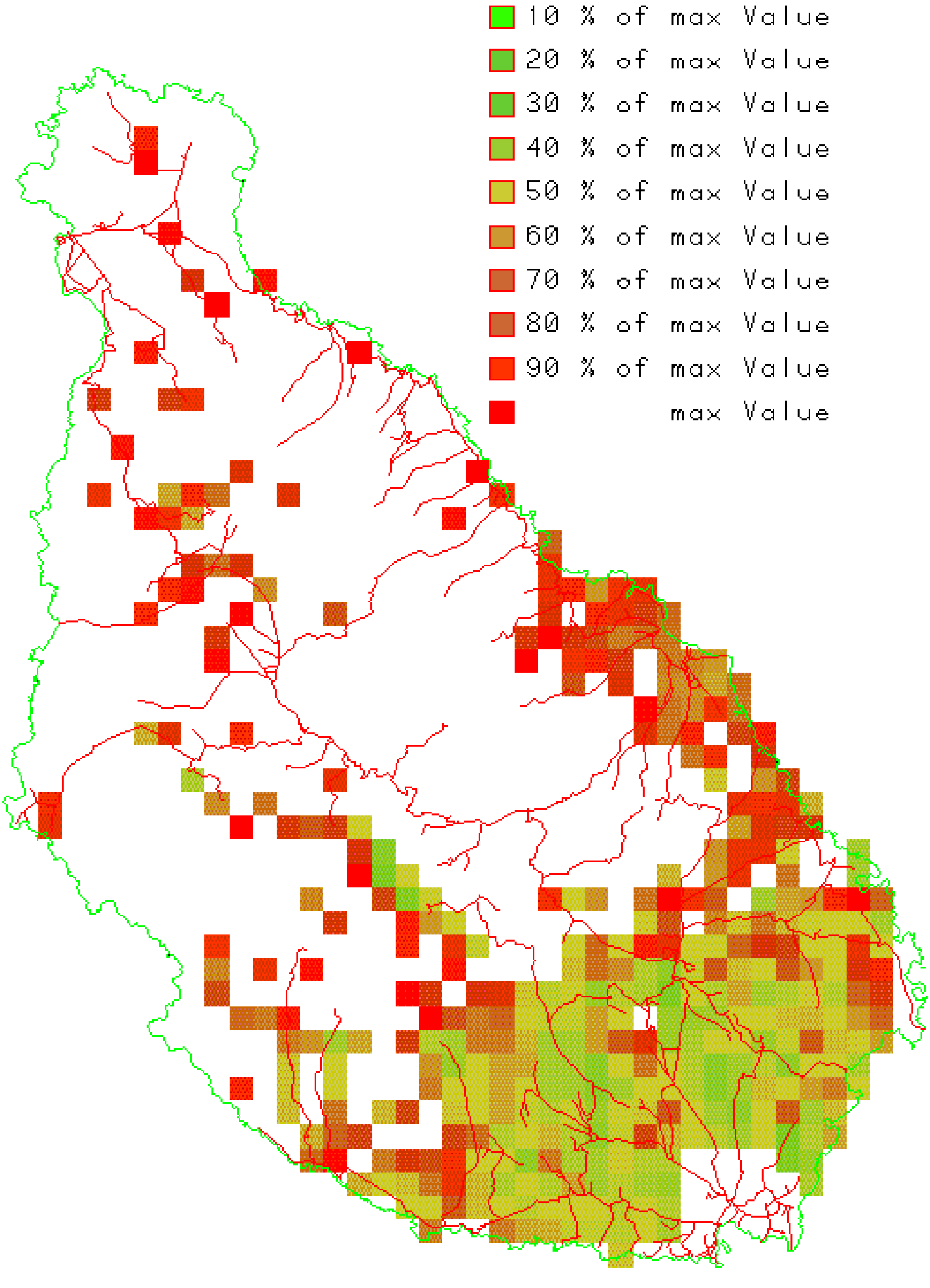


Figure 2.7 LEC map for Scenario 1 - 1 MW per km^2 in 1996

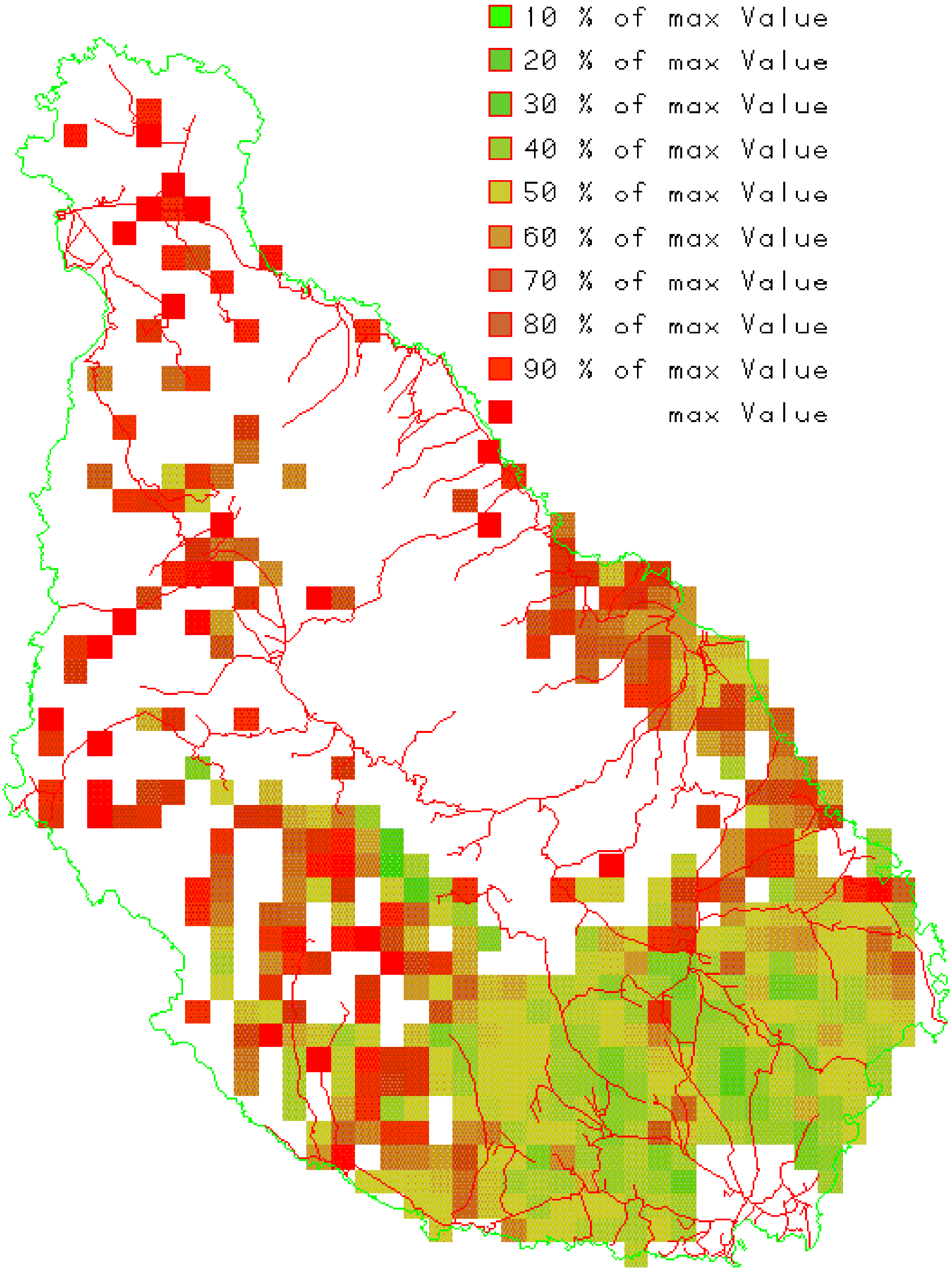


Figure 2.8 LEC map for Scenario 2 - 4 MW per km^2 in 1996

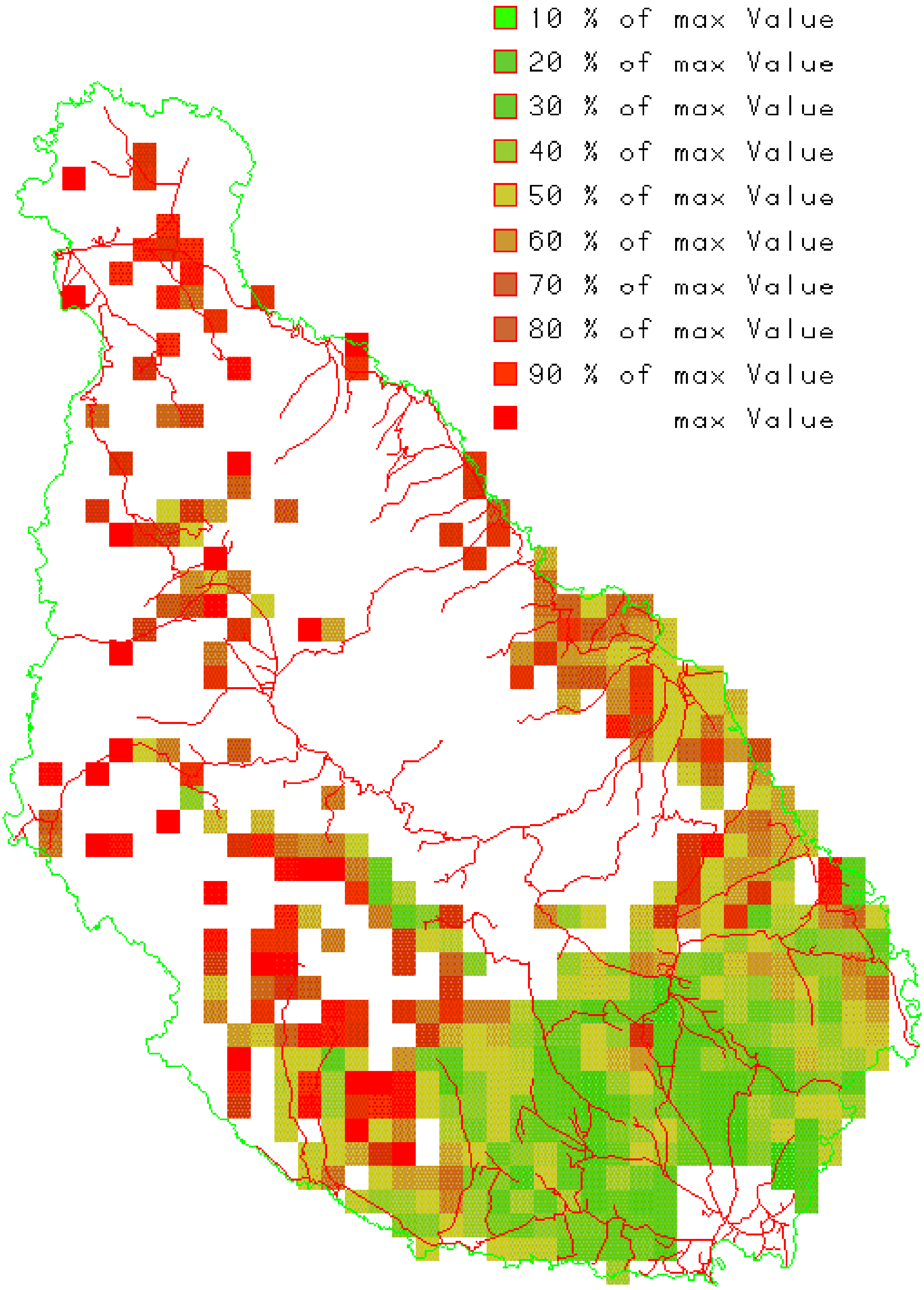


Figure 2.9 LEC map for Scenario 3 - 1 MW per km^2 in 2010

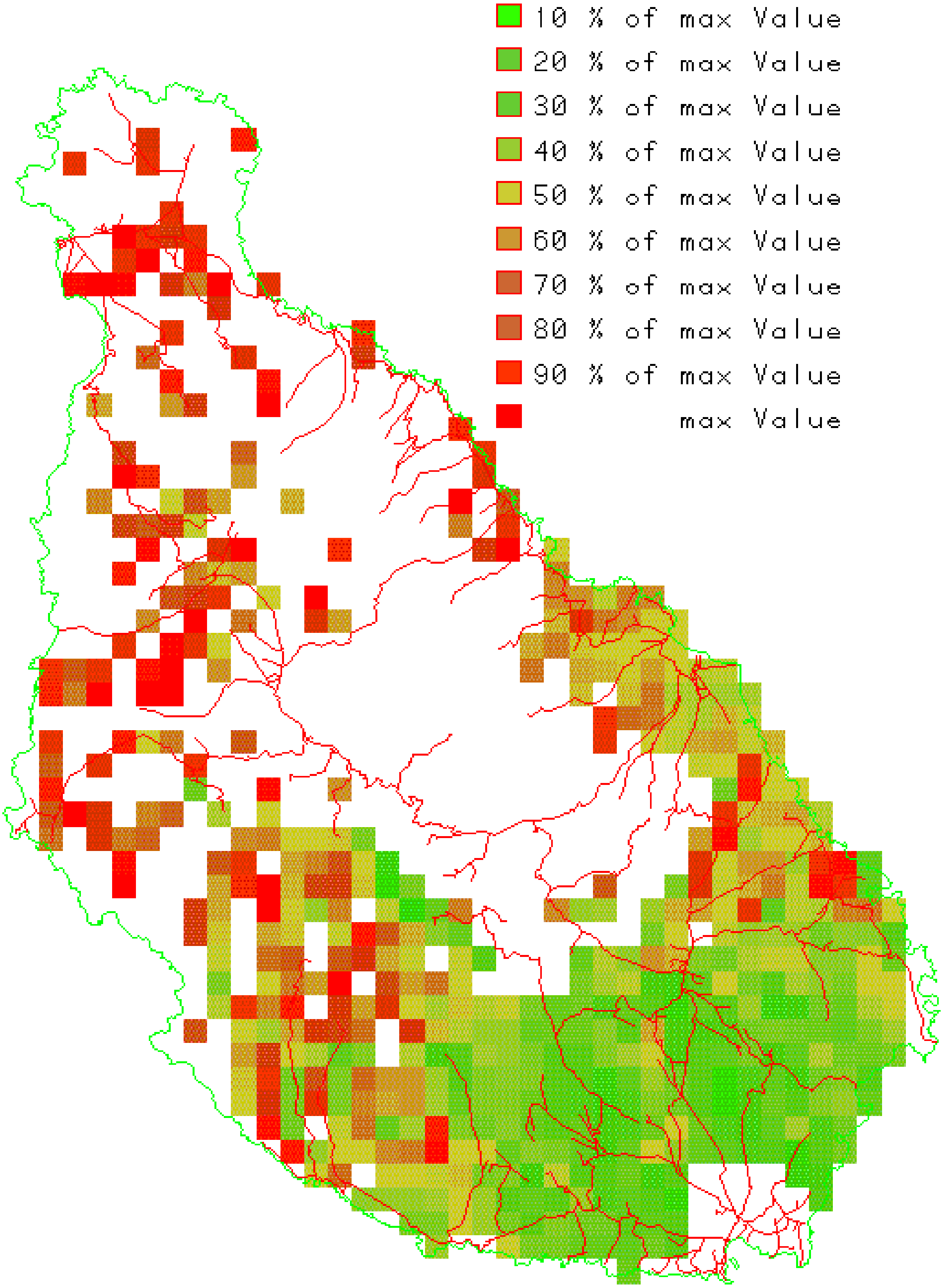


Figure 2.10 LEC map for Scenario 4 - 4 MW per km^2 in 2010

2.3.1.1.2 Wind power plants histograms for LEC maps

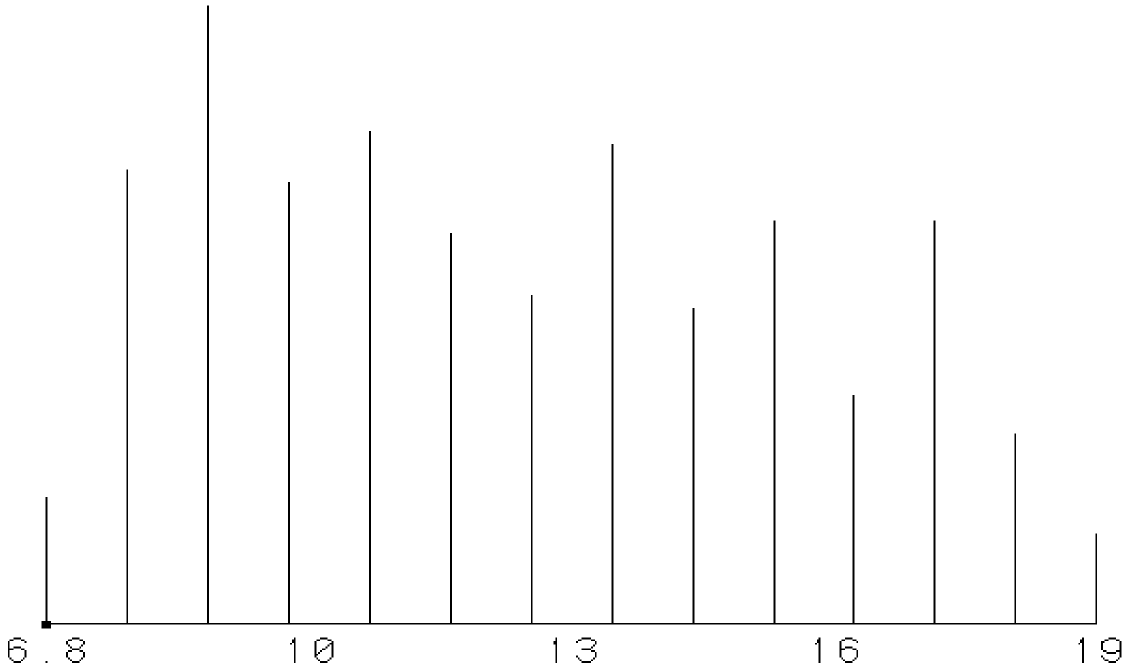


Figure 2.11 LEC Histogram for Scenario 1 - 1 MW per km^2 in 1996 (Ecu/kWhx100)

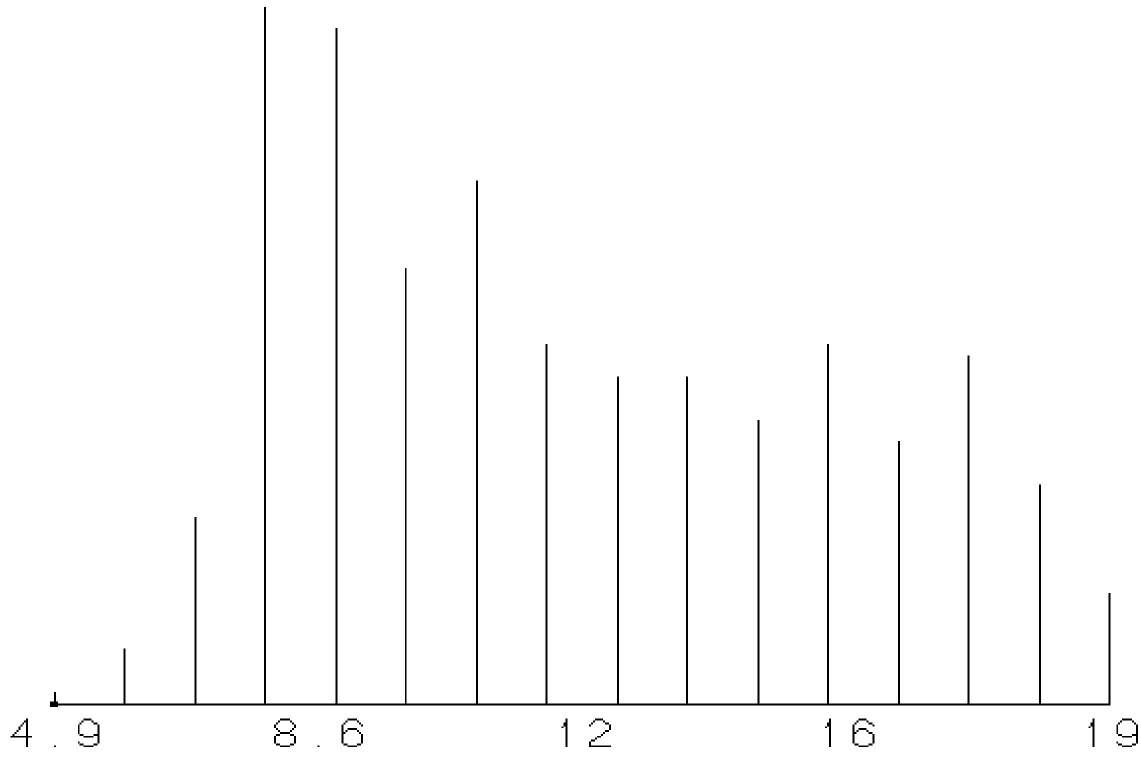


Figure 2.12 LEC Histogram for Scenario 2 - 4 MW per km^2 in 1996 (Ecu/kWhx100)

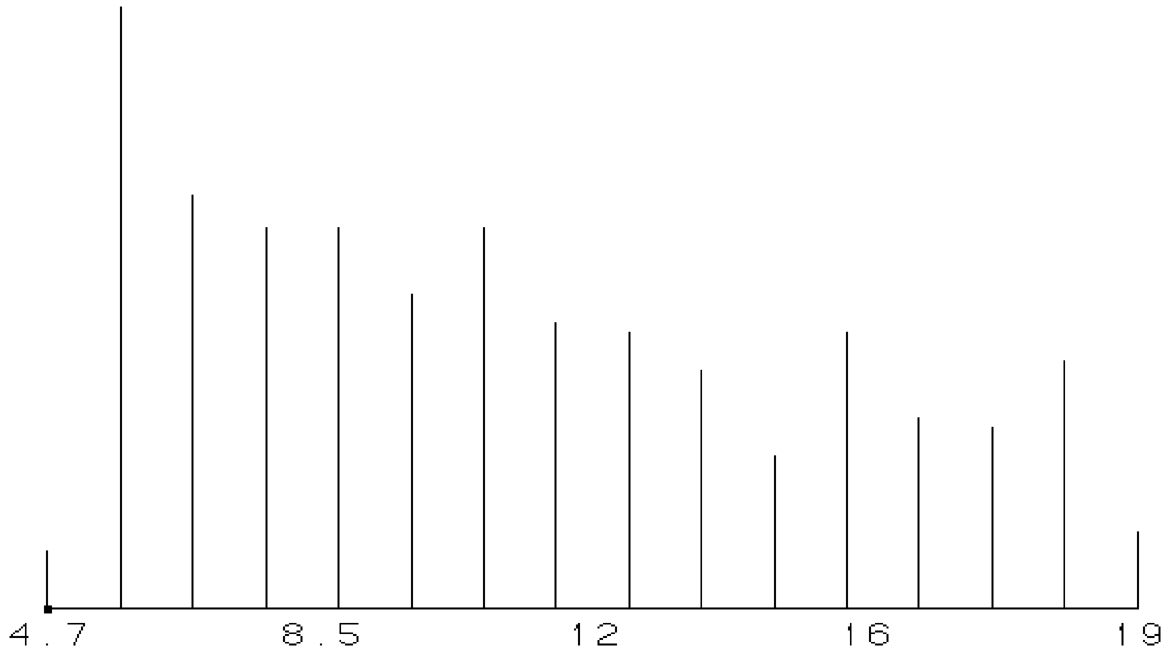


Figure 2.13 LEC Histogram for Scenario 3 - 1 MW per km^2 in 2010 (Ecu/kWhx100)

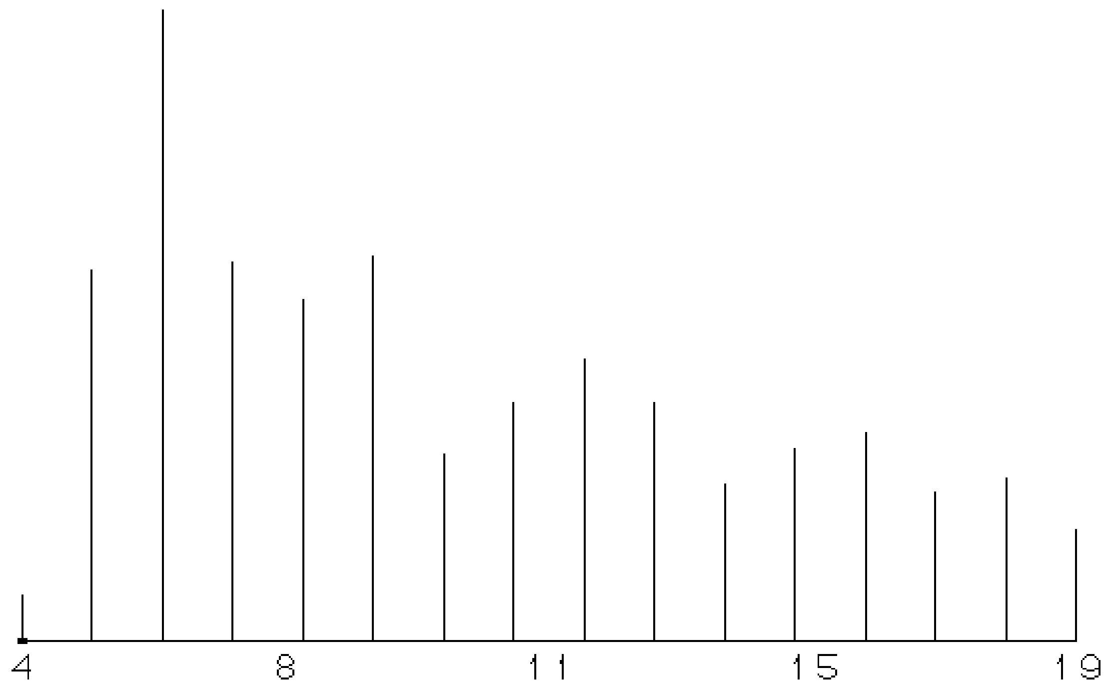


Figure 2.14 LEC Histogram for Scenario 4 - 4 MW per km^2 in 2010 (Ecu/kWhx100)

2.3.1.1.3 Conclusions

As it was expected, we may notice that the best places for the installation of wind parks correspond to the places with higher wind speed. The LEC is lower when the wind park is near the connection point and the roads.

The central area of the island has very few places for the installation of wind farms due to high inclination slopes and also due to the quantity of houses dispersed in the E-NE side. The northern side of the island has good wind potential that may be used in the future to supply the village of *Tarrafal*.

The results show the presence of excellent places in the mountain area in central *Santiago* (Mountain Range of *Pico da Antónia*). However, since the connection point is rather distant (around 15 km), we have to be careful when considering this place.

The places with best values for LEC, near the network of *Praia*, are situated in *Monte de S. Filipe*, *Achada Grande*, *Monte Babosa*, *Trindade*, *Monte Sopra Bulo* and in *Serra do Pico da Antónia*.

There are some other places somehow distant from Praia that have high future potential, depending on the evolution of Santiago's network for the next 20 years. In this manner, we have promising places in *Serra do Pico da Antónia, Achada da Baía*, in the area from *Achada Ponta* up to *Santa Cruz*, *Achada Mosquito, Santa Ana* , near *Monte Jagau,* in *Achada Grande, Chão Bom*, *Monte Covado* and *Trás-os-Montes.*

By the observation of the maps and the histograms for the scenarios of 1996, we may verify that the higher the power to be installed in a 1 km^2 area, the lower the LEC will be. However, one should notice that this inverse relation between LEC and installed power accentuates when local wind conditions are better. Comparing the histograms for set 1 and set 2 (installed power of 1 MW and 4 MW) we can conclude that the mode is not considerably altered. However, the lowest LEC values corresponding to high potential areas, are reduced of about 25% from one situation to the other.

For the scenarios of 2010, we have considered a 30% cost reduction for wind generators. Consequently the LEC is reduced of around 30%.

With the reduction of generator costs, the components relating to cable and road costs become more important. This way, in 2010, the places with higher potential become the ones closer to connection points and roads, even if average wind speed is lower.

2.3.1.2 PV power plants

For this study, we have considered the characteristics shown in the following table. The methodology automatically calculates the number of cables to be installed function of voltage drop limits and electrical characteristics, just like for the wind parks.

Resistance	0.627 Ohm/km
Reactance	0.381 Ohm/km
cosphi	1
Drop Voltage Limit	5 %
Electric Line annual costs	1500 ECU/km
Connection annual costs	3660 ECU
Road cost	40000 ECU/km
Generator+Internals cost	6400000 ECU/MW (1996)
Discount rate	8 %

Table 2.1 Input data for grid connected analysis

In this analysis we only considered the scenarios for 1996 and 2010. The scenario for 2010 differs only in the costs for the wind generators, considered to be 30% lower and in the costs for PV systems considered to be 50% lower.

Scenario	**Description**
Scenario 1	0.1 MW per km^2 in 1996
Scenario 2	1 MW per km^2 in 1996

Table 2.2 Scenarios

For the calculations we assumed the following:

- The resolution is equal to 1 km^2 per grid element.
- Average annual radiation for each grid pixel is the average of the respective 16 250X250m grid elements.
- We have excluded grid elements corresponding to inhabited areas.
- We have excluded grid elements corresponding to the airport.
- We have excluded grid elements corresponding to inclinations over 10%.

2.3.1.2.1 LEC maps for PV power plants

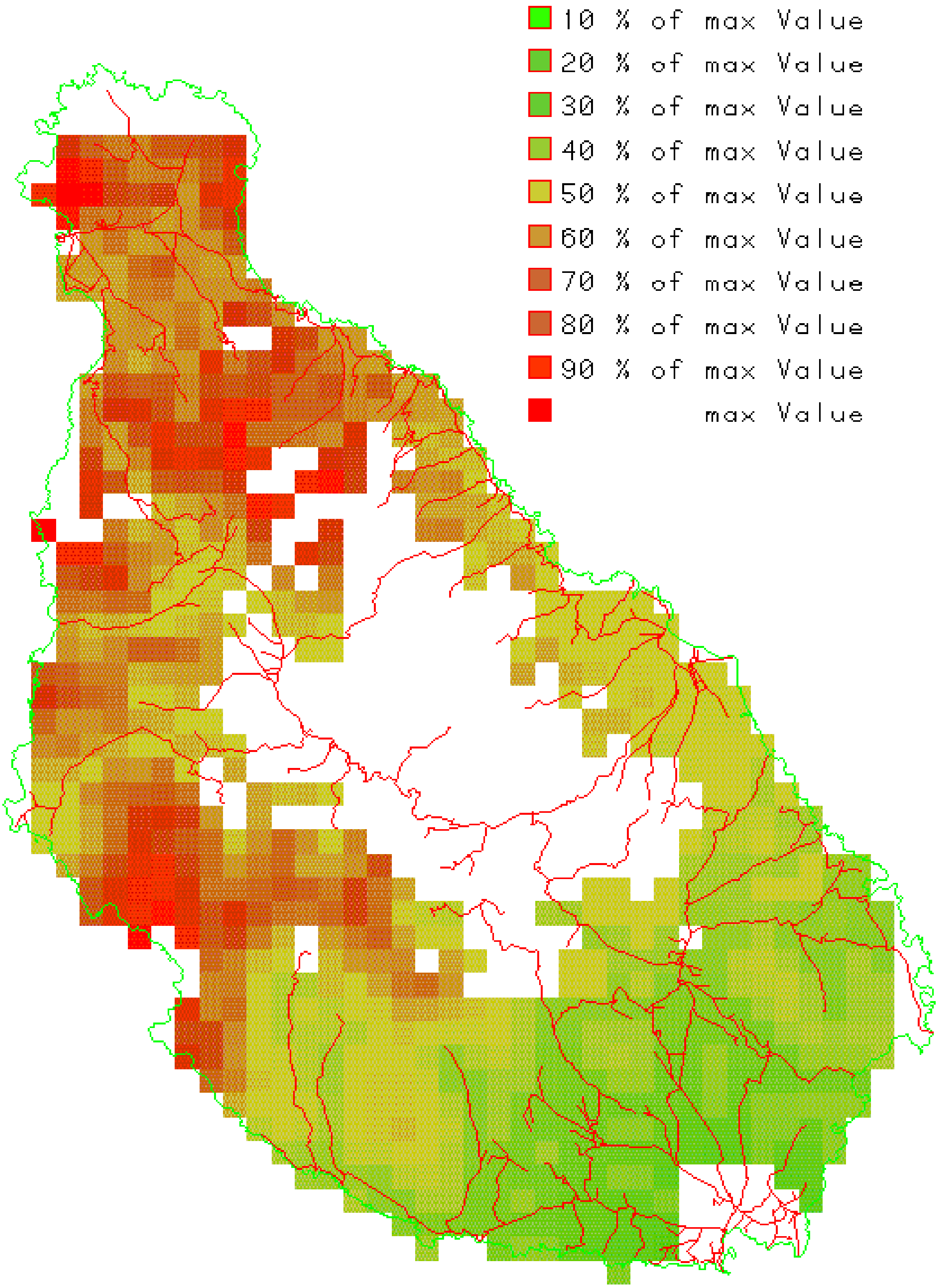


Figure 2.15 LEC map for Scenario 1 - 0.1 MW per km^2 in 1996 (max value is 1.9)

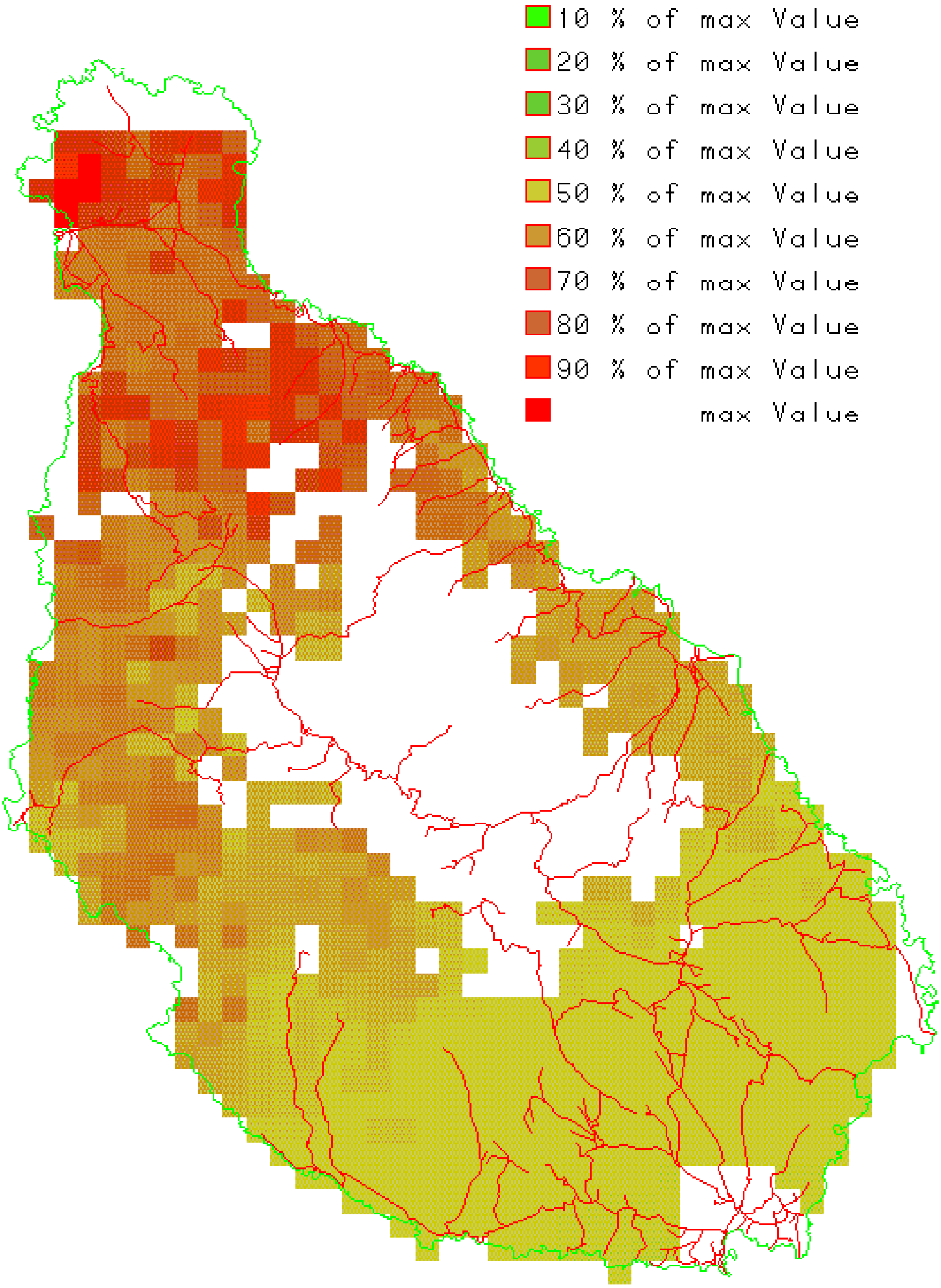


Figure 2.16 LEC map for Scenario 2 - 1 MW per km^2 in 1996 (max value is 1.1)

2.3.1.2.2 PV power plants histograms for LEC maps

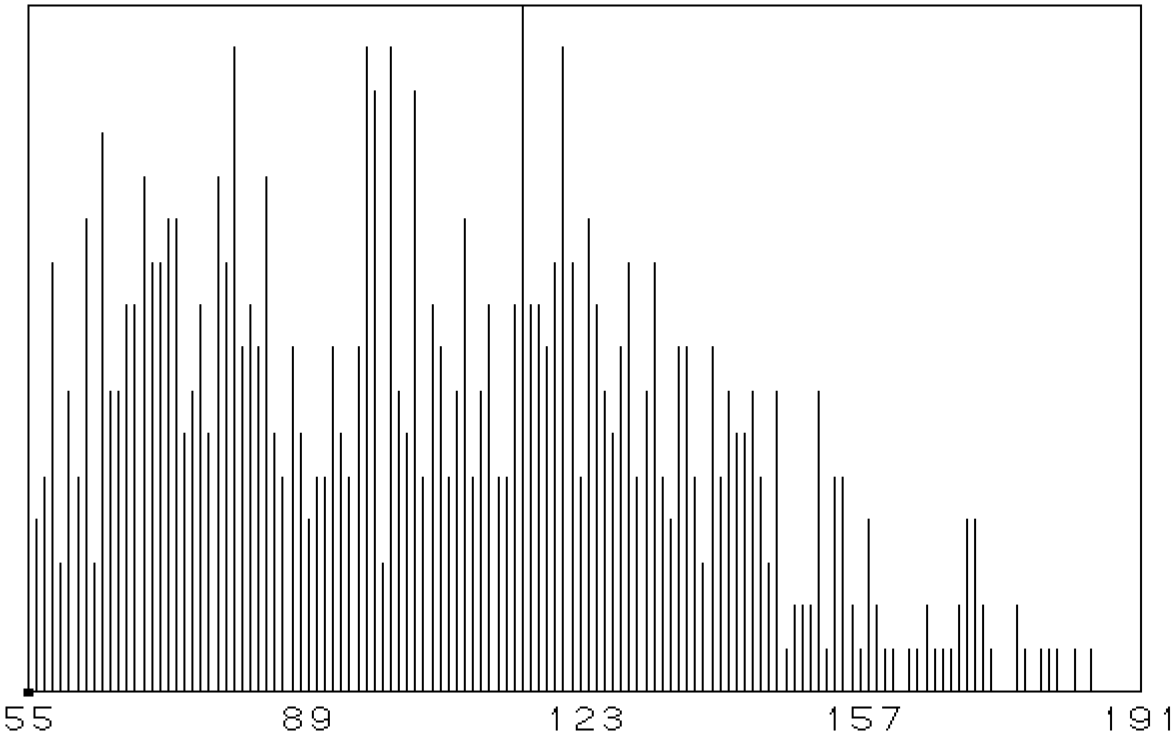


Figure 2.17 LEC Histogram for Scenario 1 - 0.1 MW per km^2 in 1996 (Ecu/kWhx100)

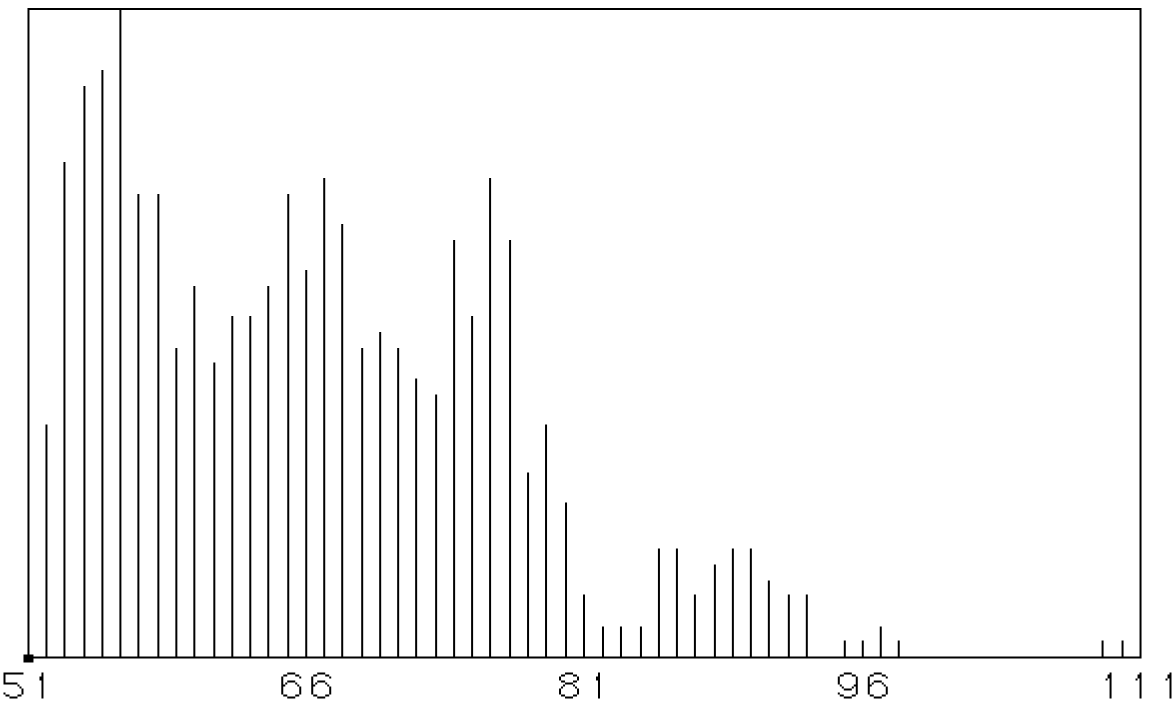


Figure 2.18 LEC Histogram for Scenario 2 - 1 MW per km^2 in 1996 (Ecu/kWhx100)

2.3.1.2.3 Conclusions

It is possible to conclude that the LEC for PV systems is considerably high when compared to wind systems. The lowest value for PV systems is approximately 0.5 ECU/kWh, which compares rather unfavorably with 0.07 ECU/kWh for wind systems with equivalent power.

From fig. 5, we realize that the localization of PV power stations depends essentially on the distance from the roads and from connection points. However, a more careful observation allows to distinguish LEC variations due to shadowing effects on the global radiation. This effect may be observed, for example in *Achada Mosquito*.

Comparing fig. 2.15 to fig. 2.16, we have reached the conclusion that, the lower the rated power of the PV power station, the higher the contribution of component, road and connection costs for LEC.

The increase in rated power of the PV park leads to the reduction of the LEC. The justification for this fact comes from a higher energy production for the same cost for road and connection construction. We conclude that the most relevant aspects when deciding the local for a PV station is not radiation resources but the existing infrastructures.

2.3.2 ISOLATED SYSTEMS

In the island of Santiago, only 45% of the population has electrical supply, being 30% of the population in Praia and the other 15% corresponding to small villages precariously supplied by isolated systems.

Several facts prevent the expansion of the network for the entire island:

- There is a growing concentration of the population in urban areas, increasing the effort for their electrification.
- Insufficient production capacity, being necessary the construction of new power stations.
- Low MT voltage levels (15 kV), which makes network expansion to remote areas near impossible.
- Rugged terrain, raising the cost for MV networks.
- The population in rural areas is highly dispersed increasing the costs for distribution networks.
- Energy demand is rather low and highly concentrated in a short peak period, leading to low network use.

This way, it is understandable that the best solution in a short and medium term, is an electrification plan based on distributed systems. In this study, we will consider and compare three types of solutions:

1. Connect the consumers to the small existing networks.
1. Supply small villages using a single system, that may be a hybrid Wind-Diesel system or a conventional diesel system.
1. 3. Supply each individual isolated house with a small PV or wind system or with a small Diesel or Gasoline generator.

In this study we have considered two different scenarios:

1. Scenario 1996 : present economical parameters are used. The demand level corresponds to the size of typical PV kits (400 Wh/(day.house) or 29.2 kWh/(capita.year)). These installations are designed to feed a few lamps, a radio and a small TV.
1. Scenario 2010. The economical tendency is very favorable to renewable energies (increase of fuels costs, decrease of photovoltaic panel and wind turbine manufacturing costs). The social level of supplied people is higher and the demand is three times higher than in ‘scenario 1996’. We have also considered a 3% annual population growth.

The calculation is performed in three steps:

1. The populated areas isolated from the electric grid are selected using the maps of rural population and distance to the grid.
1. The levelized electricity cost is calculated for different renewable and non renewable rural electrification solutions. For central systems, the demand is proportional to the population living inside the area corresponding to a pixel.
1. All costs are compared to produce a map with only the cheapest solutions.

2.3.2.1 Scenario 1996

Reference economical parameters	Unit	Investment (Ecu/unit)	Lifetime (years)	Maintenance (Ecu/unit.year)
0.25 kW wind turbine	kW	11000	15	275
2.2 kW Diesel generator	kW	900	25	10
Photovoltaic generator	kWp	8000	20	0
0.7 kW Gasoline generator	kW	400	15	20
Lead/acid battery	kWh	140	5	0
4 MW Medium voltage line	km	25000	35	1000
50 kVA MV/LV substation	1	8730	35	100
Low voltage line	km	7000	35	200
100 kW wind turbine	kW	1334	20	60
100 kW diesel generator	kW	266	20	30

Table 2.3 Reference economical parameters for scenario 1996

Load type	Lighting + radio
Load level	400 Wh/day .house = 29.2 kWh/capita.year
Mean power / maximum power	0.5
Discount rate	0.08
Diesel price	0.4 Ecu/liter
Gasoline price	0.7 Ecu/liter
Grid electricity price	0.25 Ecu/kWh
CO2 tax	0 Ecu/ton
C10 Battery capacity for WT and PV	1.2 kWh
C10 Battery capacity for diesel and gasoline	0.8 kWh
Performance ratio for WT and PV	0.6
Performance ratio for diesel and gasoline	0.95

Table 2.4 Load characteristics for scenario 1996

REGIONAL POTENTIAL	PV	WT	W/D
Total number of potential consumers	10099	1141	0
Total number of installed systems	2020	228	0
Total power of installed systems (kWc)	257	13	0
Total energy production (kWh)	294893	33342	0
Total investment (kECU)	2059	146	0

Table 2.5 Regional potential for scenario 1996

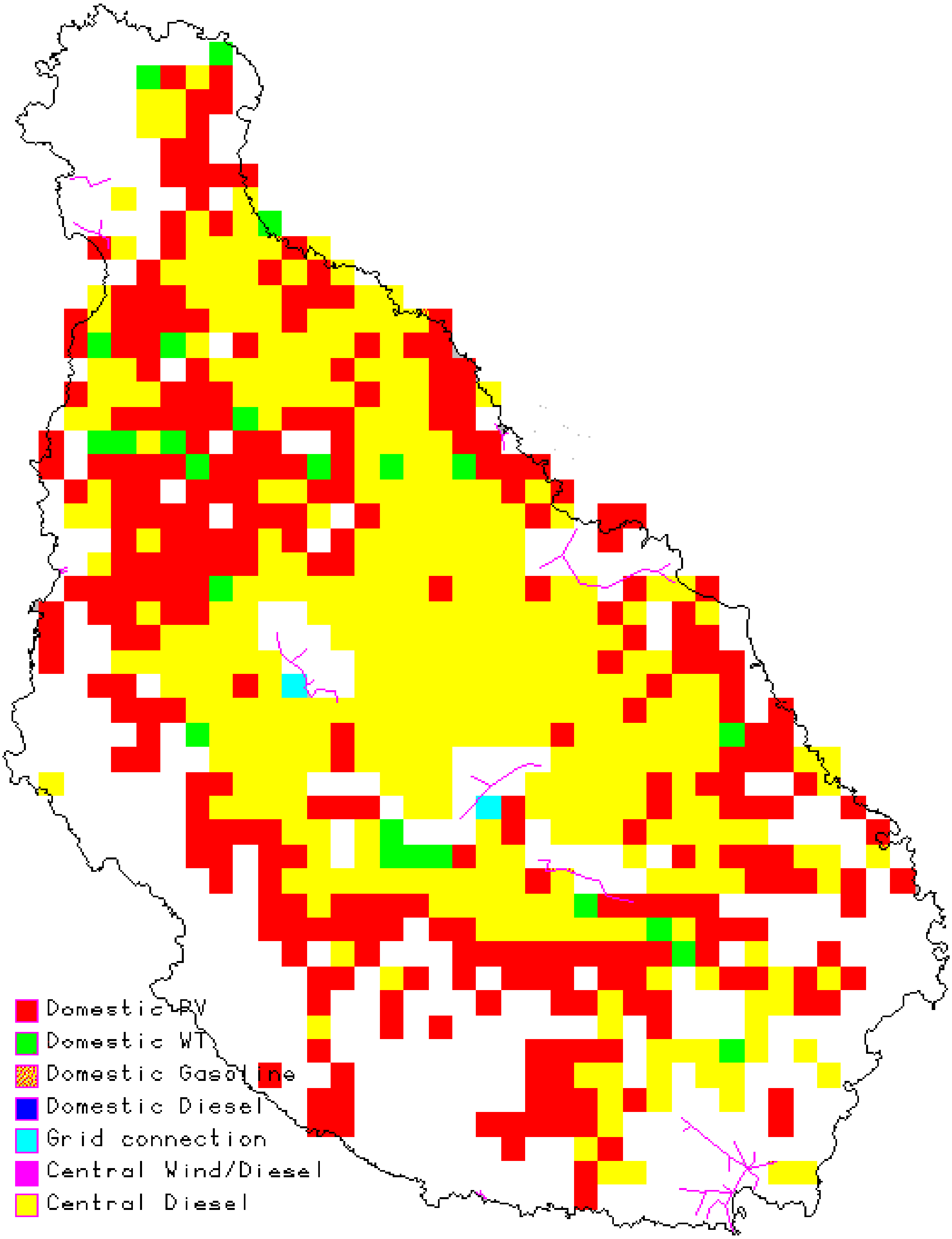


Figure 2.19 Best system for scenario 1996

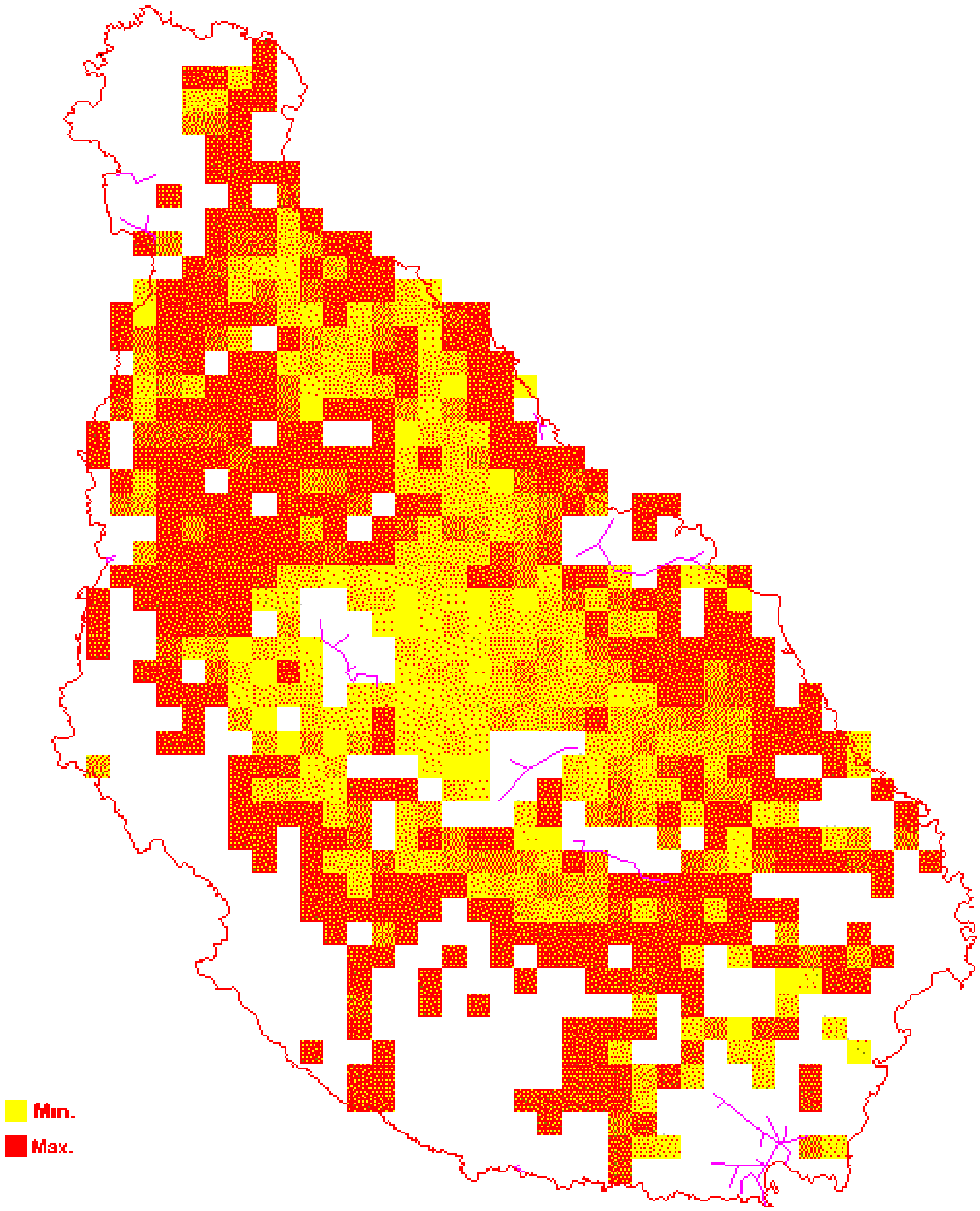


Figure 2.20 Best LEC for scenario 1996

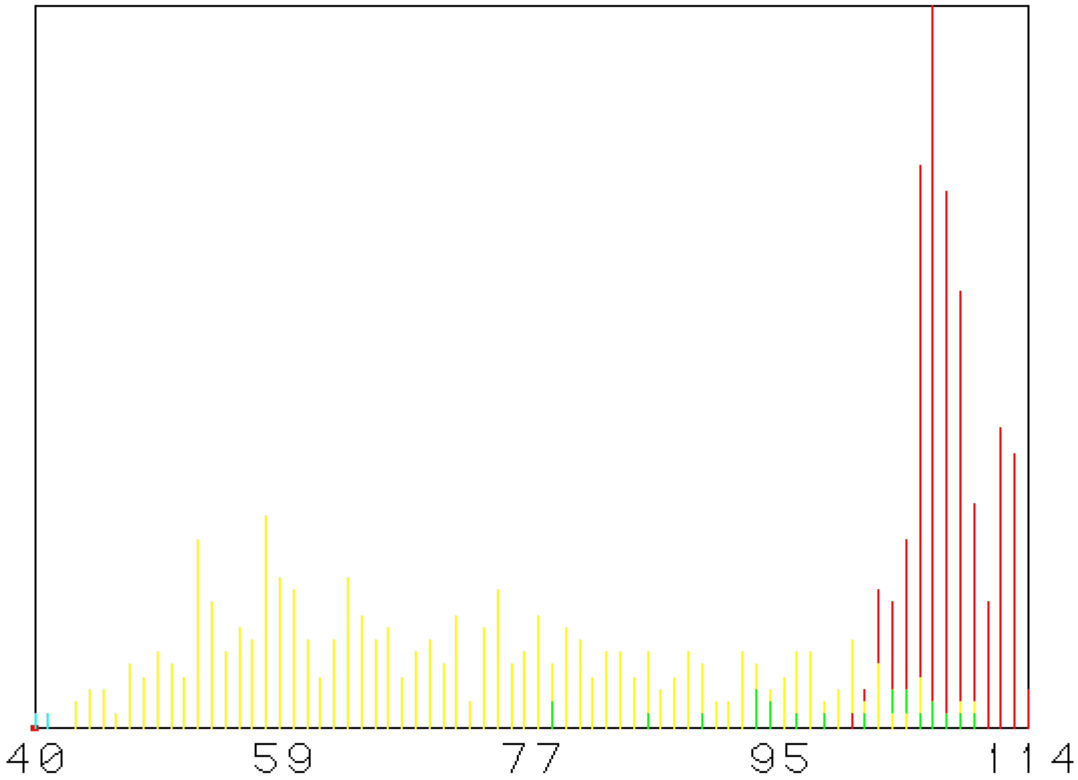


Figure 2.21 LEC for the best system grid histogram for scenario 1996 (Ecu/kWhx100)

For this scenario one may observe that the LEC ranges from 0.40 ECU/kWh to 1.14 ECU/kWh.

Figure 2.9 shows that there are some places where it is convenient to connect to the nearest network. In practice, this situation is confirmed, because some considerably densely inhabited areas, near the network, are not yet electrified. According to the people in charge of these networks, some efforts have been taken for the electrification of these areas. However, the potential consumers have considerably low demand and concentrated in a short peak period. This situation leads to the existence of a weak use of installed power, forcing the utilities to supply energy only during peak hours.

Figure 2.19 shows that Diesel systems cover the whole region corresponding to the areas of higher population density in the island, which, in some way, justifies the governmental measures for the elaboration of a plan for electrification based on these systems. However, in regions where population density is lower there is an important market for small wind and PV systems as we may see in table 2.5.

Fig. 2.21 shows the LEC grid histogram, classified according to the type of system to be used (histogram colors correspond to grid colors in fig. 2.19).

Lowest LEC values correspond to larger systems while higher values correspond to small isolated systems (PV and wind). Consumers connected to the network (blue) are the systems with lowest LEC. However, due to low demand, there are few regions where grid connection is justified.

Diesel systems (yellow) are the best solution for a large part of consumers and their LEC ranges from 0.45 to 1.00 ECU/kWh.

For low demand, the most interesting systems are small PV or wind systems, as it is possible to see in the histogram of fig. 2.21. When comparing wind systems to PV systems, we notice an accentuated predominance of PV systems. This is due to the fact that the cost for wind systems is relatively high for low power systems, being interesting only in high average wind speed regions.

2.3.2.2 scenario 2010

Reference economical parameters	Unit	Investment (Ecu/unit)	Lifetime (years)	Maintenance (Ecu/unit.year)
0.3 kW wind turbine	kW	7000	15	175
2.2 kW Diesel generator	kW	900	10	10
Photovoltaic generator	kWp	4000	20	0
0.7 kW Gasoline generator	kW	400	5	20
Lead/acid battery	kWh	140	5	0
4 MW Medium voltage line	km	25000	35	1000
50 kVA MV/LV substation	1	8730	35	100
Low voltage line	km	7000	35	200
100 kW wind turbine	kW	1334	20	60
100 kW diesel generator	kW	266	20	30

Table 2.6 Reference economical parameters for scenario 2010

Load type	Lighting + refrigerator + TV
Load level	1200 Wh/day .house = 87.6 kWh/capita.year
Mean power / maximum power	0.5
Discount rate	0.08
Diesel price	0.54 Ecu/liter
Gasoline price	0.94 Ecu/liter
Grid electricity price	0.25 Ecu/kWh
CO2 tax	0 Ecu/ton
C10 Battery capacity for WT and PV	3.6 kWh
C10 Battery capacity for diesel and gasoline	0.8 kWh
Performance ratio for WT and PV	0.65
Performance ratio for diesel and gasoline	0.95

Table 2.7 Load characteristics for scenario 2010

REGIONAL POTENTIAL	PV	WT	W/D
Total number of potential consumers	10652	168	3505
Total number of installed systems	2130	33	5
Total power of installed systems (kWc)	757	4	140
Total energy production (kWh)	933096	14719	307036
Total investment (kECU)	3007	27	267

Table 2.8 Regional potential for scenario 2010

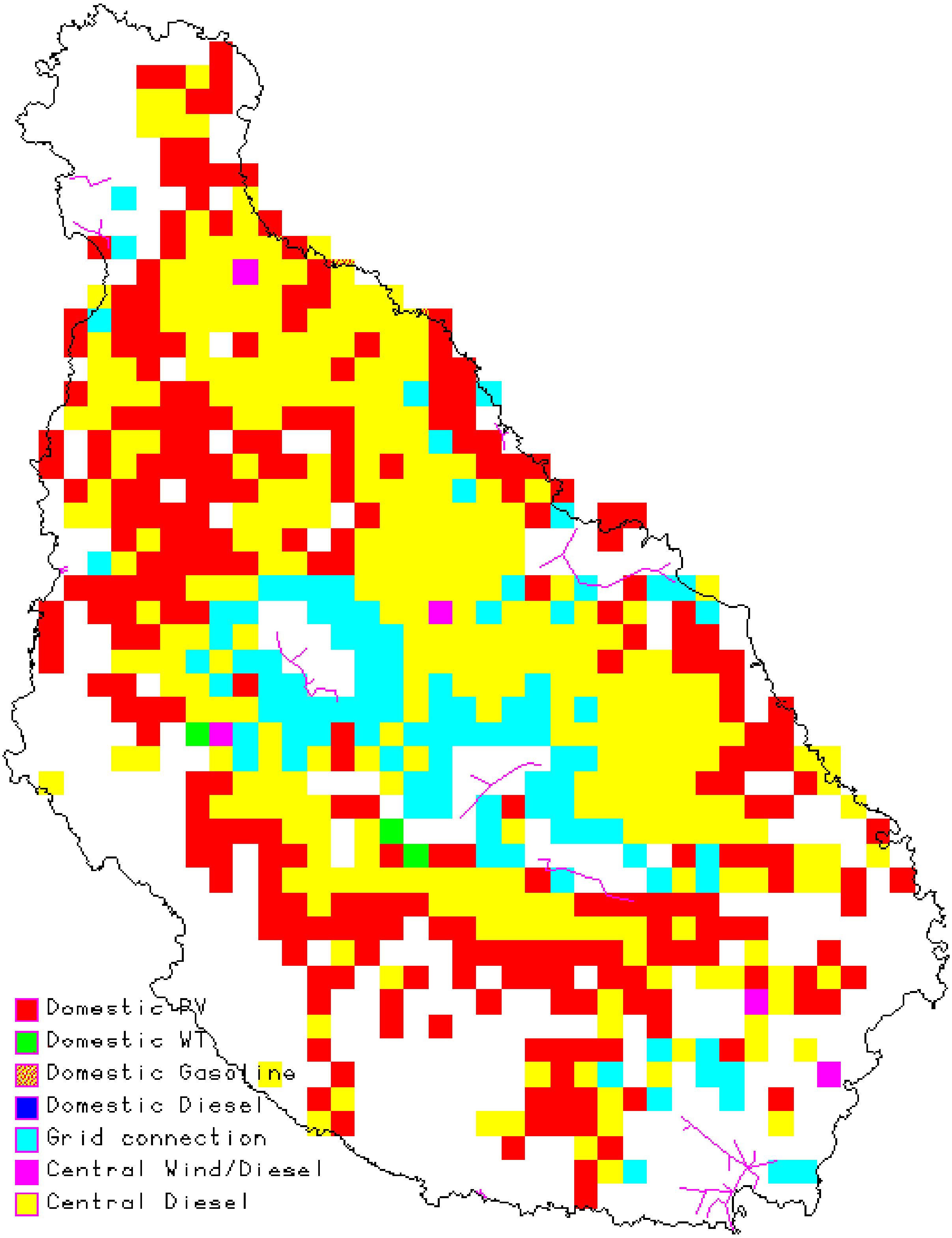


Figure 2.22 Best system for scenario 2010

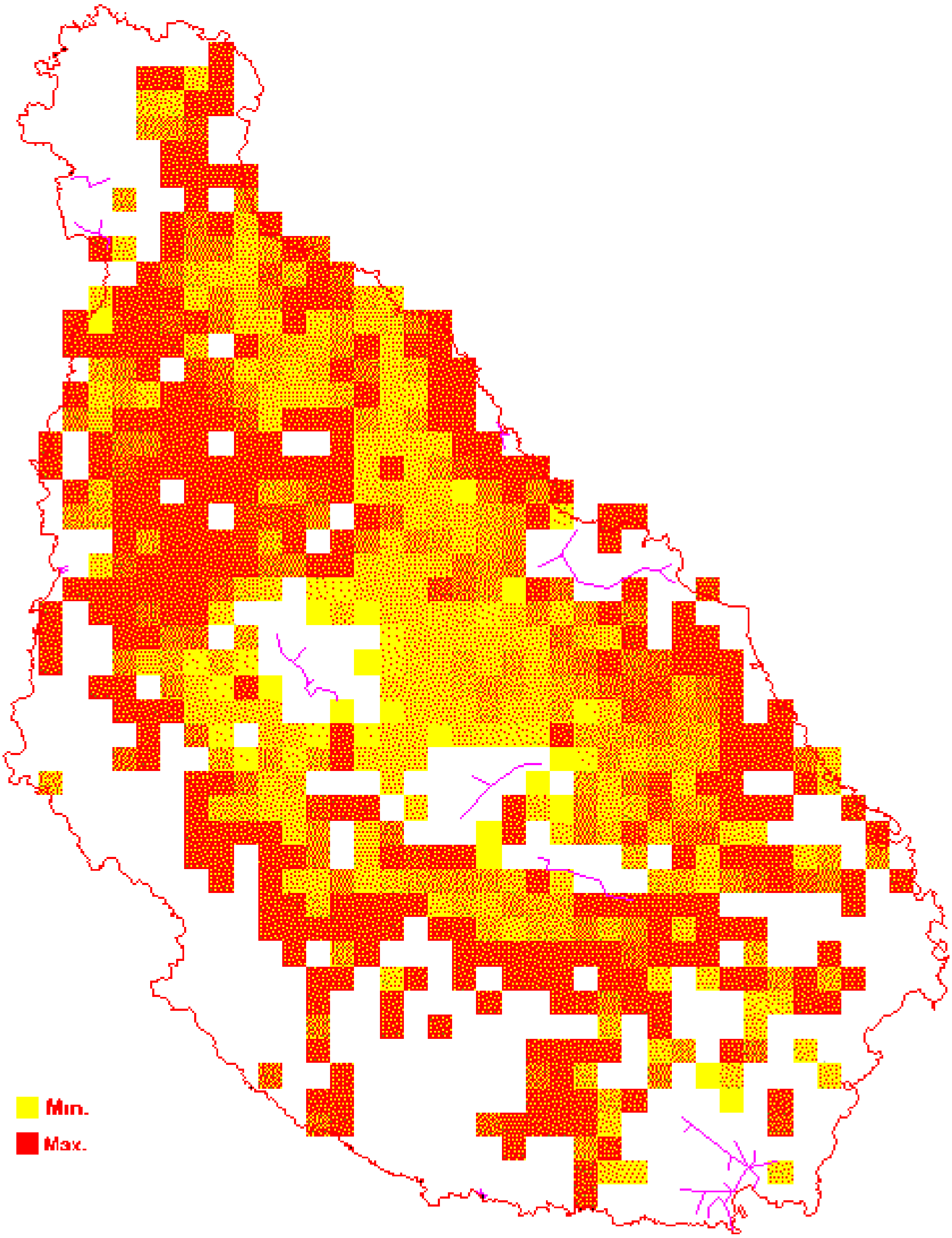


Figure 2.23 Best LEC for scenario 2010

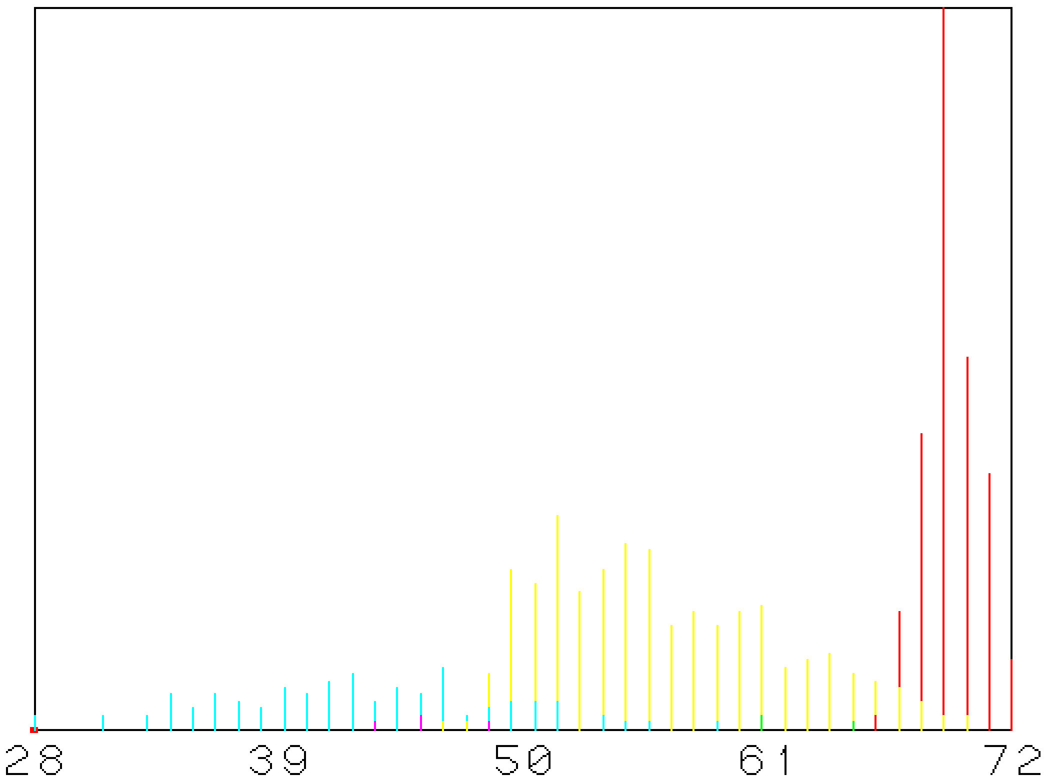


Figure 2.24 LEC for the best system grid histogram for scenario 2010 (Ecu/kWhx100)

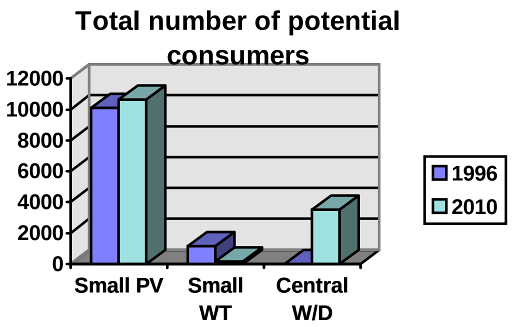
The increased demand justifies the expansion of existing small networks supplying the most important regions around these networks. On one hand, the areas closest to the networks will have lower LEC values, around 25% less. On the other hand, areas farther from the network but with reasonable demand become interesting for grid connection even when compared with Diesel systems for LEC around 0.5 ECU/kWh.

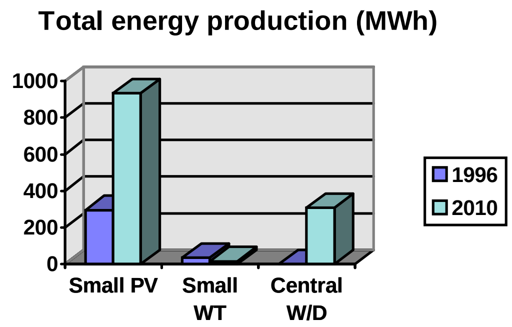
In the scenario for 2010 there are some areas interesting for the installation of hybrid WD systems. These systems are only interesting for regions with favorable wind resources and with reasonable demand in order to justify their installation.

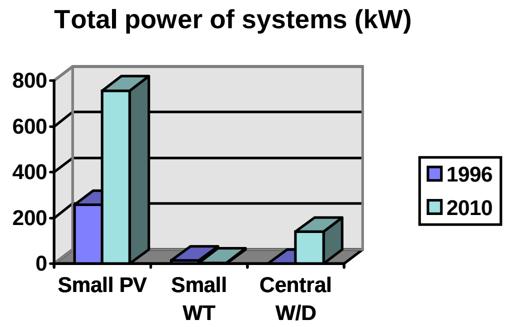
Small PV and wind systems, for the 2010 scenario, have lower values for the LEC, around 30% less. Even if PV systems are not replacing Diesel systems, we notice that the associated cost reduction keeps these systems interesting to supply and satisfy the forecasted growth in some less accessible rural areas.

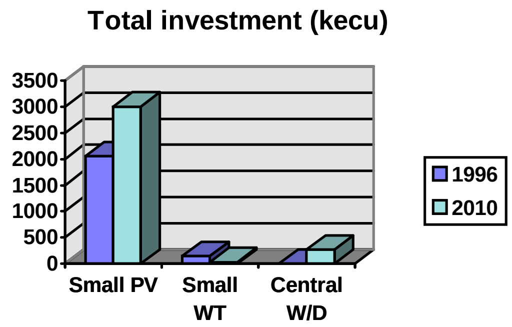
Small wind power systems are not appearing in the maps for 2010 because the forecasted 30% cost reduction is not enough to compete with the cost reduction for PV systems, around 50%.

2.3.2.3 Comparison of scenarios









These two scenarios do not represent all the combinations of economical parameters. The sensitivity to the discount rate and the CO_2 tax for instance has not been studied. A main assumption in these scenarios is that the use of electricity is limited to domestic appliances. Local industrial or agricultural development as well as the use of electricity for water pumping are not considered.

However, some conclusions may be driven from these scenarios:

1. The potential for individual photovoltaic systems is higher than for wind turbine.
1. The competitiveness between the renewable and the non renewable energy systems depends a lot on the size of the demand. This is a strategic issue. Should we provide the potential user with electricity only for lighting and radio or lighting, radio, TV and refrigerator ?

3. DETAILED CASE STUDIES

3.1 GRID CONNECTED SYSTEMS

In chapter 2 we considered a resolution of 1 km2 and the possibility of installing a wind park with a certain total power within this grid pixel. This type of approach may be applied with great efficiency in flat regions. However, in rugged mountain areas, some problems arise due to the non-consideration of several aspects:

- With this resolution it is not possible to detect ground inclinations with the necessary precision for filtering in complex orography areas. This way a large number of grid elements are not detected or excluded. As an example we may refer that in Santiago, with an 1 km2 resolution, in order to filter inclinations of over 10% we exclude very few places. However, with a 250x250 m resolution, around 50% of the island is excluded.
- The desirable distance between a wind park and inhabited areas is around 150 m. This way, we need at least a resolution of 250 m to conviniently filter these areas.
- The wind grid for the standard 1 km2 methodology uses average values calculated from a 250x250 m grid. This approximation leads to the attribution of lower wind speeds to places with best wind resources (in the 250x250 m grid), with corresponding lower LEC values.
- Due to aspects related to park layout, the efficiency of a 1 MW/km2 park is not equal to the efficiency of a 4 MW/km^2 park. This aspect is not taken into consideration in the standard SOLARGIS methodology.
- In the study where a resolution of 1 km2 is considered, we assume that the park has to be installed within this limited area, bringing some constraints to the model.

In order to solve these situation we have developed a comprehensive methodology, possible to integrate in the previous model and allowing 250x250 resolutions. It is also able to consider the park layout defined by the user as well as the number of wind turbine and generator power. With this model there is no limitation for the park dimension. However, the resolution must correspont to the are occupied by each wind turbine.

This methodology consists on the definition of the park layout on a “kernel”. A kernel is a grid element block, used to carry out a focus analysis over the grids of the region being studied.

The calculations are carried out element by element just like in the conventional model. However, we have included the following additional steps:

1. Create the kernel that defines the park layout. Generally, we assume a layout orthogonal to wind dominant direction.

1. For each grid element, a focal analysis is performed, verifying if there is sufficient area for the implementation of the predefined layout. In case this condition is not satisfied, this element is excluded.
1. If the previous condition is verified, then the average power produced by the generators is calculated and the result is attributed to the grid element being processed. Then, the LEC value is calculated following the SOLARGIS standard model.

For this calculation we assume the following:

- It is possible to place only one wind turbine within each 250X250 m grid element.
- Wind generator power may be either 300 kW or 500 kW
- Grid elements in forbidden areas are excluded.
- Grid elements containing houses are excluded.
- Grid elements corresponding to inclinations of over 10% are excluded.

The following data was used:

Resistance	0.627 Ohm/Km
Reactance	0.381 Ohm/Km
cosphi	1
Drop Voltage Limit	5 %
Electric Line annual costs	1500 ECU/km
Connection annual costs	3660 ECU
Road cost	40000 ECU/km
Generator+Internals cost	135000 ECU/MW
Discount rate	8 %

Table 3.1 Input data for grid connected analysis

For this analysis we have only considered the scenarios for 1996.

This study intends, in order to compare results, to be adequated to real studies performed on the island. There is a project intitled “Wind parks in Cape Verde” whose objective is to connect one or more wind parks to the network of Praia, with a total installed power of 3 MW. The project will be implemented in two phases. In the second phase the cable used on the first phase will be used and it is assumed that in the first phase three 300 kW wind generators were installed in Monte de S. Filipe.

In all scenarios we considered a park layout orthogonal to the dominant NE wind.

We have also considered scenarios with different values for wind generator power (300 kW and 500 kW).

Scenario	number of WT x Power
Scenario 1 (fase 1)	3 x 300 kW
Scenario 2 (fase 1)	9 x 300 kW
Scenario 3 (fase 1)	6 x 500 kW
Scenario 4 (fase 2)	6 x 300 kW
Scenario 5 (fase 2)	4 x 500 kW

Table 3.2 Scenarios

In order to facilitate the observation of maps, we have considered and mapped locals with LEC values lower than 0.2 ECU/kWh, i. e., the maximum values used in the legend is 0.2.

3.1.1 WIND POWER PLANTS

3.1.1.1 Wind power plants LEC maps

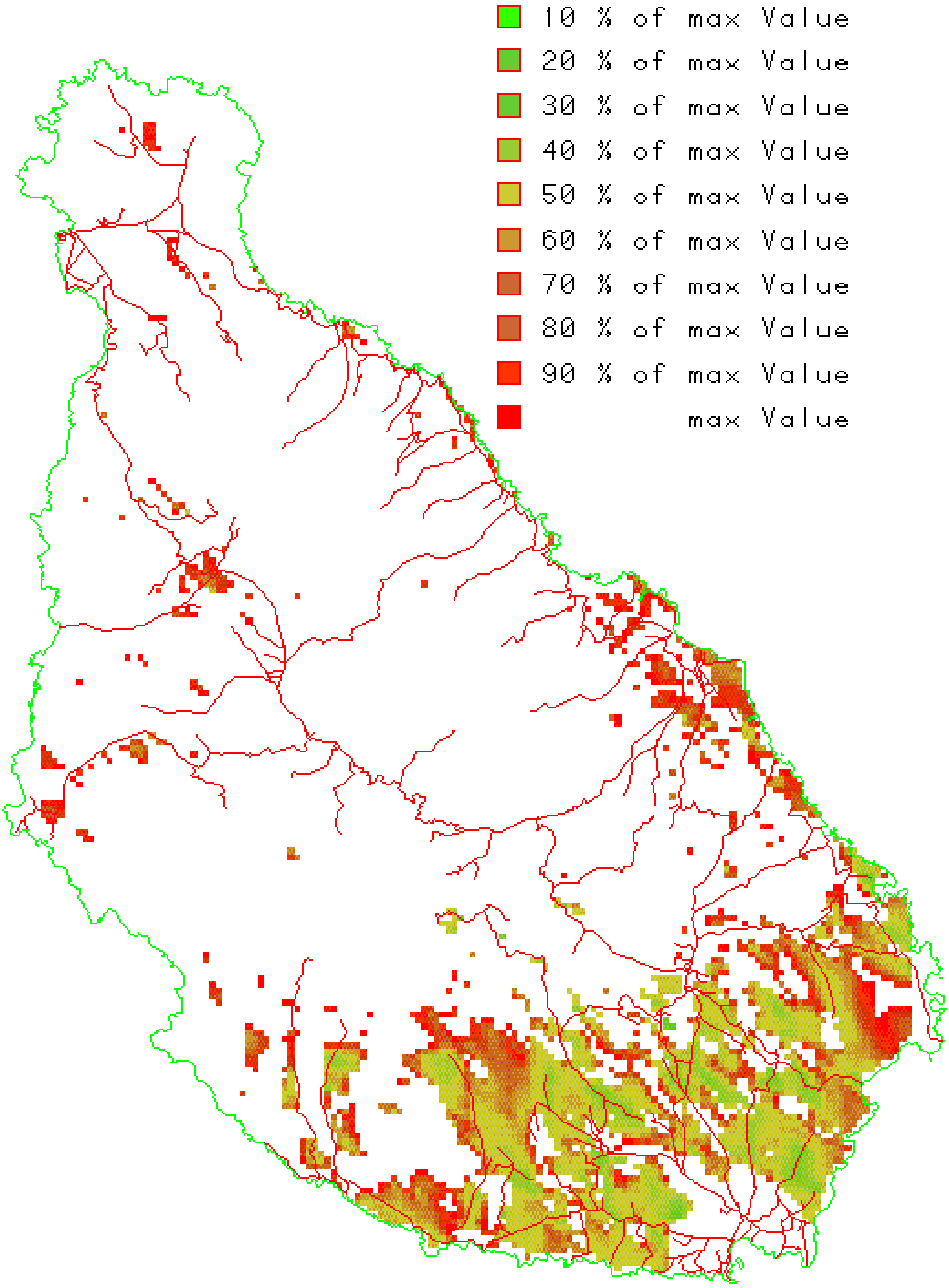


Figure 3.1 LEC map for Scenario 1 (fase 1) - 3x300 kW wind park

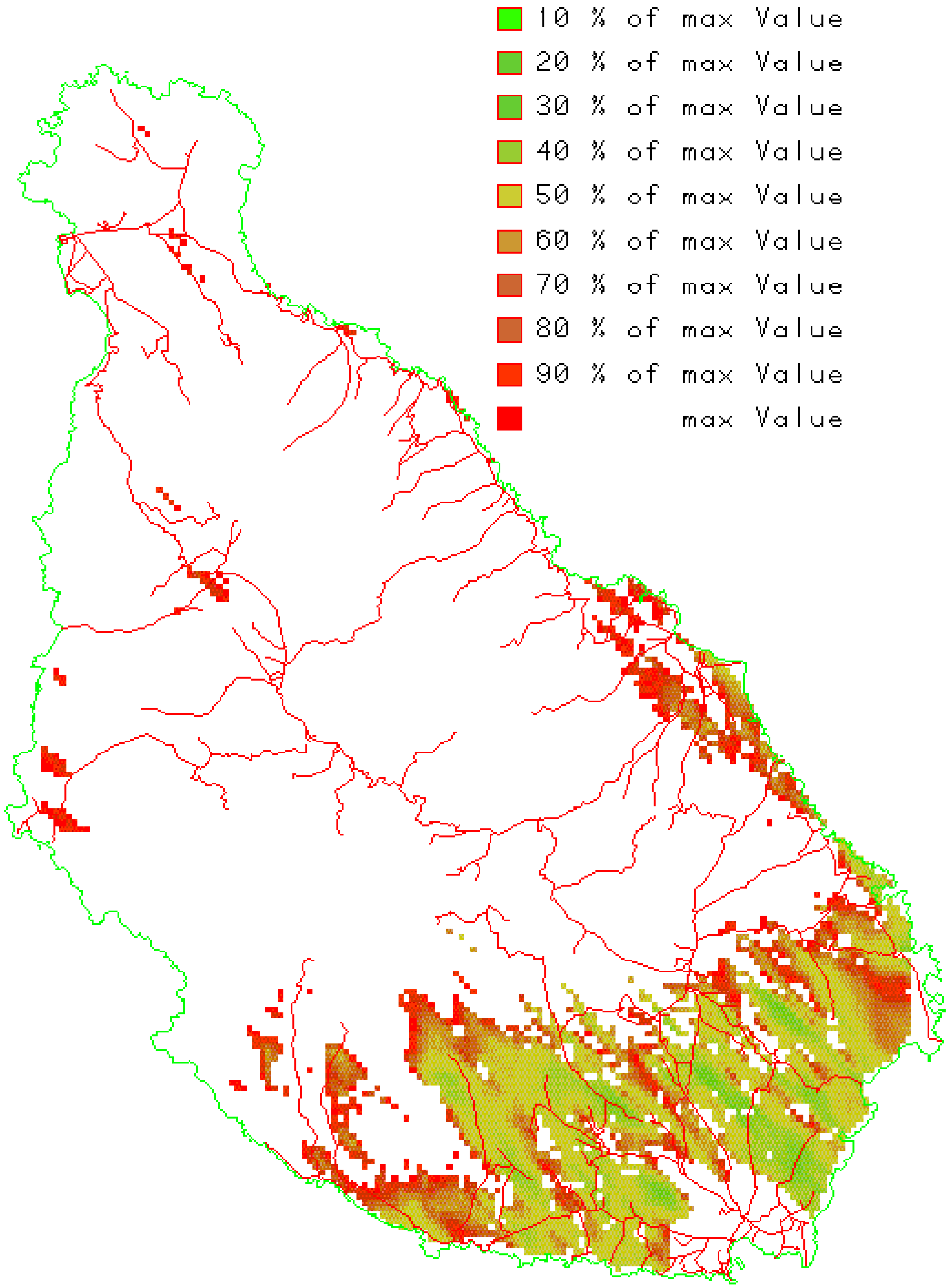


Figure 3.2 LEC map for Scenario 2 (fase 1) - 9x300 kW wind park

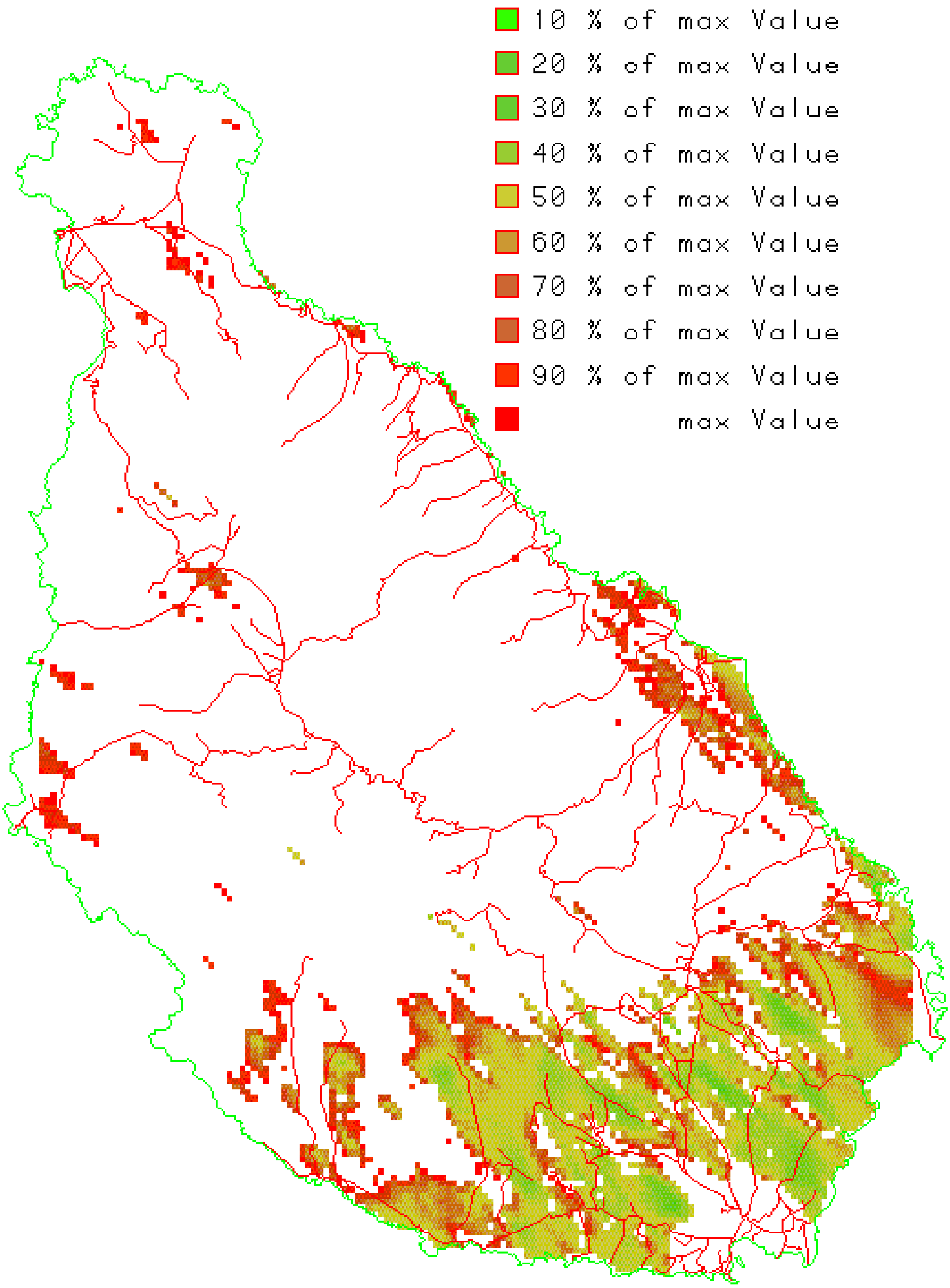


Figure 3.3 LEC map for Scenario 3 (fase 1) - 6x500 kW wind park

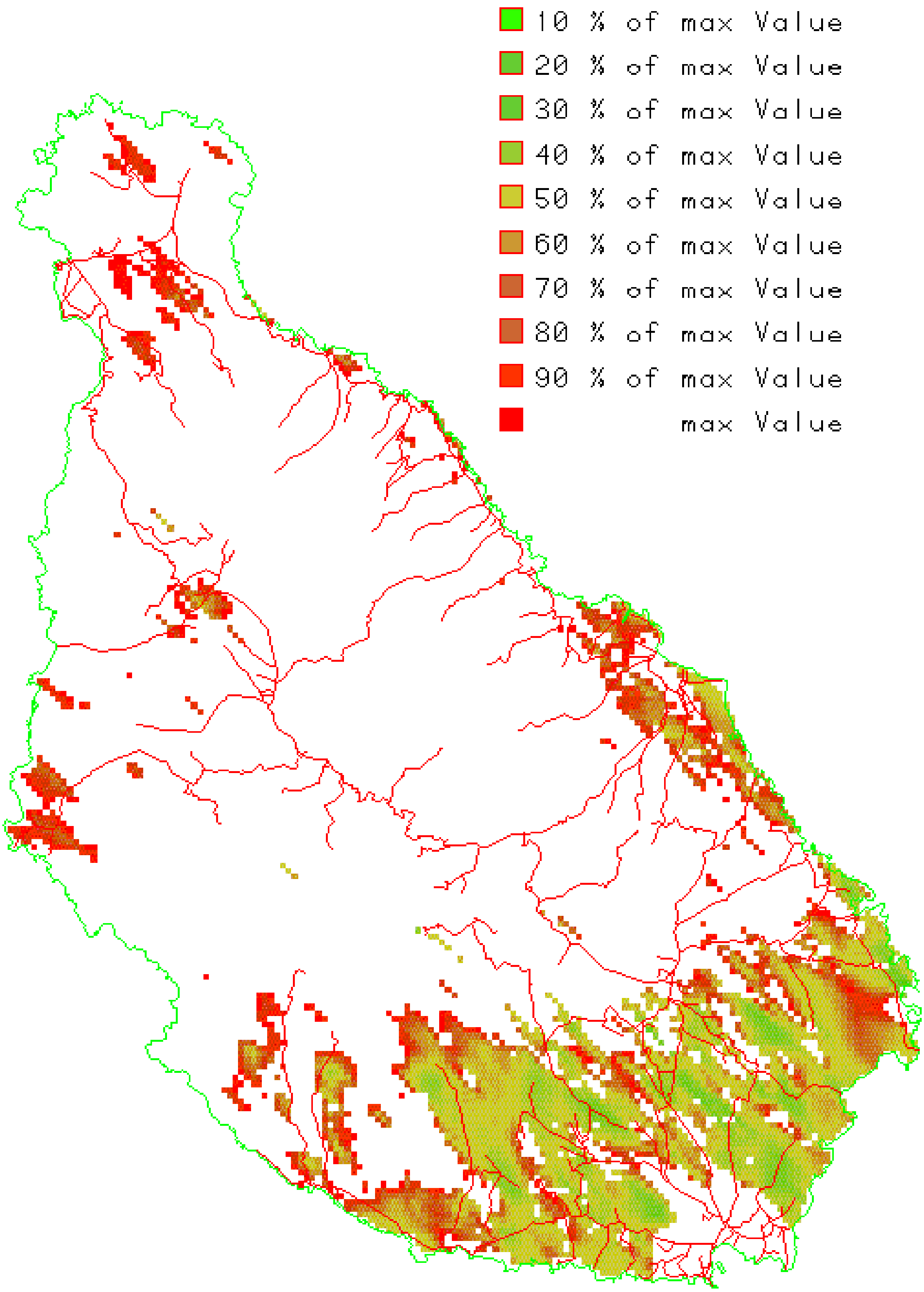


Figure 3.4 LEC map for Scenario 4 (fase 2) - 6x300 kW wind park

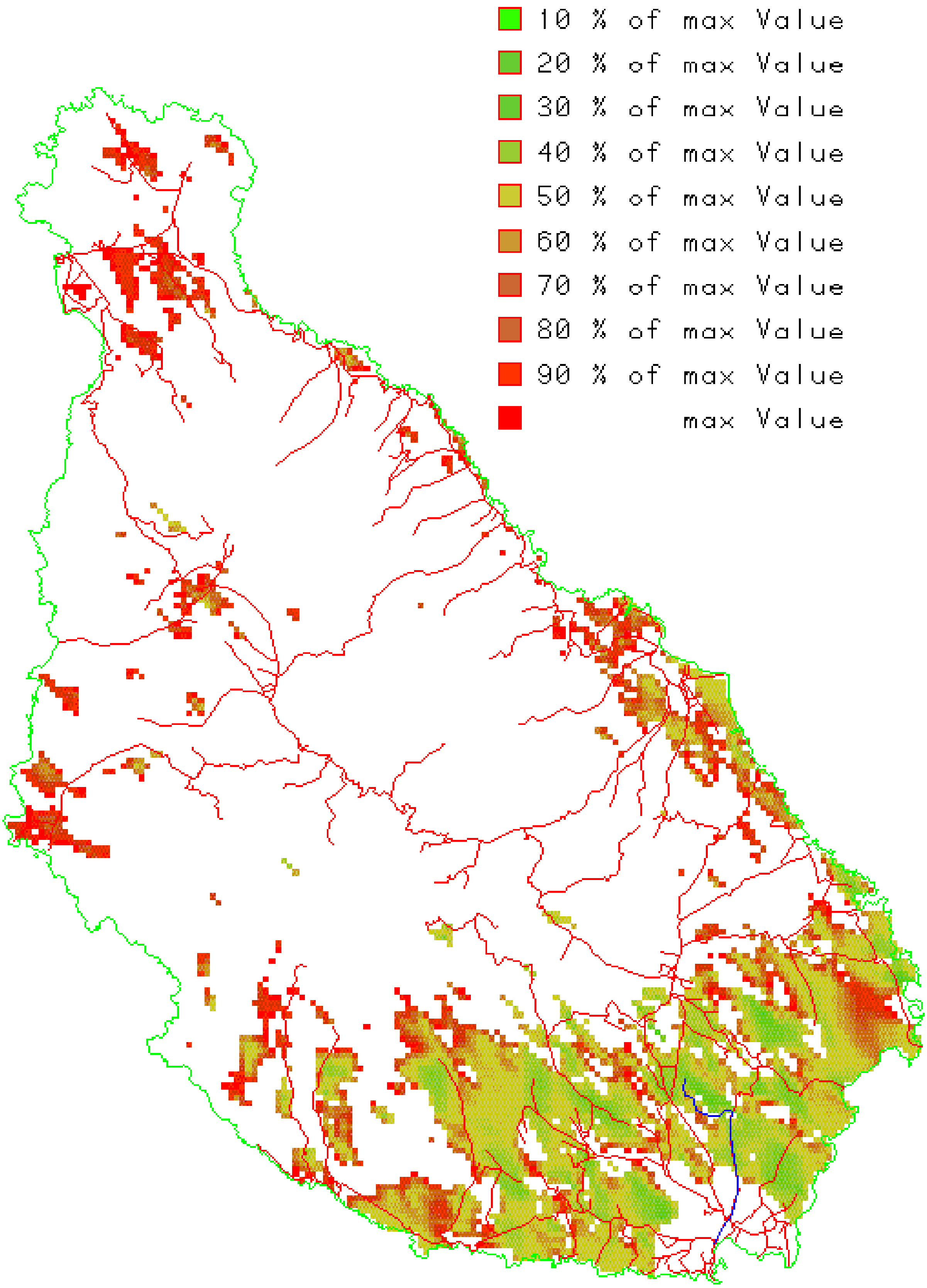


Figure 3.5 LEC map for Scenario 5 (fase 2) - 4x500 kW wind park

3.1.1.2 Wind power plants histograms for LEC maps

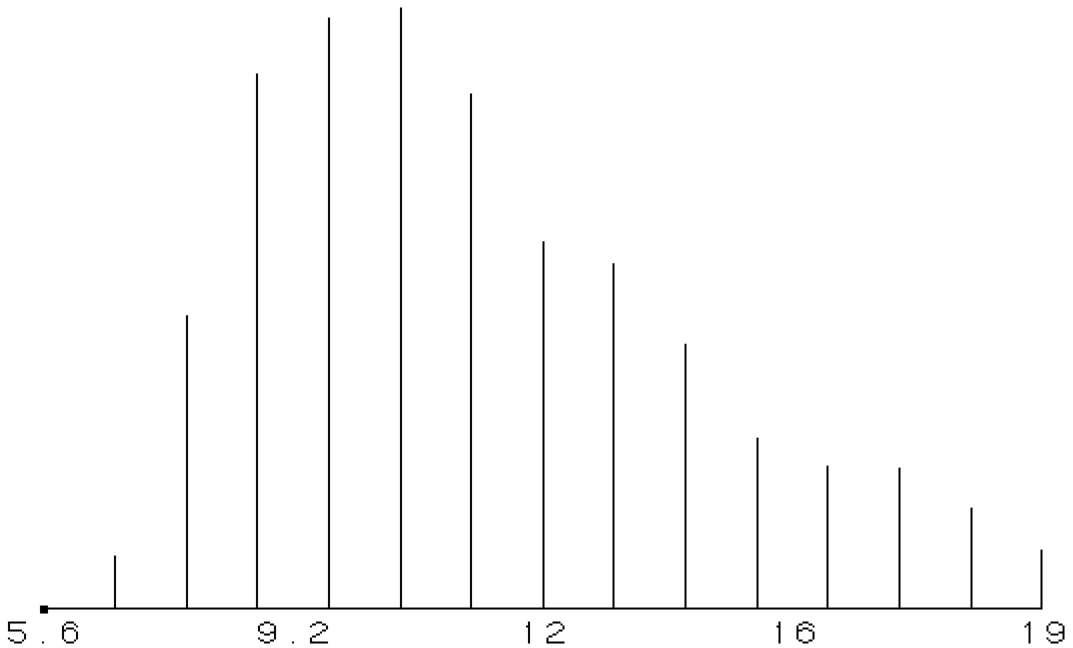


Figure 3.6 Histogram for Scenario 1 (fase 1) - 3x300 kW wind park (LECx100)

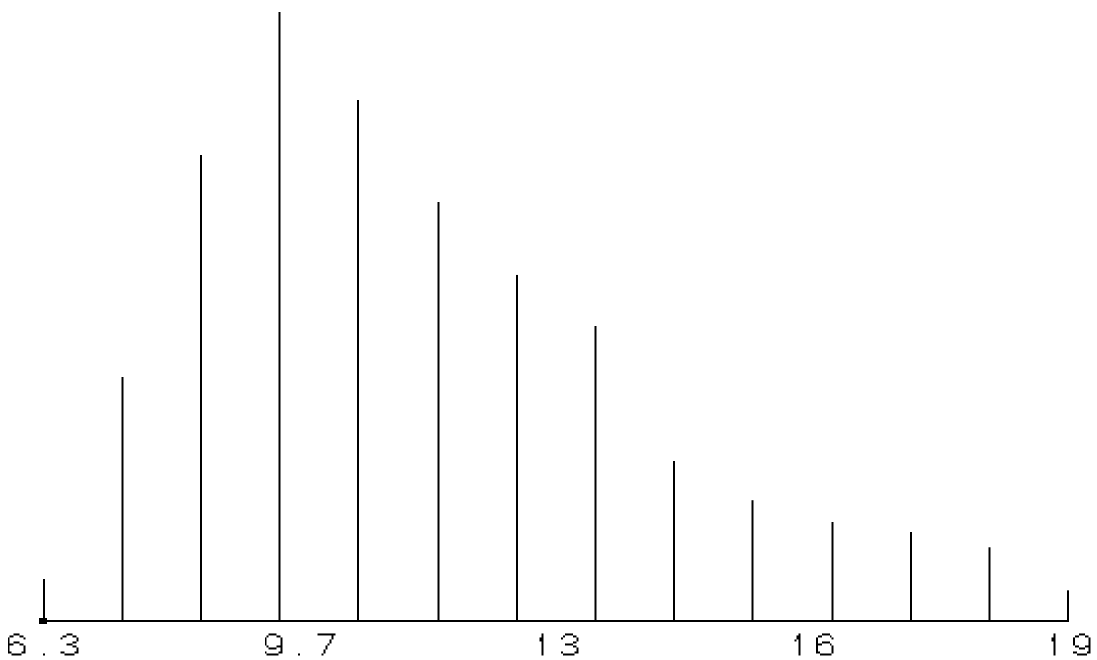


Figure 3.7 Histogram for Scenario 2 (fase 1) - 9x300 kW wind park (LECx100)

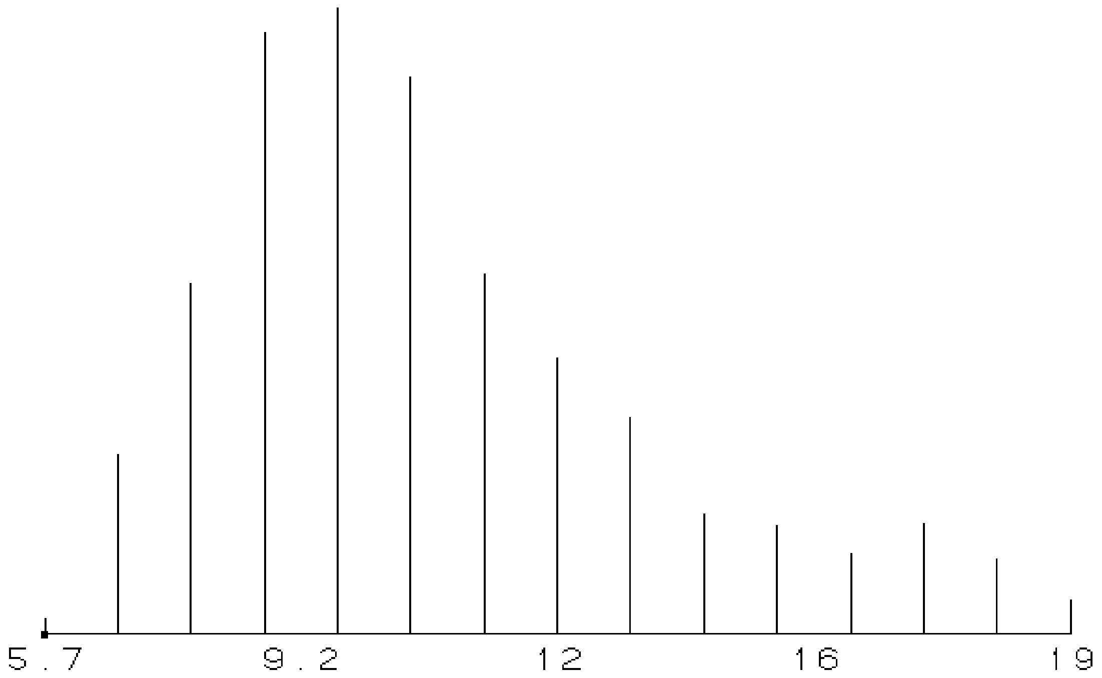


Figure 3.8 Histogram for Scenario 3 (fase 1) - 6x500 kW wind park (LECx100)

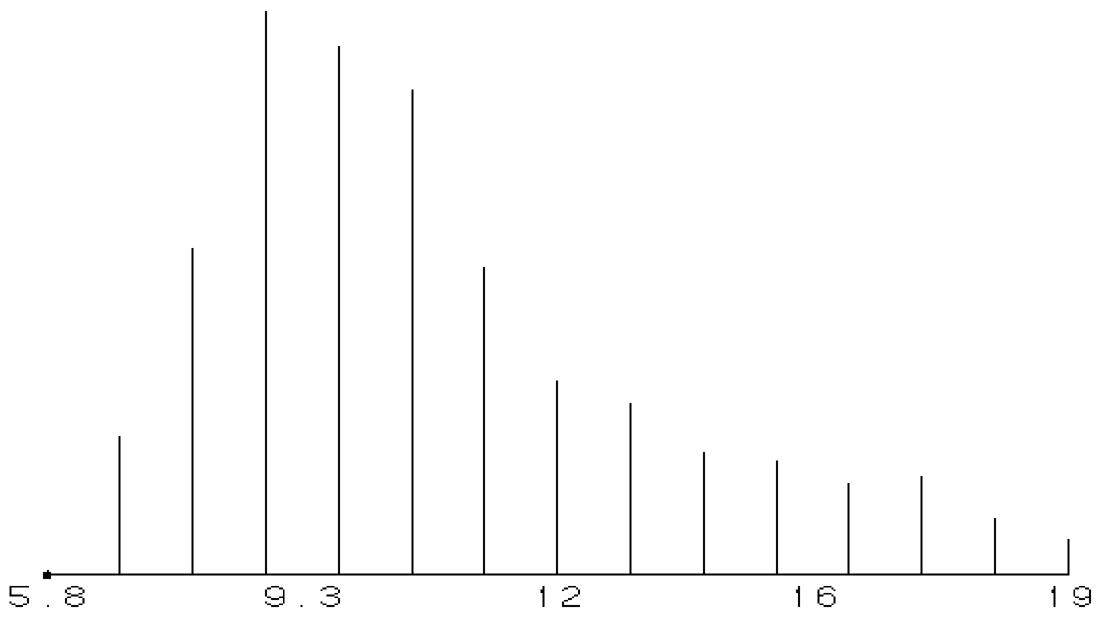


Figure 3.9 Histogram for Scenario 4 (fase 2)- 6x300 kW wind park (LECx100)

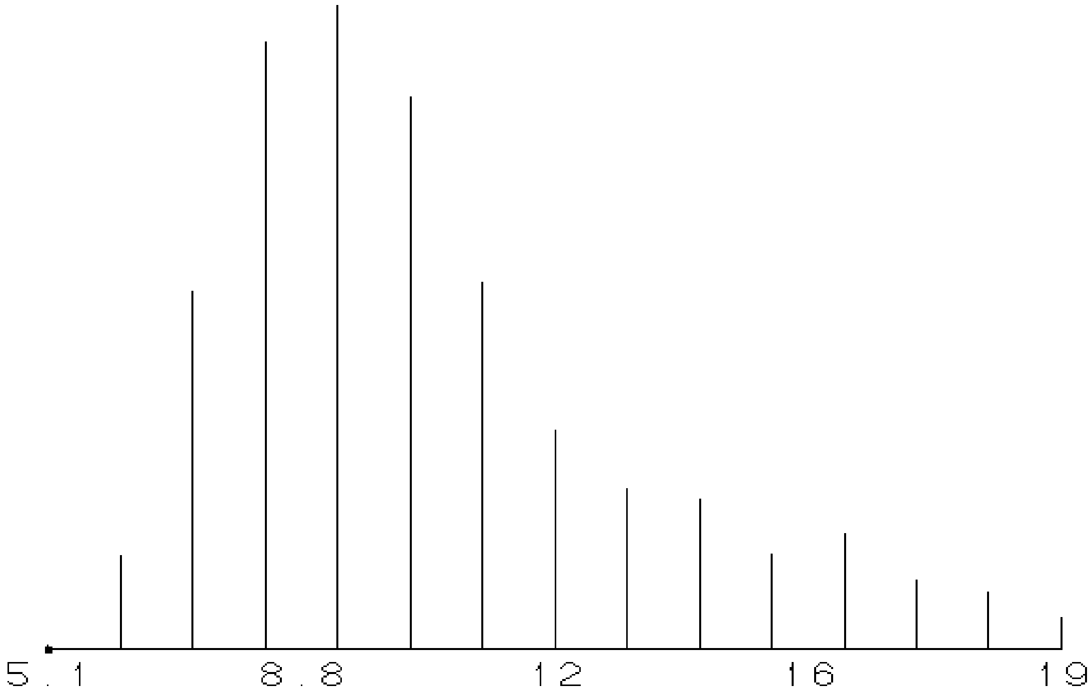


Figure 3.10 Histogram for Scenario 5 (fase 2) - 4x500 kW wind park (LECx100)

3.1.1.3 Conclusions

There LEC maps show the largest accuracy that it is possible to reach using the modified model mentioned before. A large number of areas was eliminated due to a more detailed filtering, allowing a more selctive choice of high potential zones.

All the high potential places in Serra do pico da Antónia were practically excluded due to the high inclination of the land. The inhabited areas were also excluded with reasonable detail. The area of S. Filipe, for example, was excluded for being close to inhabited areas, in spite of good conditions.

The most important conclusions, comparing the results from the two models, are related to LEC values. This can be noticed by comparing the histograms for the same installed power.

Before starting with comparative analysis it is necessary to notice that both calculations and data are similar for both models. The difference between the models resides in the way we calculate the wind speed grid. SOLARGIS standard model uses the average wind speed inside a 1 km2 area and uses it to calculate wind generator power. The new 250x250m model uses the average power produced by wind generators disposed according to the layout specified in the kernel.

Average LEC values are similar for both models. The same can't be stated for minimum LEC values which are the most important. The minimum LEC value for the 1 km2 model and for the 1 MW scenario is around 0.07 ECU/kWh but for the 250x250m scenario is around 0.06

ECU/kWh. These results derive from the fact that, with a higher resolution, the localization of wind turbines is optimized since wind speeds are higher than average values for 1 km2.

In the standard model we may also notice that, when we install a park with a higher power, LEC decreases substantially. This does not happen for the 250X250m model since there are two contradictory factors leading to an equilibrium in the LEC. On one hand we have the same infrastructure and connection costs for a higher energy production, leading to lower values for the LEC. On the other hand, the park will occupy a larger area, where some wind turbines will be installed in less favorable sites, reducing the park global capacity factor and, consequently, increasing LEC.

With this new high-resolution model, we verify that the park layout as well as the number and power of wind turbines are extremely important. We will analyse the example of *Monte Babosa*: The summit of the mount has excellent wind conditions, but only has place for 3 wind turbines. Notice that, in figure 3.1 (3X300 kW), the top of this mount is detected as being the most favorable place. On the contrary, for scenario 9X300 kW, in fig. 3.2 the most favorable place becomes the base of the mount, where wind conditions are not as good but with more space for the installation of a 9 wind turbine park.

In order to analyse the influence of the type of wind turbines, we should compare scenario 2 (9x300kW) and scenario 3 (6x500kW), considering that the same unit costs and CF curves were used. LEC maps are very similar but LEC values are lower in scenario 3 due to a more efficient attribution of wind turbines to places with better resources. One should notice that if we had used unit costs and CF curves corresponding to the 500 kW wind generators, the LEC would be even lower.

As a conclusion for the first phase, we may assert that the best places for the localization of a 3 MW park are: *Monte de S. Filipe, Achada Grande*, near *Monte Babosa*, near *Trindade, Achada Aguada*, and *Monte Sopra Bulo*.

First phase wind turbines are already installed and in operation since middle 1995. Three 300 kW wind generators were installed in Monte de S.Filipe and connected to the network by an underground cable, represented in Fig. 3.5.

In a second phase, the possibility of connecting another 2 MW was studied, considering the existence of an already installed cable. Two scenarios were considered: 6x300 kW and 4x500 kW. The results show that the installation of 500 kW wind turbines leads to lower LEC values. One may notice also that the best places for the installation of the park is still Monte de S.Filipe, where LEC values are lower near the installed cable.

3.2 ISOLATED SYSTEMS

The most important difficulty when studying isolated systems is related to load characterization.

Based on the population grid shown in Fig. 2.5 and in typical *per capita* demand, we have estimated demand for each house.

We have implemented a clustering methodology based on distances between houses: if in a group of houses the distance between each house is less than 160 m, then these houses will be considered as a cluster. The characterization of demand for hybrid systems and for systems connected to the network will be based on these clusters. With this clustering methodology it is possible to separate inhabited areas, physically grouped due to various geographical elements.

Calculations are performed in the same way as in 2.3.2. The only difference lays in the fact that in 2.3.2 clusters are delimited by 1 km2 elements, and in this study clusters are defined using the methodology described in the previous paragraph.

Our study analyses three types of systems:

1. **Small wind, PV, Diesel or gasoline systems for supplying isolated houses**. The question, in these systems, is in knowing the demand of the system to be to supplying. The solution is to assume a certain typical scenario. Result analysis should always take in account the typical demand for which the study was performed. The number of systems will be proportional to the number of existing houses. These systems are the ones that have higher LEC values and, consequently, are only interesting for dispersed houses far from the electrical network.
2. **Hybrid systems or Diesel systems for power between 20 and 300 kW**. These systems are the most appropriate for supplying small villages. The power to be installed has to be estimated. This task is more complicated for these cases than for the cases we discussed in the previous point because it is necessary not only to know the potential demand but also to delimit the area to be supplied and the consumers. The solution used in the standard SOLARGIS model was to assume that the system will only supply the area corresponding to a grid element (1 km^2). In the model presented in this report we assumed that one system will supply a group of clients determined by clustering algorithms.
3. **Systems connected to existing networks**. This approach is specially important for Cabo Verde, as there are already groups of dispersed networks that may be considered as Diesel or hybrid systems already installed. The objective is to determine the feasibility of their expansion. Network expansion is done by the implantation of a new secondary substation, supplying a cluster of clients connected to this substation and supplied by an internal LV network.

The data and scenarios for this study are the same as in point 2.2.2.

3.2.1 SCENARIO 1996

Reference economical parameters	Unit	Investment (Ecu/unit)	Lifetime (years)	Maintenance (Ecu/unit.year)
0.25 kW wind turbine	kW	11000	15	275
2.2 kW Diesel generator	kW	900	25	10
Photovoltaic generator	kWp	8000	20	0
0.7 kW Gasoline generator	kW	400	15	20
Lead/acid battery	kWh	140	5	0
4 MW Medium voltage line	km	25000	35	1000
50 kVA MV/LV substation	1	8730	35	100
Low voltage line	km	7000	35	200
100 kW wind turbine	kW	1334	20	60
100 kW diesel generator	kW	266	20	30

Table 3 Reference economical parameters for scenario 1996

Load type	Lighting + radio
Load level	400 Wh/day .house = 29.2 kWh/capita.year
Mean power / maximum power	0.5
Discount rate	0.08
Diesel price	0.4 Ecu/liter
Gasoline price	0.7 Ecu/liter
Grid electricity price	0.25 Ecu/kWh
CO2 tax	0 Ecu/ton
C10 Battery capacity for WT and PV	1.2 kWh
C10 Battery capacity for diesel and gasoline	0.8 kWh
Performance ratio for WT and PV	0.6
Performance ratio for diesel and gasoline	0.95

Table 4 Load characteristics for scenario 1996

REGIONAL POTENTIAL	PV	WT	W/D
Total number of potential consumers	19100	4821	5763
Total number of installed systems	3819	964	7
Total power of installed systems (kWc)	494	55	350
Total energy production (kWh)	557708	140771	168280
Total investment (kECU)	3950	605	667.5

Table 5 Regional potential for scenario 1996

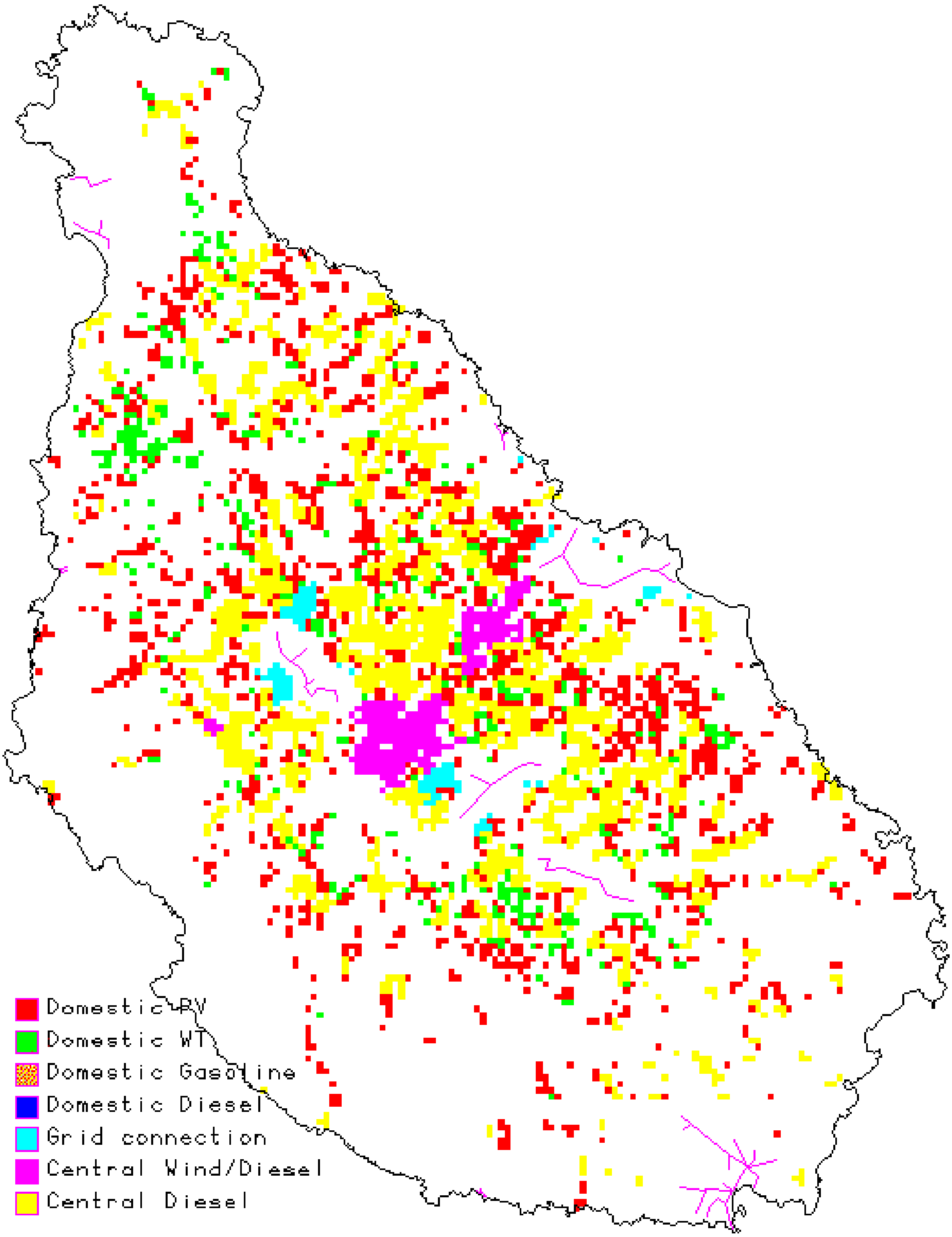


Figure 3.11 Best system for scenario 1996

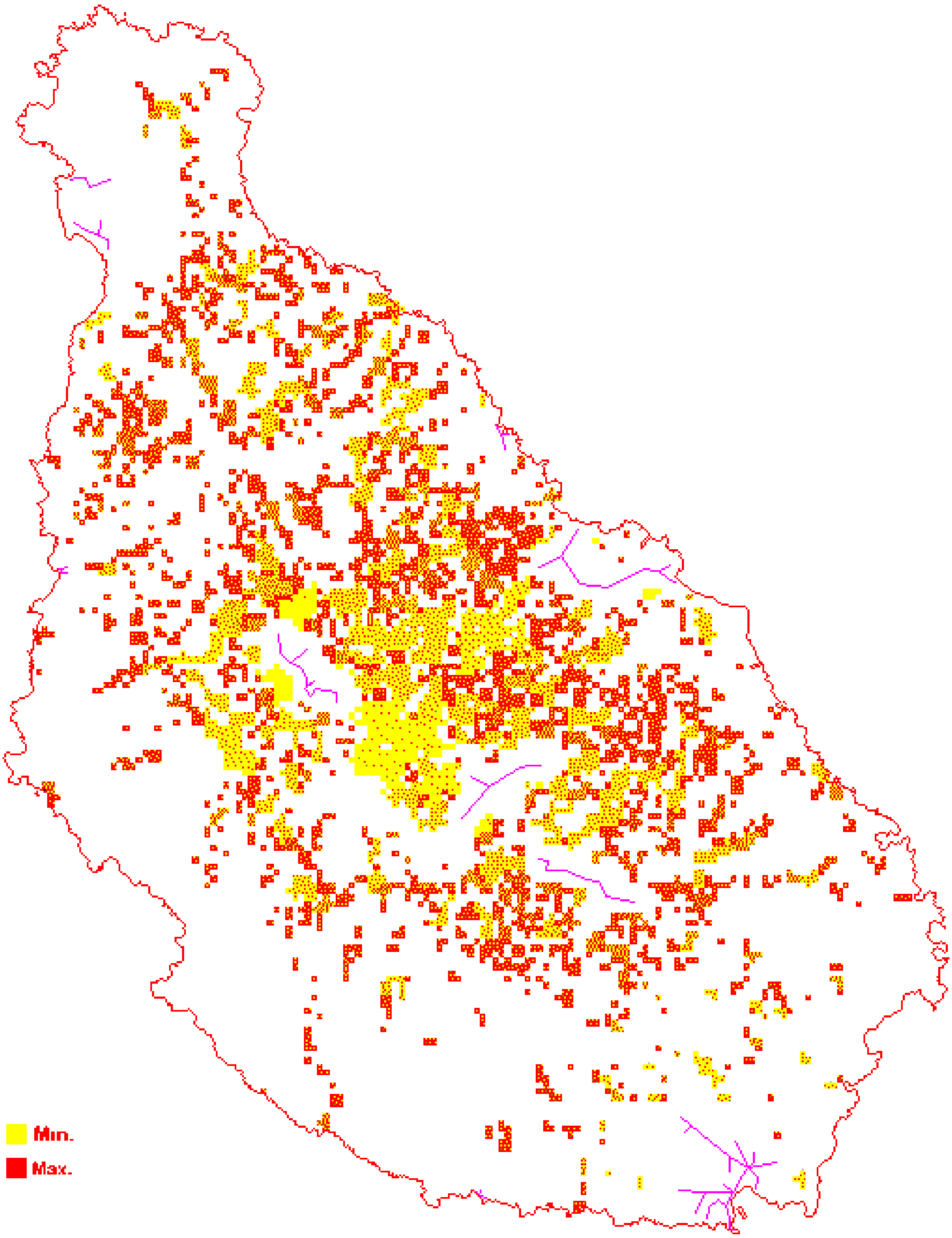


Figure 3.12 Best LEC for scenario 1996

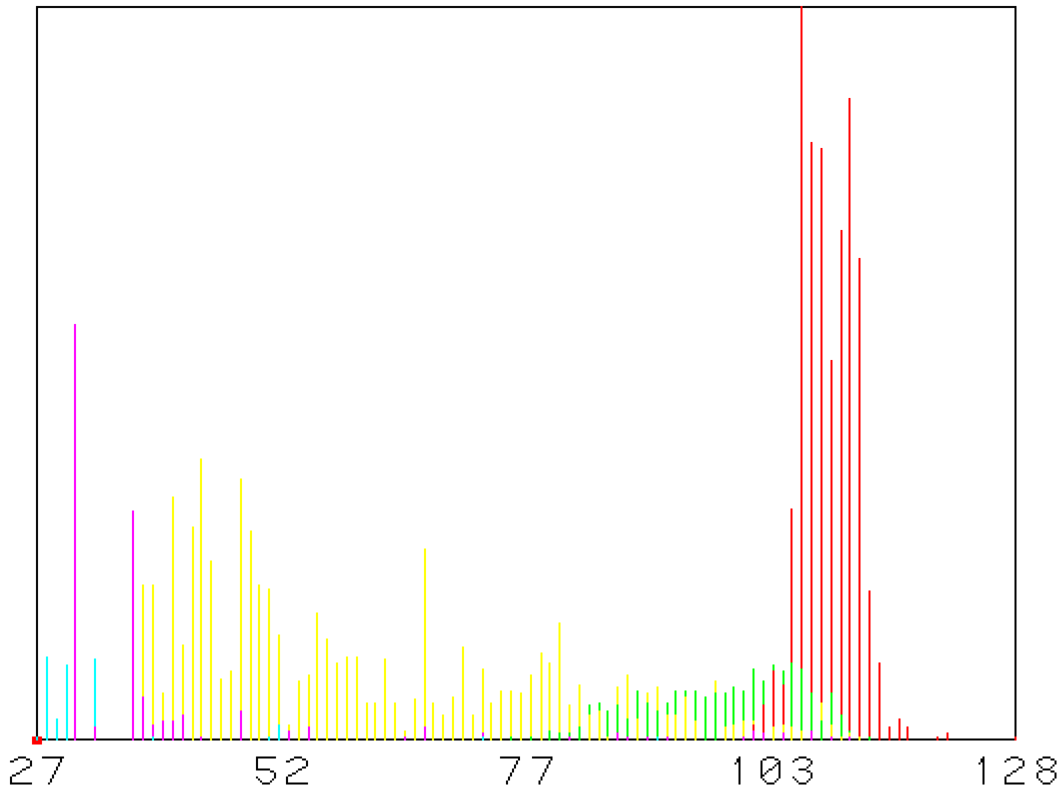


Figure 3.13 Best system grid histogram for scenario 1996 (LECx100)

Comparing results from point 2.3.2 with the results obtained with this higher resolution method, some conclusions arise:

- Filtering is more detailed, detecting a large area of non-inhabited places.
- The distribution of types of systems presented by both methods is similar.
- Small PV and wind power systems are scattered throughout the island, being difficult the definition of PV or wind areas.
- We may observe that wind systems are highly dependent on local wind conditions.
- Feasibilty of grid connection is evident in highly populated areas near the network.
- In the high resolution model, small isolated PV or wind systems are able to compete with Diesel systems, due to low demand.
- With the high resolution model, WD systems may be placed in the areas with better wind conditions nad higher population density. This was not possible with the previous model, that used average wind speed for an 1 km2 area, not being able to detect locals with higher wind speeds. Thus, with this modified model, it is possible to detect a larger market for hybrid systems that was not possible to detect with the previous model.

3.2.2 SCENARIO 2010

Reference economical parameters	Unit	Investment (Ecu/unit)	Lifetime (years)	Maintenance (Ecu/unit.year)
0.3 kW wind turbine	kW	7000	15	175
2.2 kW Diesel generator	kW	900	10	10
Photovoltaic generator	kWp	4000	20	0
0.7 kW Gasoline generator	kW	400	5	20
Lead/acid battery	kWh	140	5	0
4 MW Medium voltage line	km	25000	35	1000
50 kVA MV/LV substation	1	8730	35	100
Low voltage line	km	7000	35	200
100 kW wind turbine	kW	1334	20	60
100 kW diesel generator	kW	266	20	30

Table 6 Reference economical parameters for scenario 2010

Load type	Lighting + refrigerator + TV
Load level	1200 Wh/day .house = 87.6 kWh/capita.year
Mean power / maximum power	0.5
Discount rate	0.08
Diesel price	1.07 Ecu/liter
Gasoline price	1.58 Ecu/liter
Grid electricity price	0.25 Ecu/kWh
CO2 tax	0 Ecu/ton
C10 Battery capacity for WT and PV	3.6 kWh
C10 Battery capacity for diesel and gasoline	0.8 kWh
Performance ratio for WT and PV	0.65
Performance ratio for diesel and gasoline	0.95

Table 7 Load caracteristics for scenario 2010

REGIONAL POTENTIAL	PV	WT	W/D
Total number of potential consumers	24858	1229	3862
Total number of installed systems	4972	246	16
Total power of installed systems (kWc)	1776	33	483
Total energy production (kWh)	2177523	107641	3443154
Total investment (kECU)	7103	231	942

Table 8 Regional potential for scenario 2010

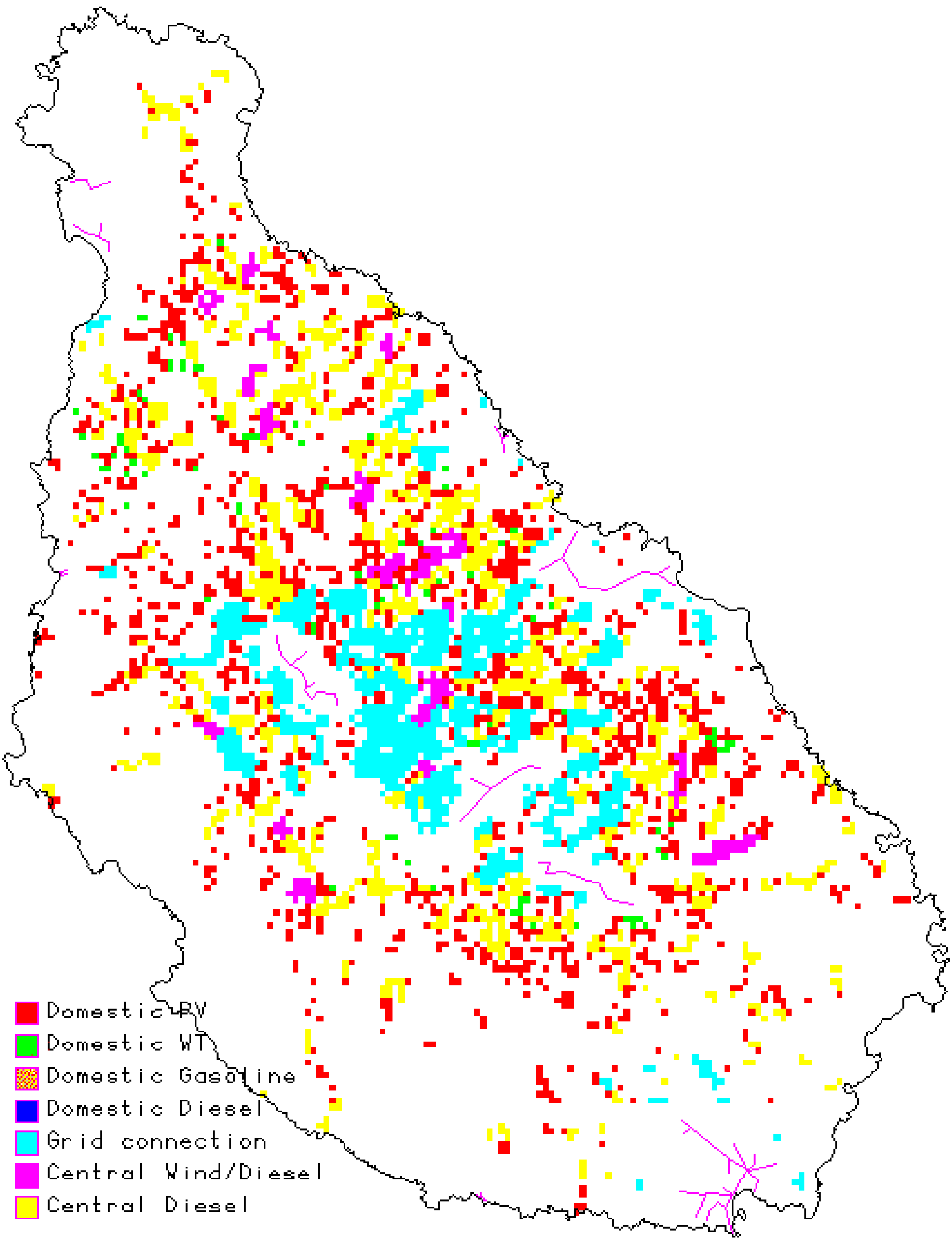


Figure 3.14 Best system for scenario 2010

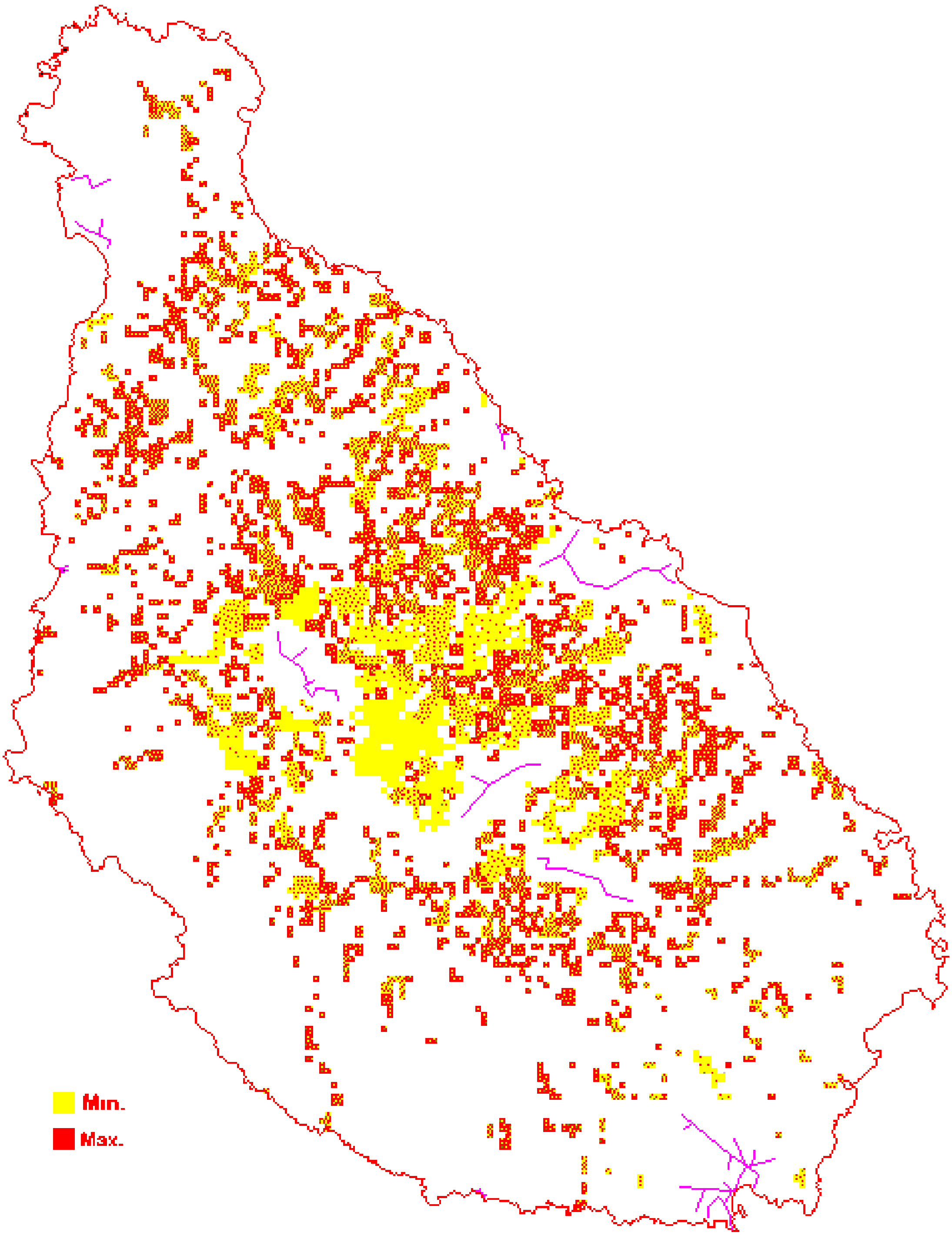


Figure 3.15 Best LEC for scenario 2010

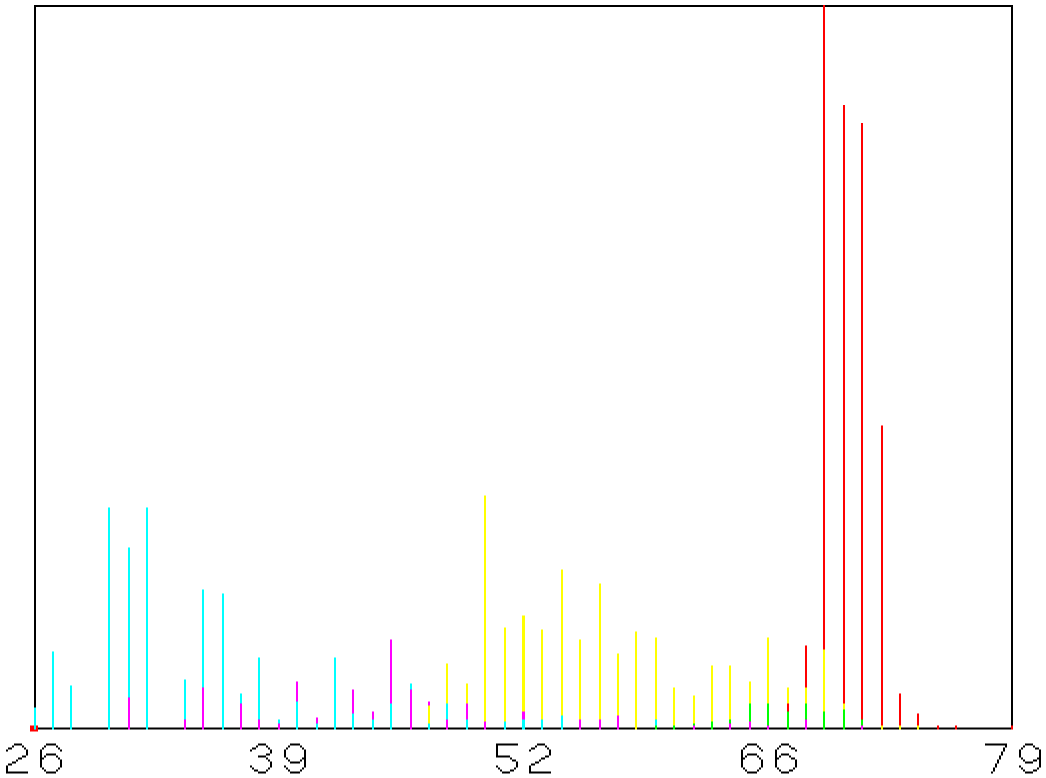


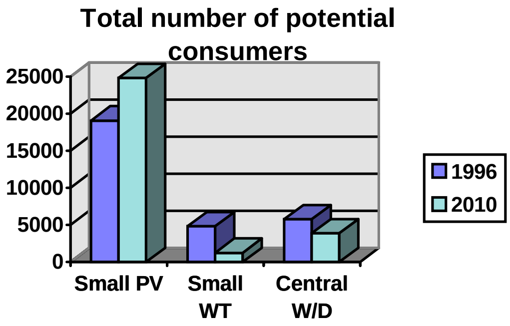
Figure 3.16 Best system grid histogram for scenario 2010 (LECx100)

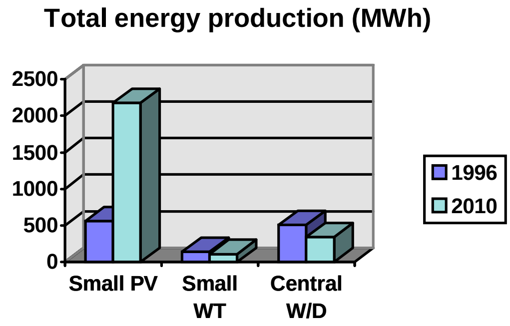
For the 2010 scenario we observe similar evolution for the results obtained in 2.2.2. Demand increase makes grid connection interesting for some groups of consumers with higher load density. Some of these places candidate for grid connection are the places that in scenario 1996 were WD systems. This way, we predict the feasibility of producing with WD systems from the small existing networks.

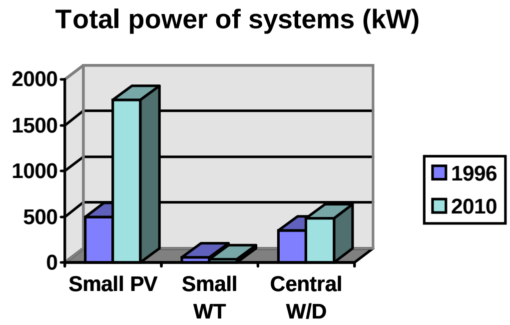
The areas for which the best systems are WD normally are areas in which demand density is high. Anyway, these places always correspond to areas of high average wind speeds.

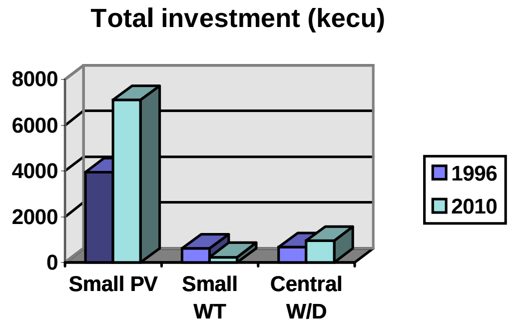
In what concerns to small systems, we may conclude that PV systems maintain their place in the market, supplying the same areas as in 1996. On the other hand, small wind systems lose market for PV or Diesel systems, for different reasons: they lose for PV systems because it is forecasted a 30% cost reduction for wind systems compared to 50% for PV systems; they lose for Diesel systems, due to increased demand, making Diesel more interesting. Curiously, we verify that there are very few cases in which wind systems give place to WD systems, because WD are only feasible for higher demand density.

3.2.3 COMPARISON OF SCENARIOS









Inspecting the charts above, we may notice that the potential market for PV systems will increase until 2010, and a 50% cost reduction is expected.

Wind systems have a smaller market, tending to disapear by 2010, unless cost reduction for these systems is over 30%, which is no likely to occur.

Regarding WD systems, we may conclude that there is a considerable market, tending to increase until 2010. One should notice that, in the results for 2010, WD systems are not considered being integrated in the electrical networks.

4. GENERAL CONCLUSIONS AND PROSPECTS

4.1 CONCLUSIONS FOR THE STUDIED REGION

This study emphasizes the aptitude of Cabo Verde for the integration of renewable energy sources. On one hand, Cabo Verde has severe energy problems allied to social and isolation problems. These problems may be solved with the integration of several renewable energy systems. On the other hand, Cape Verde is one of the countries in the world with higher wind and solar resources, justifying the efficiency of the several systems to be implemented.

The total dependence of international market on fuel can be atenuated, thanks to the integration of renewable resources like wind and solar power. These resources are one of the greatest assets of Cape Verde and should be used as a national product able to generate wealth for the country. This wealth may be seen as a direct consequence of the lack of necessity to import fuel and also as a consequence of the externalities that come from the use of renewable forms of energy and electricity in general.

Clearly, electricity is an indispensible added value for any society. Electrical energy provides comodity in domestic uses, provides safety and quality in public institutions, and furnishes the means for industrial progress. However, in Cape Verde, electricity is even more important, providing water to the population. Water is the most serious problem in Cape Verde, and electricity is one of the means to solve this problem, either by pumping or by desalination.

The necessity for electrification is obvious. However, there are the typical problems of a young developing country that delay or deter the objectives of electrification for the whole population.

The problems of existing networks are related to an insufficient production capacity. From our studies we have concluded that wind parks are a feasible investment with several possible locations, being able to help transcend these limitations. Unfortunatly, penetration of wind power conditions service quality. This means that the integration of wind power has to be accompanied by an increased production by conventional means. In Cape Verde, penetration level is reaching its limit and it is certain that by the year 2000, we will reach the maximum possible energy injected in the network from wind resources.

Presently, studies are being performed on network stability in order to estimate the maximum admissible penetration value.

It is forecasted that, by the year 2020, there will be a MV network connecting all small networks in Santiago. By that time it will be possible to take advantage of the excellent places for installing wind parks in northern and central Santiago. Meanwhile, some measures will have to be taken in order to guarantee the electrification of rural areas, using isolated systems and small local networks.

From our study, we may predict the following evolution for the electrification of the island of Santiago:

1. Presently (Fig. 3.11)

- An effort must be made to expand existing networks to areas where this expansion is feaseble.
- Measures have to be taken in order to guarantee the electrification of more populated areas, using medium size isolated systems (Diesel or wind/Diesel). Renewable systems should be incentivated by the governemnt in order to compensate for large initial investements.
- Integration plans should be developed and implemented for small wind or PV systems, supplying individual houses.

2. For the year 2010 (Figure 3.14)

- According to our studies, load growth will justify the expansion of presently isolated networks, leading to an interconnection of adjacent networks.
- Some of the isolated systems will be integrated in nearby networks. Thus, during their installation one should choose the adequate equipment in order to minimize the cost of future modifications.
- In places of good wind conditions, some Diesel systems may become wind/Diesel due to an increased demand. In these cases, it is necessary to consider some technical details when installing these diesel systems.
- Small isolated systems will still be the best solution for isolated houses. In 2010, there should be a strong and perfectly implanted market functioning as a commercial and technical support for this type of systems.

3. For the year 2020

- By the year 2020, it is forecasted that the whole island will be connected, with an MV line between *Praia* and *Assomada* and another two MV lines between *Assomada* and *Pedra Badejo* and *Assomada* and *Tarrafal*. There's also the possibility of building a conventional power station in central or northern Santiago. These changes will allow the implantation of new wind parks in extremely favourable areas in northern or central parts of the island.

- Small isolated networks will be inteconnected to the island's main grid, being explored globally by a single distribution company.
- Probably, some isolated areas will still be supplied by small individual systems or by medium size isolated systems, depending on the technology existing in 2020. One should notice that in 2020 the main concern will be quality and not quantity of electrification.

Since the 80s that Cape Verde has been a stage for inumerous experiments in renewable forms of energy. However, these experiments have, as main objective, the test for new technologies and not precisely the search of solutions for the country's energy problems. The insufficiency of global planning for the energy sector leads to the lack of solid structures for the integration of renewable forms of energy in an efficient manner. There has only been a group of initiatives falling short of their objectives due to deficient planning, accompanying and continuity.

In order to avoid losing another great opportunity for renewable forms of energy in Cape Verde, we suggest the following:

- The constitution of a fund for the development of renewable forms of energy, offering good loan conditions and guarantees for investment. This fund should be supported by the state and by development banks, assisted by a technical committee for control and counseling. The access to these funds should be possible through local banks.
- Assure the cooperation between the several government departments in order to guarantee a convergence of objectives leading to the incentive of renewable energy.
- All these initiatives should be integrateble in a global plan aiming at 2020. The most important step will be to create a strong support structure in order to ease the integration of renewable energy in the years ahead.
- Elaborate adequate legislation permitting the existence of independent producers and, at the same time, create control and coordination mechanisms in order to guarantee the necessary competitively in the energy market and to assure price normalization.
- Create professional and industrial organizations, in order to ensure technical formation and the development of commercial structures and technical assistance at reasonable costs.

Finally we hope that, in Cape Verde, renewable forms of energy will no longer be an experiment, becoming the solution for the energy problems of this country.

4.2 SOLARGIS CONTRIBUTION

In this project, we have proven the efficiency of Geographical Information Systems in the study of the integration of renewable forms of energy. It is important to notice that 90% of the information, in a study such as this, has geographical characteristics. Thus, it is obvious the need for the use of this type of tool in the analysis, manipulation and elaboration of maps.

The first and most time-consuming phase of the project, was the gathering of data and the development of the databases necessary to the implemented methodologies. These databases constitute one of the final products of the project and may be used in future projects involving GIS. Several thematic coverages were built such as: orographic coverage, digital land models, hidrographic network, road network, house coverage, administrative coverage, etc.

The second phase of the project involved the mapping of solar and wind resources.

For wind potential mapping, we used several methodologies internationally recognized, while for solar potential mapping we have implemented platform-specific GIS methodologies. As a result we have obtained wind speed and global radiation grids for the island of Santiago with a 250x250m resolution.

Apart from the studies presented in this report, there are some tools implemented in GIS that allow the introduction of new input data obtaining different output maps, allowing an interactive analysis by the planners. These tools constitute a powerful support mean for integration planning allowing, in an user-friendly manner, to change technical and economical parameters and to view the results with adequate detail.