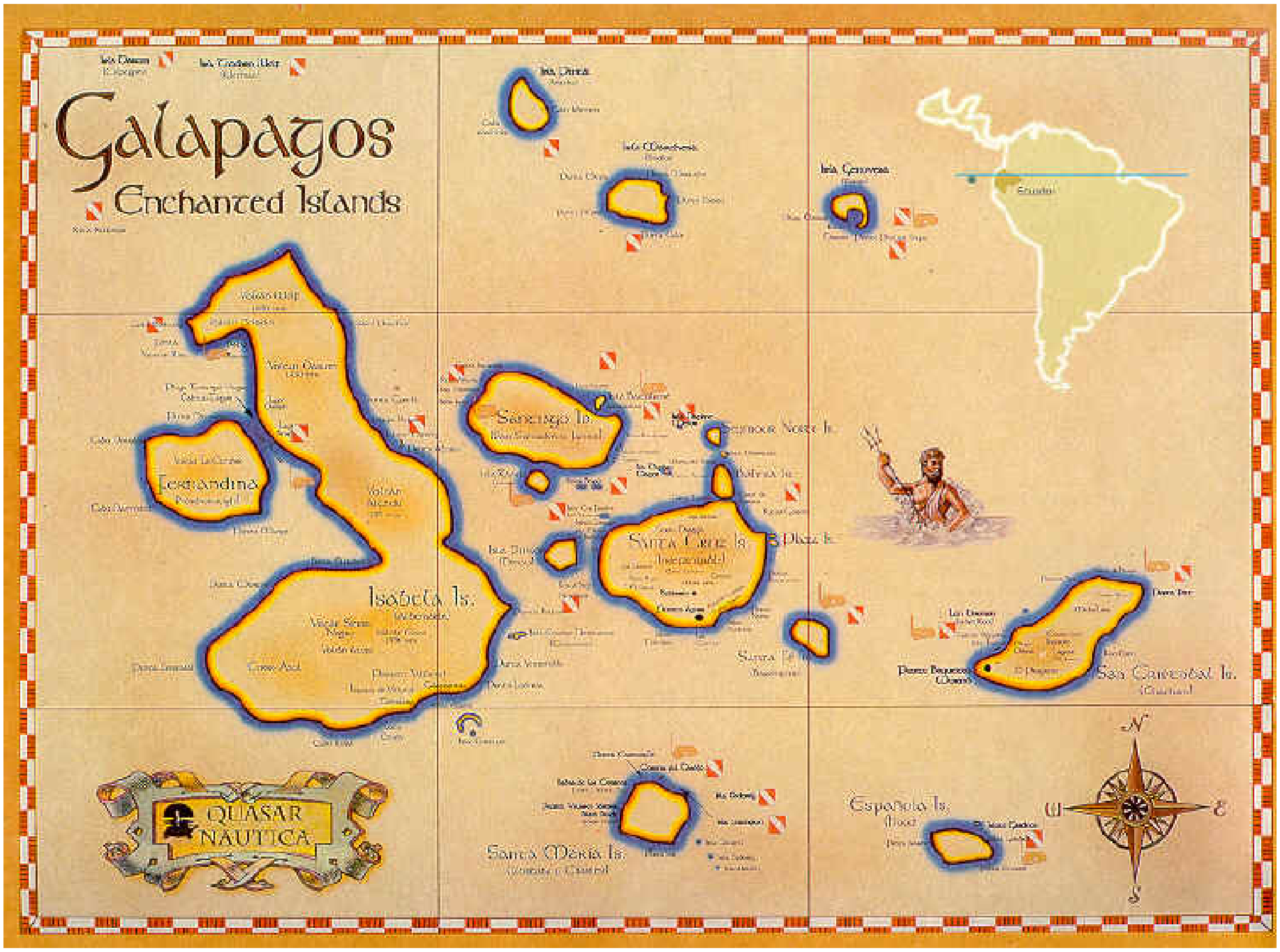
An Assessment of Energy and Water in the Galápagos Islands



Debora Ley

Master's Project Report
Building Systems Program
University of Colorado

Table of Contents

1. ABSTRACT 1-3
2. INTRODUCTION AND BACKGROUND 2-4
   2.1 Geographical Location 2-6
   2.2 Date and History of Establishment 2-7
   2.3 Area 2-8
   2.4 Altitude 2-8
   2.5 Physical Features 2-8
   2.6 Climate 2-8
   2.7 Cultural Heritage 2-8
   2.8 Local Human Population 2-9
   2.9 Economy 2-9
   2.10 Visitors and Visitor Facilities 2-10
   2.11 Conservation Value 2-10
   2.12 The Jessica Oil Spill 2-10
   2.13 Trip Observations 2-12
3. POPULATION AND SERVICES IN GALÁPAGOS 3-15
   3.1 Population 3-15
   3.2 Buildings by Island 3-18
      3.2.1 Santa Cruz: 3-18
      3.2.2 San Cristóbal: 3-19
      3.2.3 Isabela: 3-19
   3.3 Schools 3-20
   3.4 Additional information 3-21
4. ENERGY GENERATION AND CONSUMPTION 4-24
   4.1 Supply of Fuel on the Islands 4-24
   4.2 Fuel Consumption 4-24
   4.3 Emissions 4-25
   4.3 Electricity Generation 4-27
      4.4.1 Sta. Cruz 4-28
      4.4.2 San Cristóbal 4-30
      4.4.3 Isabela 4-31
      4.4.4 Floreana 4-32
   4.5 Utility Data 4-32
      4.5.1 Residences 4-36
      4.5.2 Hotels 4-39
      4.5.3 Schools 4-39
5. RESOURCE DATA 5-41
6. WATER 6-44
   6.1 Introduction: Water Requirements and Availability 6-44
   6.2 Sta. Cruz 6-47
   6.3 San Cristóbal 6-49
   6.4 Isabela 6-50
7. BOATS 7-51
8. RENEWABLE ENERGY IN GALÁPAGOS 8-53

8.1 Schools 8-53
8.2 Hotels 8-57
8.3 Stores 8-58
8.4 Solar System of the Research Station of the Bolivar Canal, Galápagos National Park 8-58
8.5 Other uses 8-59
8.6 Wind and Biomass 8-59
9. NEW PROPOSALS AND STUDIES 9-60
9.1 Floreana’s renewable energy electrification project 9-60
9.2 Waste Management in the Galápagos Islands 9-62
9.3 Other Renewable Energy Activities and Proposals 9-66
10. HOMER SIMULATION 10-68
10.1 Components 10-68
10.2 Simulation Parameters 10-70
10.3 Simulation Results 10-72
11. CONCLUSIONS 11-74
12. BIBLIOGRAPHY 12-78
13. ACKNOWLEDGEMENTS 13-80
14. APPENDIX 14-81
14.1 People Visited 14-81
14.2 Inventory of Documents 14-82
14.3 Detailed Population Data 14-84
14.4 Utility Data of Some Schools, Hotels, Stores and Offices 14-85
14.5 Electricity Generation 14-88
14.6 Complete List of Tourism Facilities and Boat information 14-93

1. ABSTRACT

This report assesses energy and water conditions and analyzes the use of distributed generation in the Galápagos Islands. As a protected area, the use of fossil fuels is problematic because spills and air pollution could have detrimental effects on the environment and permanently damage the fragile ecosystem. The water quality and quantity concerns also present unique challenges to each individual island. In general, the problem constrains development and affects the quality of life of the islands' inhabitants. The collected information identifies the particularities of each island's energy and water situation and the potential to make improvements.

2. INTRODUCTION AND BACKGROUND

The World Wildlife Fund has initiated a sustainability and renewable energy program in the region, with the goal of having 70% of the electricity production come from renewable energy by the year 2010.

Due to its remote location, the transportation of fossil fuel to the islands is difficult and has the inherent danger of spilling and contaminating the sites. In fact, such spills have already occurred twice. On the other hand, several photovoltaic and solar water heating systems are in service and have been achieving good results. Consequently, the prospect of significant growth of distributed generation is expected.

The distributed generation systems designed and included in a report for a prior class entitled "Distributed Electricity Generation" were optimized using three different models that employed several key assumptions. The first system was designed for an eco-tourism hotel located in the coastal region. The second system was designed for a village containing 20 dwellings and a school. We assumed that the village did not provide all basic services and that the villagers had to travel to the nearest town to find these services. The last system was designed for an entire town. The town would be largely self-contained, including a hospital, school, and small offices. The town's system was sized to meet the loads of 200 dwellings and a proportional number of services. To size the proportional loads for the town's systems, assumptions were made regarding the relationship between population and loads. The most significant assumption is that heating and cooling loads do not exist.

The islands have two distinct environments, the mountains and the coast. The wind and solar resources are classified according to island and environment type. As such, five systems were presented for each of the four populated islands; one hotel for eco-tourism, one town in the mountains, one town on the coast, one village in the mountains and one village on the coast.

The main objective of this report is to verify the data that was used for the project worked during the Distributed Electricity Generation class, CVEN 4830, during Fall Semester 2001. A variety of assumptions were taken for the design of the renewable energy systems, since the necessary data was not available. The main activities carried out on each of the three islands visited[1] (Santa Cruz, San Cristóbal and Isabela) were as follows:

[1] The island of Floreana was not visited due to time constraints. Also, access to Floreana is difficult since there is no airport and the only way to get there is by boat. During the weeks I was there, waters were getting rough because of winter and I was informed that the minimum length of time I had to stay in Floreana was of one week, thus, the island was not visited. This didn't affect the outcome of the trip since utility data was obtained from Elecgalápagos headquarters

1. Obtain the current actual production and perform a survey of the existing photovoltaic installations, find out what problems the systems have had, operation and maintenance issues and performance.

2. Verify the average monthly temperature, solar insolation and wind velocity. Obtain recent resource data. Go to the monitoring stations and see how the equipment was set up and how the monthly averages were obtained. Also, the maximum and minimum values should be obtained, if they exist. Were the measurements taken every hour? Or were they an average of the hourly variations? Is there information on the predominant wind direction? Are there graphs?

3. Our original load profiles were obtained from DOE2 output files. In order to have accurate information, I need to obtain monthly electrical bills for several years (at least three) in order to obtain the trend in energy consumption. We need to know if it has remained constant, and, in the case that it has changed, the average annual increase that occurs. With the utility bills we can get a better idea of where the energy goes to - the percentages of energy consumption by sector. The number of buildings per type and by island also has to be determined. With the electrical bills we would know the monthly loads for the different building types that we considered. The electricity consuming equipment used in each building should also be assessed to verify our assumptions.

4. Obtain recent population data. Find out what happens in the regions between the coast and the mountains. Is there any population? Is the installation of monitoring stations in these regions planned? Were our village and town assumptions correct, in terms of what a town and a village have? To answer these questions, it would be good to visit a rural and an urban typical household to find out loads as well as average population (number of people in urban and rural dwellings and percentage of dwellings on hill and coast). Finally, the number of immigrants per year also has to be obtained in order to have a better feel of the population growth.

5. Visit existing power generation plants, and find out the type, the capacity, and O&M costs. Investigate if there are any wind systems in the region and if so, see what the system configuration is, its production, applications, specifications, etc.

6. Verify component and O&M costs specific to the Galápagos. Also, obtain operational costs and characteristics for generator installation to verify our assumptions that were fed into HOMER.

---

and population information was obtained from the Census. Information regarding the use of renewable energy was also obtained, and can be seen in Section 9 of this Report.

7. Since it was found that the Galápagos Islands have poor water conditions (water is brackish), and groundwater is contaminated, if there is time, I would like to study the possibility of using photovoltaic and wind energy for water purification.

8. The tourism industry, just like any other industry, is an important component of the built environment. The activities that take place due to the tourism installation are a source of environmental impacts. These effects could reach inconvenient characteristics in countries where tourism is one of the main economic activities. It is evident that these adverse effects affect the same activity that generates them. With this in mind, it is important to quantify the impact of tourism in the area. This aspect is out of the scope of the project, but I think it's important to know the seasons in which the maximum number of tourists visits the Islands, as well as the estimated number of tourists for design purposes and a better calculation of the load profile of the hotels. How do the energy requirements vary in the different tourist attraction regions?

9. Investigate the number of boats (for tourism and for fishing) and the capacity range since boats are big fuel consumers.

10. Obtain general information on the effects of the January 2000 Jessica oil spill, as well as information on the oil spill that occurred on July 5th, 2002.

11. As a last item, and time permitting, I would like to do some research, probably in the Darwin Center, of the change in biodiversity since the Islands have been populated. Even though the species may live in harmony with the humans, it would be interesting to see how much impact humans and their activity actually have.

A general description of the geographical, cultural, social and economical background of the Galápagos Islands is presented prior to the trip results just to give an idea of what the environment is like. Information is presented in this format to better understand the way each activity was carried out. More detailed aspects will be discussed in other sections of this report.

2.1 Geographical Location

The Galápagos Archipelago is situated in the east Pacific Ocean (1°40' N - 1°36' S, 89°16' - 92°01'W), 1000km from the mainland of Ecuador, with the equator running through Wolf and Ecuador volcanoes on Isabela Island.

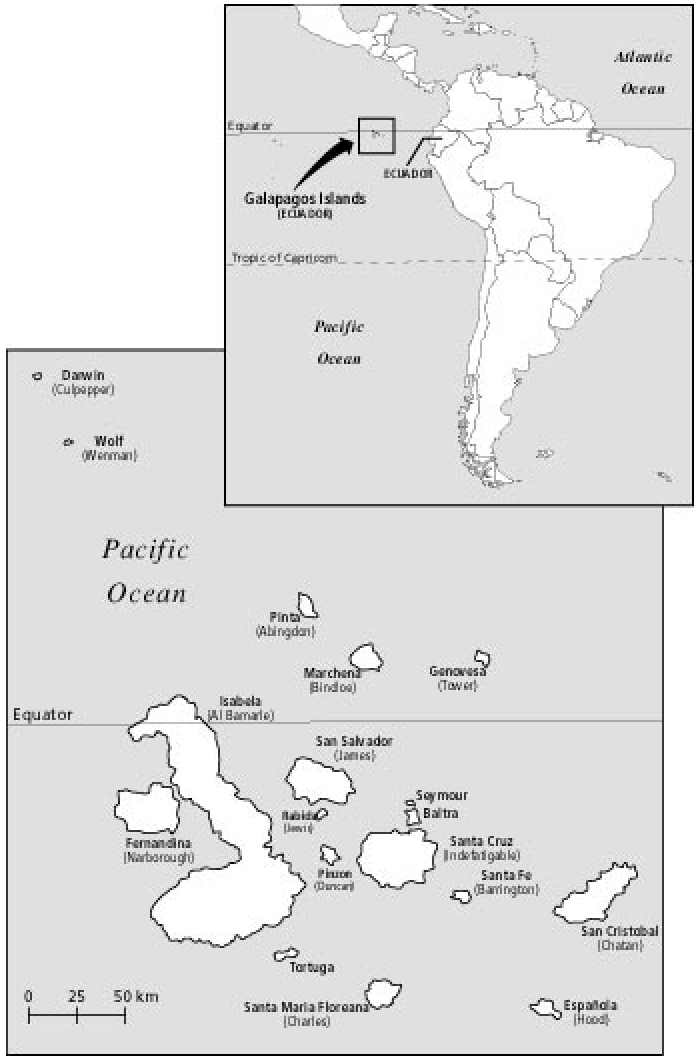


Figure 2.1 Geographical location of the Galápagos Islands

2.2 Date and History of Establishment

Galápagos National Park was established on May 14th, 1936 and ratified on July 4th, 1959. At that time, the boundary of the National Park was fixed to include all Galápagos Islands, except those that had already been colonized as of July 20th, 1959. After final establishment of the boundaries in 1968, 96% of the land area of the archipelago was included in the park. The Galápagos Islands were inscribed on the World Heritage List in 1978 and were internationally recognized as a Biosphere Reserve under the UNESCO Man and the Biosphere Programme in 1984. In 1986, the Galápagos Marine Resources Reserve (GMRR) was established including all waters within 15 nautical miles of a baseline joining the outermost points of the Galápagos Islands. This was upgraded to a Biological Reserve of Marine Resources in December 1996.

2.3 Area

The area of Galápagos National Park is of 766,514ha, comprising 96.6% of the land area of the archipelago. The marine reserve covers some 7,990,000ha.

2.4 Altitude

The altitude varies from sea level to 1,707m (Wolf Volcano), which is the highest in the Archipelago.

2.5 Physical Features

The Archipelago of Galápagos is situated on the Galápagos Submarine Platform, and consists of about 120 islands, with a total surface of 8000 km^2. In geological terms, the islands are young and it is calculated that even the oldest parts are only three to four million years old. Volcanic processes formed them and most represent the summit of a volcano, some of which rise over 3,000m from the Pacific Ocean floor.

Freshwater is limited and among the inhabited islands, only San Cristóbal has an adequate perennial supply for human consumption. Seasonal springs occur on Santa Cruz and Floreana, and brackish water is available on all islands.

2.6 Climate

The Galápagos Islands' climate is strongly influenced by oceanic currents. The relatively cold Humboldt Current flows around and through the islands during most of the year. This current meets the warm tropical waters from the Gulf of Panama at a point north of the Archipelago. From January to April the convergence moves south and the warm current surrounds the islands. There are two seasons due to the shifting of the currents: 1) Cool temperatures (17°C-22°C), a fairly persistent fog or 'garua' that envelops the highlands of the larger islands in mist and drizzle, and southeasterly winds are common during the dry season. 2) Warmer temperatures (23°C-27°C), light easterly winds and seasonal rains characterize the variable short, hot season, caused by the warm current. Approximately every four years, heavy rainfalls occur during the warmer season. Temperatures generally decline by some 0.9°C for every 100 m altitude. At the wettest place at sea level, the mean annual precipitation is 356 mm, whilst at 200 m above sea level the equivalent figure is 1092 mm. More detailed weather information can be found in the Resource Data section (Section 5) of this Report.

2.7 Cultural Heritage

According to the writings of Miguel Caballo de Balboa, the Incas in the middle of the 15th century reportedly first discovered the Galápagos Islands. In

1535, the Bishop of Panama, Tomás de Berlanga, christened them Las Islas Encantadas and during the XVII and XVIII centuries, sailors, buccaneers and whalers used them as a stop-off. In 1832, colonel Ignacio Hernández colonized the Islands in the name of Ecuador. In 1835, Charles Darwin visited the Galápagos while on his voyage aboard the explorer ship *Beagle* and his observations while there, on species diversity between the islands, were later to support his theory of evolution, published in “The Origin of Species”. Despite visits by passing ships, the islands remained largely unsettled until the end of the last century. In 1959, the government of Ecuador converted the islands into a National Park with limited access.

2.8 Local Human Population

The 1996 resident population was estimated at around 15,000 inhabitants, who inhabit approximately 3% of the of the land area of the islands, specifically living on the islands of Santa Cruz, San Cristóbal, Isabela and Floreana. Population on the islands increased at a rate of 7.8% during the period 1990-1995, 1.7% due to natural increase, and 6.1% due to immigration from the mainland. Estimates of future population growth give an increase of 14,000-20,000 in 2003, 40,000 in 2015 and 80,000 in 2027. The greatest population increases have been on Santa Cruz and San Cristóbal Islands, where tourist facilities are based, and Isabela Island due to fishing activities. More detailed population information can be found in Section 2 of this report.

2.9 Economy

Tourism, cattle grazing and fishing are key components of the islands' economy. Cattle herds, numbering 3,000 on southern Isabela and 300 on Floreana, are kept by local people.

The administrative center is located in Puerto Baquerizo Moreno, in the Island of San Cristóbal. In the islands, different vegetables, tropical fruits, corn, sugar cane, cotton and coffee are cultivated. The main fishing products are tuna, jewfish and lobster. The islands also have good sulfur and salt mines.

The mainland-based business sector has been growing steadily since the 1980’s. It consists of two clearly differentiated groups: the tourism industry and the commercial fishery.

Each inhabited island has its own port and a farming area on the edges of wetlands beginning at an elevation of 300 m above sea level. People are engaged primarily in tourism, fishing, conservation work, and public administration. Two of every three economically active people are now employed either directly or indirectly in tourism-related activities, although this proportion may vary sharply from one island to the next. Small-scale fishing is a very important traditional activity and employs 13% of the economically active population; on some islands, this figure is as high as 30%.

2.10 Visitors and Visitor Facilities[2]

Approximately 42,000 tourists visited the islands in 1988. This figure increased to 56,000 in 1995, and to 62,000 in 1996. The value of Galápagos tourism to the national economy is estimated at US$55 millions per year. People visit the islands aboard large cruise ships, or arrive by air and use smaller boats for 6-12 passengers. Tourists are admitted into three of six zones and parts of islands are designated as 23 Intensive Visitor Zones, where a maximum of 90 people are allowed simultaneously on shore. The 17 Extensive Visitor Zones are only open to groups of less than 12 individuals. There also are 13 Recreative Zones. The use of licensed guides and marked trails is obligatory. Tourist scuba diving is increasing and major dive sites include Roca Redonda, Punta Vicente Roca (Isabela), Tagus Cove, Isla Albany (Santiago), Devil's Crown (Floreana), and Islands Darwin and Wolf. More tourism information can be found in Section 3 of this Report.

2.11 Conservation Value[3]

These volcanic islands have been called a unique "living museum and showcase of evolution". One-third of the island chain's vascular land plants are endemic, as are most of the land birds that breed here. The flora and fauna of the islands are of great value in terms of their endemism and diversity. The wealth and peculiarities of the marine environment are less well known but are equally interesting and special. Because of oceanographic conditions and the variety of coastal habitats, there is wide ecological and biological diversity. The islands constitute a refuge for threatened animal species, especially whales and green turtles.

The land and marine resources of the islands are important in terms of:

- Information for scientific research and study of species evolution and adaptation;
- Conservation of biodiversity in its natural setting.

2.12 The Jessica Oil Spill[4]

The fuel tanker Jessica grounded on Shiavioni reef at the entrance of Wreck Bay, San Cristóbal, at 10 pm on January 16th, 2000 carrying 240,000 gallons of fuel oil consisting of 160,000 gal of Diesel Oil #2 (DO#2) and 80,000

---

[2] "Islas Galápagos." Enciclopedia Microsoft Encarta 2001. 1993-2000 Microsoft Corporation.
[3] *Idem.*
[4] Biological Impacts of the Jessica Oil Spill on the Galápagos Environment, A Preliminary Report, August 2001. Charles Darwin Research Station and Galápagos National Park

gal of Intermediate Fuel Oil 120 (IFO 120, or bunker fuel). Approximately 5,000 gal of IFO and 55,000 gal of diesel were removed by the US Coast Guard, the Ecuadorian Navy and the local fishermen. By January 29th, most of the remaining 180,000 gal of fuel oil (75,000 gal of IFO 120 and 105 gal of DO#2) had dispersed to waters within the archipelago.

Researchers from the Charles Darwin Research Station and the Galápagos National Park contacted experts in the US and Africa and carried out the Galápagos Coastal Oil Survey. The results of the survey indicate that environmental contamination from the Jessica spill was broadly and thinly dispersed throughout the southwestern Archipelago. Bunker fuel went ashore at sites as remote as the coastlines of Fernandina and Isabela. The heaviest levels of shoreline contamination occurred on Floreana and Isabela, and lower levels were found at Santa Fe, Santa Cruz and San Cristóbal and secondary contamination (oiled debris and foam) was found on Española and Fernandina. Only one survey site contained sufficient coverage of oil to be termed 'moderate'. All other sites had 'light' or 'very light' surface oil.

The largest numbers of affected animals were found on San Cristóbal and Santa Fe, and were reported shortly after the spill. The smaller numbers of affected animals on other islands might be due to two factors:

- The most toxic elements in oil are also the most volatile, and evaporated quickly in the strong, warm season sunshine, with the result that the oil that reached other islands was less likely to harm the animals.
- The density of the slick decreased as it moved away from San Cristóbal, making it less probable that animals would encounter oil.

As for wildlife, 79 oiled sea lions were recorded around the islands of San Cristóbal, Santa Fe, Isabela and Floreana during the period immediately after the spill. One dead pup was found at Floreana covered in fresh bunker, and was assumed to have died because of the oil. More than half of the 79 oiled sea lions required washing and other treatment, but no immediate mortalities were observed. All three sea lion colonies studied on San Cristóbal as part of a long-term monitoring program in the southern Galápagos region exhibited population declines during the months following the spill. Only one of six monitored colonies on other islands exhibited a substantive decline in population numbers over the same period. Longer term monitoring is recommended to assess recovery of the San Cristóbal populations.

Only 370 large animals were reported to the Charles Darwin Research Station to be affected by oil. Tens of thousands of fish and invertebrates, such as crabs, were also affected. The reported mortality of birds appears limited to less than 10 animals in total. On the other hand, there is evidence of subtle, potentially long-term effects that is emerging.

On July 7th, 2002, a container carrying fuel from the tanker BAE TAURUS to the coast of Pto. Villamil, Isabela, sunk and spilled 2,000 gal of diesel ordered for the electric plant. Actions to avoid the dispersal of the fuel were taken immediately with successful results: a barrier was extended to hold the diesel and dispersant was applied. A couple of hours later, staff from the Charles Darwin Research Station and the National Park installed a new barrier with absorbing material to contain the fuel. The beaches of Isabela have been surveyed and no marine or terrestrial specie has been found to be affected.

The potential impacts of the accidents are not known yet and the monitoring process of the stain and the effects of the spill will begin.

2.13 Trip Observations

As mentioned previously, the visit to the Galápagos Islands involved doing research in diverse institutions and with different people of the three islands[5]. The purpose was to gather data[6] as accurate as possible that would be useful in the design of a distributed electricity generation system for electrification. In the beginning, I must admit that I was quite nervous because I didn't know what to expect from the people and if all the activities I wanted to accomplish would have a happy ending.

Gathering information resulted easier and more pleasant than I thought. Easier because the people I met were all very helpful and willing to cooperate, and pleasant because of the friendliness. In some cases, I had to go back to the same institutions a couple of times and they were all very eager to answer questions. Perhaps most valuable was the fact that I got to interact with the local people and learn more about their lifestyle and their concerns about the energy and water situation. Some people even asked me to take a look at their homes because they can't figure out why they pay so much for their utility bills each month.

A very interesting contrast was the one I found among the population of the three different islands I visited. Even though I knew that Sta. Cruz had the largest population and received most of the tourists, I didn't expect such a sharp difference in attitude. It almost appears as if people in San Cristóbal were just curious about tourists, and I remembered that while in Sta. Cruz somebody mentioned that San Cristóbal wants more tourism, but they don't know how to treat tourists. While people in Sta. Cruz would actually go out to meet with you, or just start chatting with you in the middle of the street, people in San Cristóbal just seem to go near you to see what you look like. Most of the people I met with in San Cristóbal were just as friendly with me, but while doing the surveys of homes, hotels, schools and stores, I did find the home and store owners to be more timid and perhaps scared of giving the information away. In some cases, it

[5] A list of institutions and people visited is in the Appendix
[6] An inventory of documents gathered is in the Appendix

took up to 20 or 30 min. to explain my project before they gave me their energy consumption data or allowed me to do a brief energy audit. In general, people of the three visited islands were very shy about taking photos, and in most of the cases, photos of the interior of the houses were not taken as respect to their privacy.

After seeing the results of all the surveys and of all other information gathered, I consider it was well worth the visit to the three islands. It gave me the opportunity to really visualize the difference between the different Puertos (Ayora, Baquerizo Moreno and Villamil) as well as the different highlands and just get a better insight and more complete information on what really happens. For example, in the Alcaldía of Sta. Cruz I got studies on the water quality for three islands and the water treatment and purification plans for Isabela and San Cristóbal. However, in all cases, the people working directly in those projects or proposals are the ones that can better describe what they're doing and what problems they've encountered, so by going to the three islands, I was able to get a more detailed description.

I also want to point out that some the data presented may not be too reliable because information varies depending on the source; such as the population of a certain location and the utility data from Elecgalápagos. Some islands would have two kWh numbers for the same month, and they don't know why this happens.

Some people were also of great help when they referred me to other scientists or boat owners whom they knew were working on renewable energy projects. Since the islands are so small it was fairly easy to locate them and make an appointment.

The trip was a great experience in all aspects, from gathering data to learning the culture to appreciating wildlife and nature. The continuous work the Galápagos National Park does to keep the environment as natural as possible is indeed remarkable. One clear example is the road to get to one of the crevices near Pto. Ayora, where you have to walk over stones and boulders and around a lagoon before you get to it. Yes, it was difficult to walk there, but it is definitely better than tearing everything down and having a paved road!

It is evident that the Galápagos National Park can't have control over everything at all times, and there were several 'incidents' in the trip that I didn't like and I thought would be good to mention because they are good examples of human impact and how the environment can deteriorate if these practices continue. On the way from the Canal de Itabaca to Pto. Ayora, we ran into six road kills. Cars drive really fast down that road and only slow down when approaching the control cottage of the Park. The second incident occurred while I was on a *fibra*[7]. A woman next to me was smoking and using the sea as a big

[7] Fibra is a motorboat

ashtray while joking that fish like nicotine. During the stay in San Cristóbal's Hotel Orca, I saw a man dumping oil on the ground to kill ants. The ground had big black blotches that looked terrible, not to mention the fact that sea lions live nearby. The last incident occurred while visiting the giant tortoises that are in the Charles Darwin Research Station. A woman told her little son to sit on the tortoise to take a photo. The tortoise was evidently uncomfortable because it hid completely in the shell and started hissing. Even though there are signs all over the place and rules to follow, some people just don't seem to understand!

The peace and quietness of the islands, even the most populated one, added to the friendliness of the people and the wonderful nature and wildlife that can be found everywhere, made this trip a very fruitful one. It is amazing how after a hard day of work, one could just walk half an hour to Tortuga Bay and feel so relaxed listening to the sound of the waves and the barking of the sea lions. It is then that I realized how much would be lost if there continue to be more oil spills and other forms of human caused pollution. It was a common sight to see trash thrown in the property of the Galápagos National Park, especially if there was a nearby trail. However, it was also common to see different wildlife approach people. I guess I've never been near animals that hadn't met any predator and that weren't scared of humans, so it was very amazing for me to see sea lions, iguanas and different bird species just look at me and come near me in the most natural way. Sometimes they just sit next to you, and express the same awe you express about them.

3. POPULATION AND SERVICES IN GALÁPAGOS

Energy requirements of any location depend on its population, among other variables. Current population data[8], as well as the population growth rate, was collected to give us an idea of how much the energy requirements will be increased due to population. The number of buildings by building type (and assuming a proportional growth rate with the population), number of people per hospital bed, hotels, etc. was also obtained mainly from the municipalities of each island and from the latest Fundación Natura-WWF Galápagos Report. Some information sources had global information for the Galápagos without breaking it down by island, and I did find some disparities within the data collected depending on the source, as can be seen in this section.

Our original population assumptions stated that there was a town and a village in the coastal region and a town and a village in the mountain region. This assumption was wrong because towns are in the coastal region, or lowlands of the islands, and villages are in the mountain area, or highlands. Villagers do go to the town for basic services since the town does have hospitals, government offices, etc. Our initial assumption of villages only having homes and schools was correct – but I also found some commerces (family business) in the villages. In Sta. Cruz, Pto. Ayora is the town in the coastal region and Bella Vista and Sta. Rosa are in the highlands. In San Cristóbal, Pto. Baquerizo Moreno is the coastal town and El Progreso is in the highland village. Finally, for Isabela, Pto. Villamil is the coastal town and in the highlands we have La Esperanza, Tomás de Berlanga and Sto. Tomás.

3.1 Population

The last 25 years have seen a sudden increase in the population. Population growth rates are near 6% and the main causes are attributed to immigration and a lack of birth control.

Table 3.1 Population in the Galápagos Islands, 2001[9]

Island	Population	Homes	Males	Females
San Cristóbal	5,682	1,913	3,080	2,602
Isabela	1,474	472	815	659
Santa Cruz	9,920	3,070	5,276	4,644
Floreana	88	42	56	32
TOTAL	**17,164**	**5,497**	**9,227**	**7,937**

[8] The population data we had used previously was from 1998.
[9] REI-G Diagnóstico Situacional, Informe Final, 2001. Pág. 14

Table 3.2 indicates the birth and death rates in the Galápagos Islands from 1985 to 1999. We can see that both values have fluctuated, however, the birth rate has always been much higher than the death rate.

Table 3.2 Birth and Death Rates (born and deceased for every 1000 people)[10]

Year	Birth	Death
1985	23.1	2.9
1986	20.2	1.5
1987	17.7	3.3
1988	19.8	1.8
1989	16.2	1.2
1990	16.1	1.6
1991	16.9	1.8
1992	17.4	1.8
1993	17.9	1.4
1994	17.4	1.4
1995	17.2	2.1
1996	14.8	2.1
1997	14.4	1.6
1998	15.0	1.2
1999	19.8	1.2

Following the population growth trend of the past years, Table 3.3 shows an estimate of the population for the year 2020[11]:.

Table 3.3 Estimated Population for the Year 2020

Island	2002	2020
Floreana	120	178
Isabela	1,494	2,229
San Cristóbal	5,990	8,173
Santa Cruz	10,285	14,256

Tourism is also important to consider, since the number of tourism facilities, such as hotels, has also increased, thus increasing the energy requirements of the islands.

The following graphs[12] show us the number of tourists that visit the Galápagos Island each year. A local newspaper reported recently that in the last three years, there's been an increase of 139 people because of immigration.

[10] Informe Galápagos 2000-2001, Fundación Natura and WWF
[11] Propuestas para la Gestión Integral de los Desechos en las Islas Galápagos. Institut Catalá d'Energia, Barcelona, Octubre 2001, pag. 18
[12] Informe Galápagos 2000-2001, Fundación Natura and WWF, pag. 118

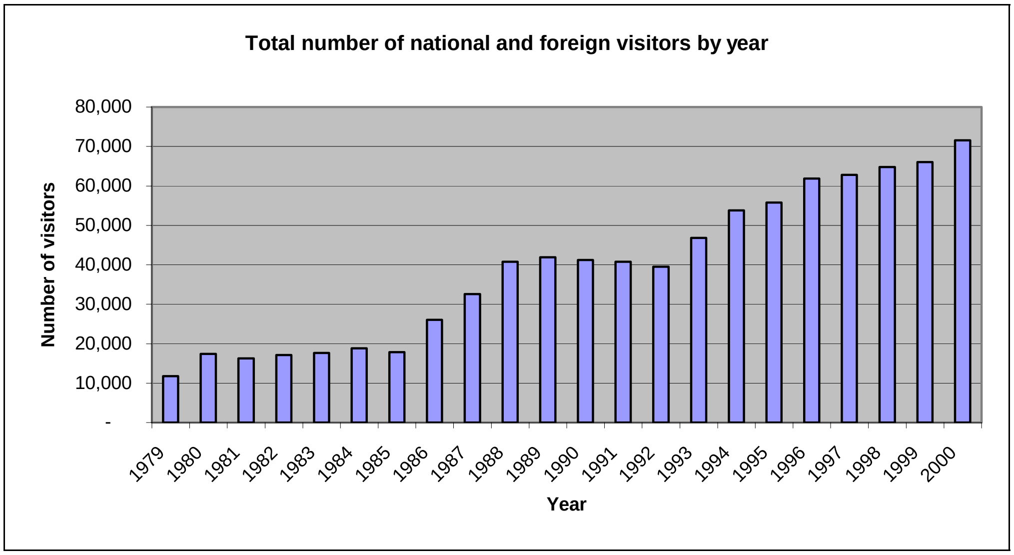


Figure 3.1 Total Number of National and Foreign Visitors by Year

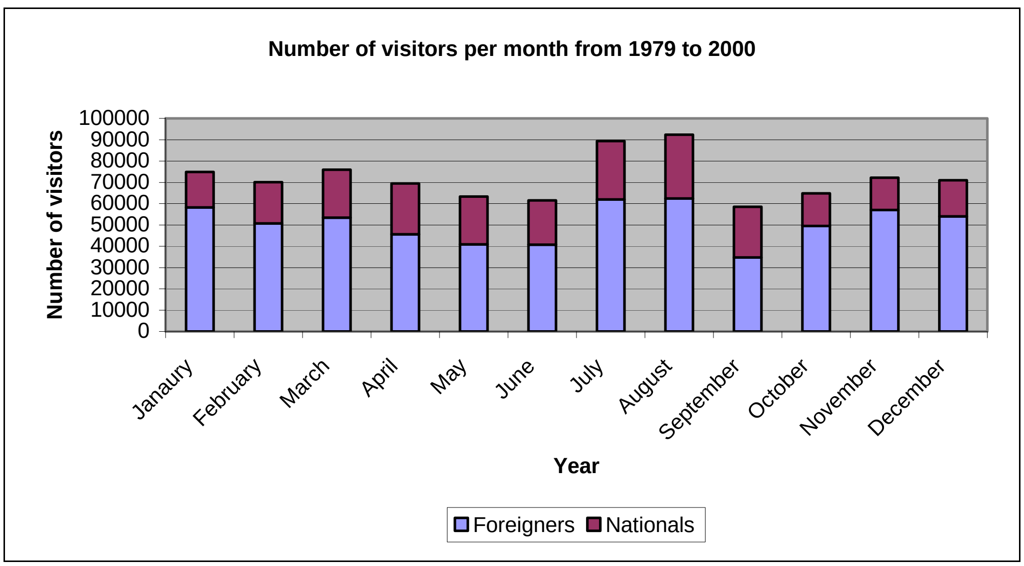


Figure 3.2 Total Number of National and Foreign Visitors from 1979 to 2000

About five years ago, the Government of Ecuador limited immigration to the Galápagos Islands. Every person having five or more years of residency on the islands would receive a ‘carnet’, which is an identification for residents of the Galápagos. However, some immigrants entered the Islands a couple of days before this law was put into action and got their carnet. Even now, people from the continent still manage to get their residency identification without really being residents. Despite the existing ‘illegal’ immigrants, this law has been of great help to cut down population growth due to immigration.

3.2 Buildings by Island

The number of buildings per building type also had to be researched. A brief description of the three islands in terms of services and number of buildings per building type is presented.

3.2.1 Santa Cruz[13]:

The Municipality of Pto. Ayora provided the following information from the 2000 Census.

- Annual population growth rate is of 6.7%
- Area of Sta. Cruz Island is of 986 km^2
- The urban area of Puerto Ayora is of 176 consolidated hectares.

Puerto Ayora has:

- 1079 homes
- 14 hotels
- 293 apartments
- 545 rooms
- 96 homes of divided roof of corrugated sheet
- 14 ranches
- 2 shanties or huts
- 1 military barrack
- 1 hospital
- 2 convents
- 36 collective constructions

The municipality considers 4.41 people per house.

Around 52.7% of the population is economically active, divided in the following category:

- 60%: services sector
- 14.3%: commercial activities
- 8.7%: construction
- 6.1%: agriculture
- 5.9%: manufacturing
- 5.0%: fishing

[13] Obtained from the Municipio de Puerto Ayora, Santa Cruz. Censo Diciembre 2000

3.2.2 San Cristóbal[14]:

TOTAL PROPERTIES IN PUERTO BAQUERIZO MORENO: 2227

- Number of properties with construction: 849
- Number of properties without construction: 1378

TOTAL PROPERTIES IN EL PROGRESO: 123

- Number of properties with construction: 73
- Number of properties without construction: 50

- Total of commercial and industrial establishments: 308

(Both in Pto. Baquerizo Moreno and El Progreso)

Table 3.4 Number of Water and Sewer Connections in San Cristóbal

		Potable water				Sewer System		
			Categories				Categories	
	Number of properties	Number of connections	Residential	Commercial	Industrial	Number of connections	Residential	Commercial
Puerto Baquerizo Moreno	Urban: 2202	1048	716	316	16	617	366	251
	Rural: 12							
El Progreso	Urban: 122	161	148	12	1	57	45	12
	Rural: 332							

3.2.3 Isabela[15]:

Puerto Villamil has:

- 1760 inhabitants
- 359 homes
- 15 stores
- 5 restaurants

The number of hotels hasn't yet been determined properly because 15 to 20% of the homes rent out their rooms and give bed and breakfast service.

[14] Obtained from the Municipio de Puerto Baquerizo Moreno, San Cristóbal, Jefe de Evalúos y Catastros.

[15] Obtained from the Municipio de Puerto Villamil, Isabela with the latest information they have available.

3.3 Schools

The energy requirements of schools are dependent upon the number of students and the equipment they have. The following tables summarize the number of schools in each island, and the number of students and professors for each school.

Table 3.5 Total Number of Schools in the Galápagos Islands[16]

Island	No.	Educational Institutions	No. of Professors	No. of Students	Rel. Prof./Stud.
San Cristóbal	1	Ignacio Hernández*	18	128	7.11
	2	A. Humboldt Diurno*	34	315	9.26
	3	A. Humboldt Nocturno*	1	3	3.00
	4	Alejandro Alvear	24	399	16.63
	5	Eugenio Espejo	2	14	7.00
	6	Pedro Pablo Andrade*	23	341	14.83
	7	Charles Darwin	9	35	3.89
	8	Centro Educativo Naval*	15	67	4.47
		Sum	126	1302	
Isabela	9	Fray A. de Azkunaga*	18	133	7.39
	10	Cornelio Izquierdo*	12	187	15.58
	11	Mentor Gamboa**	1	9	9.00
	12	Odilo Aguilar**	1	10	10.00
		Sum	32	339	
Santa Cruz	13	Galápagos Diurno*	44	400	9.09
	14	Miguel A. Cazares*	19	208	10.95
	15	Loma Linda*	17	243	14.29
	16	Colegio San Francisco*	21	230	10.95
	17	San Francisco*	28	541	19.32
	18	Julio Puebla Castellanos	3	16	5.33
	19	Tomás de Berlanga*	18	106	5.89
	20	Galo Plaza Lazo*	14	275	19.64
	21	Oswaldo Guayasamín	3	54	18.00
	22	Caupolicán Marín*	7	91	13.00
	23	Delia Ibarra de Velazco*	3	33	11.00
		Sum	177	2197	
		TOTAL	**335**	**3838**	

[16]REI-G Diagnóstico Situacional, Informe Final. Pág. 16

Table 3.6 Average Number of Students in School per School Year[17]

Year	Junior High	Elementary
1993-1994	160.0	93.0
1994-1995	148.0	88.0
1995-1996	146.0	88.0
1996-1997	127.0	106.0
1997-1998	136.6	99.7
1998-1999	129.9	116.5

Table 3.7 Average Number of Students per Professor per School Year[18]

Year	Junior High	Elementary
1993-1994	9.0	17.0
1994-1995	7.0	14.0
1995-1996	7.0	13.0
1996-1997	8.0	15.0
1997-1998	9.2	13.6
1998-1999	8.3	13.0

3.4 Additional information

Other information that we had been looking for, and assumed during the CVEN 4830 course, was the number of people per hospital bed and number of hotels in the islands. I was able to obtain this information and it's presented in the following tables.

Table 3.8 Number of Beds for Tourists in Galápagos, 2000[19]

Type of establishment	Floreana	Isabela	San Cristóbal	Santa Cruz	Total	%
On Land	39	111	239	778	1167	43
On Boat (cruises)	0	0	630	920	1150	57
TOTAL	**39**	**111**	**869**	**1698**	**2317**	**100**

[17] Informe Galápagos 2000-2001, Fundación Natura and WWF
*Indicates schools visited. Other schools were not visited because they were in their vacation period.
**Indicates meeting with the director of the school, even though the school was not visited.
[18] *Idem.*
[19] *Idem.*

Table 3.9 Number of Hospitals Beds and Doctor (value for every 1000 people)[20]

Year	Beds	Doctors
1984	3.6	2.0
1985	3.3	2.2
1986	3.9	2.2
1987	3.7	2.2
1988	3.5	2.0
1989	3.3	3.7
1990	3.1	1.8
1991	2.9	1.9
1992	2.7	1.3
1993	2.5	1.2
1994	2.4	1.4
1995	2.2	1.6
1996	2.1	1.1
1997	2.0	1.3
1998	1.9	1.3
1999	1.9	1.5

Services and appliances for homes in the lowland and highlands varied greatly. This is a very important consideration because the energy requirements change significantly (as will be seen in Section 4) and we need to know the loads that we are required to meet.

The following table indicates the percentage of homes that have certain services and facilities. This is important to know in terms of loads required to meet.

[20] *Idem.*

Table 3.10 Characteristics of Homes[21]

Characteristic	Percentage	Characteristic	Percentage
Type of Home		Sanitary Services	
Home	71.9	Toilet and sewer	46.9
Apartment	14.5	Toilet and septic tank	52.5
Shanty	4.7	Latrine	0.2
Rented room	8.1	None	0.4
Ranch	0.9	Other	0.0
Other	0.0	Fuel for cooking	
Type of Ownership		Gas	99.1
Owned	58.6	Wood/coal	0.6
Rented	36.0	Other	0.3
Lent without pay	4.1	Electric Energy	
Services	1.3	Yes	99.6
Other	0.0	No	0.4
Water Supply		Telephone	
Piping inside house	49.30	Yes	35.00
Piping outside house	18.80	No	65.00
Public use piping	7.20	Total	100.00
Lake, river, ditch	1.30	Number of surveys	469
Open well	0.90		
Tanker truck	11.70		
Other	10.90		

More information on population and tourism facilities can be found in the Appendix.

[21] *Idem*

4. ENERGY GENERATION AND CONSUMPTION

4.1 Supply of Fuel on the Islands[22]

Petrocomercial, a subsidiary of the government-owned petroleum corporation, has a central terminal on Baltra Island and a tanker ship, which supplies fuel to the islands every 25 days on average, makes deliveries. After supplying fuel to Baltra Terminal, the tanker ship stops in San Cristóbal, Santa Cruz and Isabela. The fuel is transferred by barge from ship to shore and is then transported by tanker trucks to the various supply points. In Figure 4.1 we can see the amount of diesel and gasoline supplied to Baltra Terminal by month. It is clear that diesel predominates the fuel market of the Galápagos Islands.

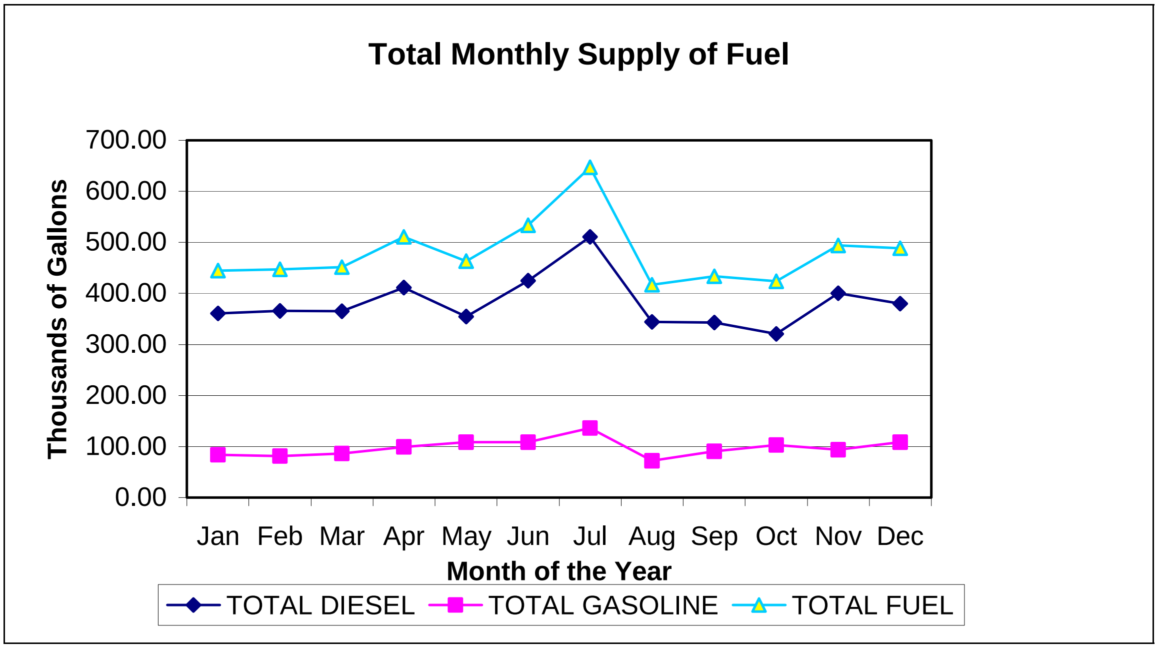


Figure 4.1 Supply of Fuel to the Islands by Type of Fuel

4.2 Fuel Consumption

The consumption by Island was determined from the data on deliveries by the tanker ship every 25 days. These amounts were assumed to be the monthly average. The two main consumers are the electricity and gasoline sectors.

The average monthly totals consumed are 396 thousand gallons of diesel and 126 thousand gallons of gasoline. Santa Cruz has the highest levels of

[22] Cardenas, S., 2001. A Study of Transport and Energy in the Galápagos Islands. World Wildlife Fund (WWF), Quito.

consumption, with 36% and 26% of the total gasoline and diesel supplied, respectively.

The tourism sector is the sector with the largest consumption of fuel, accounting for almost 50% of the total amount supplied (diesel and gasoline). The next largest sector is the electricity sector, with 21%.

Figure 4.2[23] shows the consumption by Galápagos' Electric Utility, Elecgalápagos. In reality, there is a decrease in consumption in 1999 due to changes in the administration (error in data entries)[24], however, the chart indicates a predicted value.

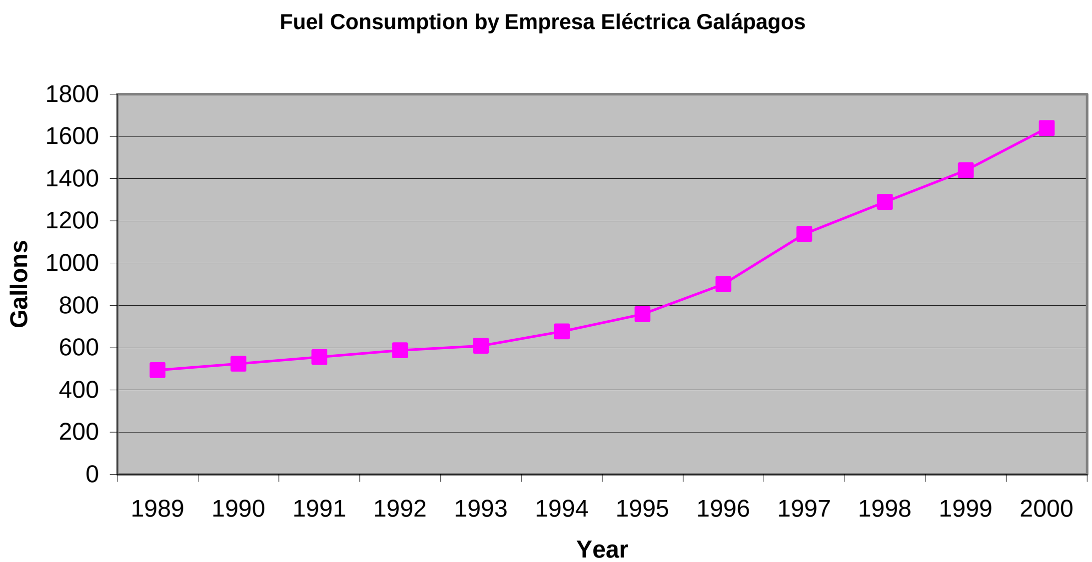


Figure 4.2 Fuel Consumption by Empresa Eléctrica Galápagos

One of the objectives of Empresa Eléctrica Galápagos is to diversify their options and include renewable energy in their energy mix.[25]

4.3 Emissions

Emissions from the energy sector threaten the earth because of several environmental impacts, such as: air pollution, acid rain, and climate change.

---

[23] *Idem*
[24] See Section 4.5
[25] Personal conversation with the 'Jefe de Agencia' of Elecgalápagos in Sta. Cruz, Abraham Rosero

Methane and carbon dioxide (CH_4 and CO_2) are gases that can be found in natural form in the troposphere, and, together with ozone, water vapor, nitrogen oxide, sulfur hexafluoride, hidrofluorocarbons, perfluorocarbons, and chlorofluorocarbons (CFC), absorb and retain part of the infrared radiation that comes from the Sun, just like a greenhouse effect. Without them, it is estimated that the planet's temperature would be of 13 °C[26]. The greenhouse effect is a benefic phenomenon and is necessary for the planet to hold life. However, its substantial modification is alarming, due to the fact that greater concentration of these gases absorbs more infrared radiation and breaks the equilibrium between the energy that enters and leaves the atmosphere.

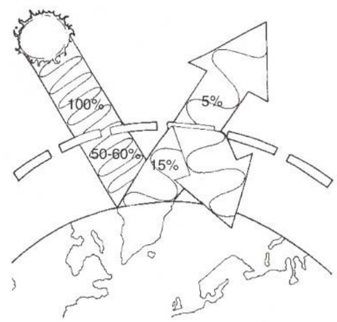


Figure 4.3 Greenhouse Effect

It is well known that one of the main sources of greenhouse gases comes from burning fossil fuels. This is because fossil energy resources are "historic" biomass –generated million of years ago– and when burnt, they return the "historic" carbon they contain to the organic cycle of nature. By reincorporating more than 5000 millions of tons per year we are contributing to global warming and climatic instability.

For the year 2050 it is estimated that energy will need to be supplied to at least 7,000 million people. However, due to the negative impacts related to carbon based energy resources, it is not advisable to meet these energy requirements under conventional canons.

Energy is the fundamental unit of measure; hence, the search for sustainable development depends on its amount and nature of its resources. Taking the last consideration into account, it will be possible to reach sustainable development as long as energy production and consumption practices are modified effectively and gradually. It is required that science and technology search for an equilibrium between development and environment, and to find and foster less pollutive energy paths. In this sense, sun, wind and water have been used for many centuries, and technological research has made power conversion from these resources more efficient.

---

[26] UNFCCC

In the following table, we can observe the difference in CO_2 emissions from the different technologies of energy generation. These numbers include the emissions that result from the manufacturing of the equipment. For example, for photovoltaic and wind energy, the amount listed is only associated with manufacturing processes.

Table 4.1 CO_2 Emissions in Electricity Generation[27]

Technology	Metric Tons/GWh
Conventional coal fired power plant	1057.1
Combined cycle integrated with a gasification power plant	750.9
Fuel Oil Power Plant	762.2
Gas Power Plant	484.0
Minihydraulic	10.0
Wind Energy	7.4
Photovoltaics	5.9
Solar Thermal Energy	3.6

Table 4.2 indicates the diesel consumption and the related CO_2 emissions in the Galápagos Islands. We must take into account that electricity generation produces only 8%[28] of the total emissions in the Islands.

Table 4.2 Diesel consumption and CO_2 Emissions in the Galápagos Islands

Island	Gal/año	CO_2 Emissions (Ton/year)
Sta. Cruz	463,884	4,769
San Cristóbal	866,031	8,903
Isabela	115,862	1,191
Floreana	7,713	79
TOTAL	1,453,490	14,942

4.3 Electricity Generation

Table 4.3 summarizes the number of users, as well as the installed capacity, and energy generation and demand for the year 2000. The chart was developed by the Energy and Mines Ministry of Ecuador.

[27] Foster, Robert E. 1998, Photovoltaic market development and barriers in México, Thesis to obtain the degree of Masters in Business Administration, New Mexico State University. Page 20
[28] Information provided by Manuel Sáenz of the Environmental Ministry of Ecuador. The year this chart corresponds to is unknown.

Table 4.3 General Characteristics of Energy in the Year 2000[29]

Island	Population	Users	Generated Energy (MWh/year)	Demand (kW)	Installed Capacity (kW)
Sta. Cruz	8,700	2,584	10,300	1,980	3,700
San Cristóbal	5,500	1,625	5,400	1,180	3,040
Isabela	1,500	487	1,176	350	1,425
Floreana	120	32	56	26	205
TOTAL	15,820	4,728	16,932	3,536	8,370

The following sections describe the electricity generation and power plants for each island.

4.4.1 Sta. Cruz[30]

Equipment: The electricity generation equipment consists of diesel and electric generators. The Planta de Luz of Pto. Ayora has 5 units that work alternately according to the energy demand. One generator is of 1032 kW and the other four are of 650 kW. All of them generate at 480 V.

In the cold and rainy season, the energy consumption at daytime decreases since 50% of the homes have air conditioning. During nighttime, there is hot water heating for showering. During the hot season, the air conditioning is running throughout the entire day, thus, the energy consumption increases.

Fuel: A tanker ship brings the fuel and a hose does the transfer of fuel. The monthly fuel consumption is of 120,000 gal. The storage capacity of the tanks is of 88,000 gal.

Generation: The average daily generation during the cold season is 2,500 kWh and 2,900 kWh during the hot season. The power plant generates an average of 87,000 kWh per month. Electricity is generated at 13,200 V in medium tension and distributed at 120 and 240 V ± 5%.

Losses: The losses in the grid range between 150,000 to 170,000 kW per month, representing 10 to 12% of the generation.

[29] Presented by Juan Carlos Galarza, of Ministerio de Energía y Minas, Ecuador
[30] Personal communication with Abraham Rosero of Elecgalápagos Sta. Cruz.

Billing[31]: The cost per kWh depends on the kWh consumed per month. The rates are separated in different ranges. The lowest cost is of 7 cents of USD and it increases when the consumption is above 230 kWh and in increments of 50 kWh (for example, from 230 to 280 kWh, there is one kWh cost, from 280 to 330 kWh, the cost increases, and so forth). Elecgalápagos froze their costs until the end of the year 2002. The deficit in their monthly income is near 35%, this is, the utility company only receives 65% of their total generation costs. They also charge an additional 12% over the total cost for garbage collection. This fee goes back to the municipality.

Customers: The Pto. Ayora office of Elecgalápagos serves 2,670 customers.

The graph below shows the energy generation for Sta. Cruz Island since January 2000 until now. We can see some generation peaks during the cooling season because 50% of the buildings use air conditioning and many homes and offices use ventilators. The table with all the generated MWh values can be found in the Appendix.

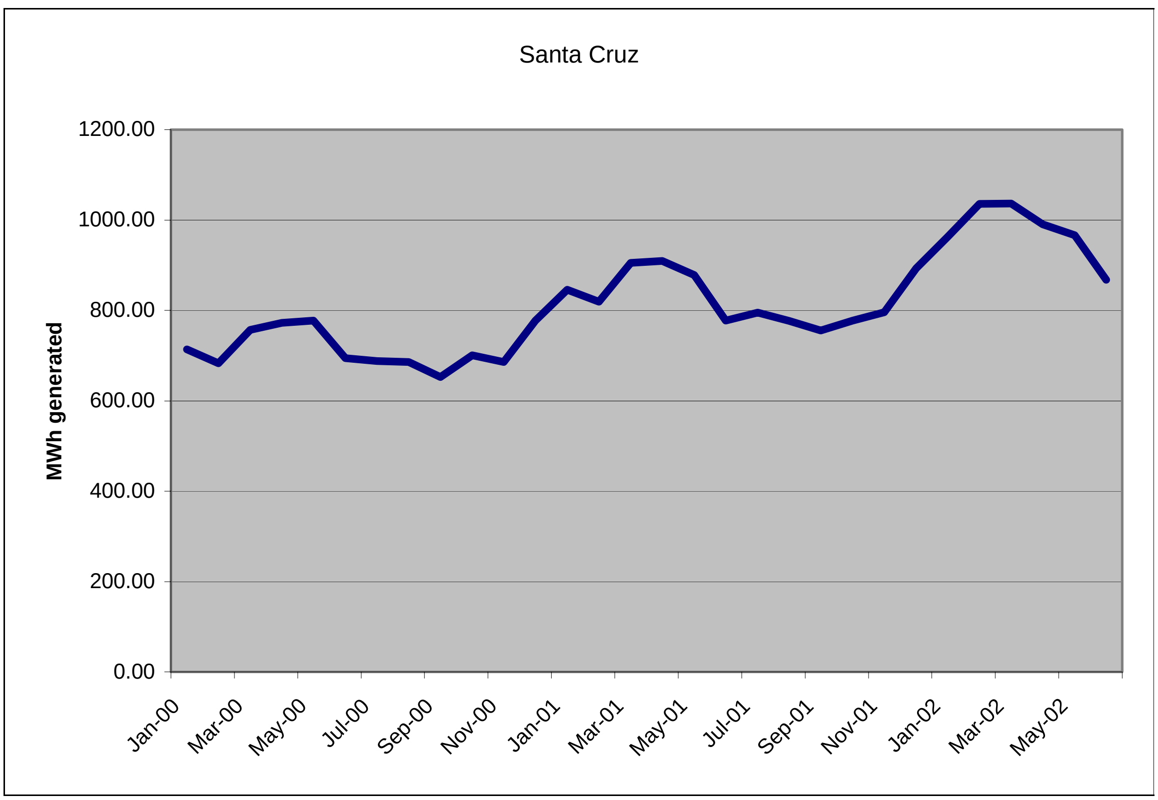


Figure 4.4 Energy Generation in Sta. Cruz

[31] The same applies to all islands.

4.4.2 San Cristóbal[32]

Equipment: The electricity generation equipment consists of diesel and electric generators. The Planta de Luz of Pto. Baquerizo Moreno has 7 units that work alternately according to the energy demand. There is one generator of 345 kW, two of 310 kW and four of 650 kW. During non-peak hours, the generator of 650 kW and the one of 310 kW operate, and during peak hours, usually from 6 to 8 pm, there are two generators of 650 kW working. All of them generate at 480 V, three phase. The conductors are being changed for ones with a higher ampacity because the current transmission and distribution lines were put up 15 to 20 years ago and the demand has increased quite a bit since then.

Fuel: A tanker ship brings the fuel and a hose does the transfer of fuel to a 10,000 gal tanker. The fuel is transported to the substation and stored in tanks. The tanker has to make from three to four trips the day the fuel is delivered (once a month). The monthly fuel consumption is of 125,000 gal of diesel. The storage capacity is of 55,000 gal.

Generation: The hourly generation ranges from 700 to 800 kW during non-peak hours, and from 900 to 1000 kW during peak hours. The power plant generates an average of 87,000 kWh per month. Electricity is generated at 13,200 V in medium tension and distributed at 120 and 240 V ± 5%.

Losses: The losses in the grid range between 10 to 12% of the generation.

Billing[33]: The cost per kWh depends on the kWh consumed per month. The rates are separated in different ranges. The lowest cost is of 7 cents of USD and it increases when the consumption is above 230 kWh and in increments of 50 kWh (for example, from 230 to 280 kWh, there is one kWh cost, from 280 to 330 kWh, the cost increases, and so forth). Elecgalápagos froze their costs until the end of the year 2002. The deficit in their monthly income is near 35%, this is, the utility company only receives 65% of their total generation costs. They also charge an additional 12% over the total cost for garbage collection. This fee goes back to the municipality.

[32] Personal communication
[33] Personnel from the San Cristóbal office said the cost per kWh was of 85 cents of USD.

Generation costs[34]:

Table 4.4 Average Electricity Generation Costs

Concept	Average Cost (USD)
Fuel	98,000
Preventive maintenance	4,000
Corrective maintenance	80,000
Overhaul (every 10 years)	75,000

4.4.3 Isabela

Equipment: The electricity generation equipment consists of diesel and electric generators. The Planta de Luz of Pto. Villamil has 4 units that work alternately according to the energy demand. The capacities of the generators are 350, 310, 455 and 499 kW. All of them generate at 220 V, three phases.

Fuel: A tanker ship brings the fuel and a hose does the transfer of fuel to a 2,000 gal tanker. The fuel is transported to the substation and stored in tanks. The tanker has to make five trips the day the fuel is delivered (once a month). The monthly fuel consumption is of 11,000 gal of diesel. For lubrication they use 60 gal/month of oil.

Generation: The monthly generation is of 10,000 kW. Electricity is generated at 13,800 V in medium tension and distributed at 110 and 220 V ± 5%.

Losses: The losses in the grid range between 10 to 12% of the generation.

Billing: The cost per kWh depends on the kWh consumed per month. The rates are separated in different ranges. The lowest cost is of 7 cents of USD and it increases when the consumption is above 230 kWh and in increments of 50 kWh (for example, from 230 to 280 kWh, there is one kWh cost, from 280 to 330 kWh, the cost increases, and so forth). Elecgalápagos froze their costs until the end of the year 2002. The deficit in their monthly income is near 35%, this is, the utility company only receives 65% of their total generation costs. They also charge an additional 12% over the total cost for garbage collection. This fee goes back to the municipality.

[34] These values are for all the islands, information provided at Elecgalápagos Headquarters.

4.4.4 Floreana[35]

The monthly electricity demand is of 5 MWh and the maximum capacity is of 26 kW.

4.5 Utility Data

Before 1999, the utility company of each island was run independently and supervised by INECEL. At the end of January 1999, ElecGalápagos was formed as the utility company for the Galápagos Islands. The headquarters are located in Pto. Baquerizo Moreno, San Cristóbal and they supervise all the activities of the three other islands. To obtain utility data for the four islands, one can go to the headquarters in San Cristóbal. However, if we want data from years previous to 1999, we would have to go to each of the islands since Elecgalápagos doesn't keep any records of data generated before its inauguration. During this change in administration, there were some mistakes in the data collection to which the difference in kWh values is attributed.[36]

Their sums of the totals for each islands (sum of the kWh of each sector) and of the total kWh of all the islands doesn't coincide with mine. The utility bill for each month is divided in different sectors and the numbers reported in the table are the sum for each month. Their total does not match the one I calculated and some of the differences are considerable. At first, I attributed this difference to the bad quality of the copies and me not being able to read the characters correctly, however, some of the copies did turn out very well and the numbers are exactly the same on the spreadsheet as on the copy. Table 4.5 shows the total monthly energy consumption for the four islands, the total of the four islands as calculated by Elecgalápagos and myself and the difference between these last two values.

The monthly utility data for the four islands, since Elecgalápagos took charge as the main utility company, is in Table 4.5. For the cells that are blank I couldn't get the information because Elecgalápagos doesn't have it recorded[37].

[35] See Section 9 for data on Floreana's renewable energy system.

[36] See Figure 4.2 and Table 4.5. The total kWh values calculated by hand and provided by Elecgalápagos differ.

[37] In the San Cristóbal office they gave me all the binders with utility data and those entries were missing. When I asked them about it, they said that if it wasn't in the binder, they didn't have it.

Table 4.5 Energy Consumption by Month and by Island, in kWh

	Total Provincial	Santa Cruz	San Cristóbal	Isabela	Floreana	Calculated total	Difference
Dec-98	285,677						
Jan-99	377,066	571,224			3,125		
Feb-99	55,872	552,140					
Mar-99	46,782	591,036					
Apr-99		644,877		52,806			
May-99		609,770		53,413			
Jun-99		541,658		52,324			
Jul-99		594,219		61,070			
Aug-99		501,141		61,592			
Sep-99		576,111		64,316			
Oct-99		561,460		63,007			
Nov-99		521,860		63,007			
Dec-99		594,203		67,604			
Jan-00		612,199		71,511			
Feb-00		634,714		69,706			
Mar-00		-		71,961			
Apr-00		623,263		80,994			
May-00		670,531		72,667			
Jun-00		668,421		76,349			
Jul-00		566,529		67,437			
Aug-00		579,185		73,608			
Sep-00		625,720		71,907			
Oct-00		559,075		72,403			
Nov-00		614,005		80,024			
Dec-00		696,005		72,382			
Jan-01	1,177,263	692,182	410,359	70,113	4,609	1,177,263	-
Feb-01	1,287,571	783,685	419,163	80,100	4,623	1,287,571	-
Mar-01	1,225,097	730,070	402,049	88,298	3,780	1,224,197	(900)
Apr-01	1,402,364	817,516	482,540	97,891	4,417	1,402,364	-
May-01	1,288,210	768,162	464,042	81,475	4,531	1,318,210	30,000
Jun-01	1,267,584	-	419,038	86,783	4,155		
Jul-01	1,090,581	621,246	385,262	79,915	4,158	1,090,581	-
Aug-01	1,151,873	694,350	370,426	83,309	3,788	1,151,873	-
Sep-01	1,171,900	703,096	381,531	84,305	3,712	1,172,644	744
Oct-01	1,087,835	627,008	375,038	81,996	3,793	1,087,835	-
Nov-01	1,200,315	708,499	396,590	87,693	4,533	1,197,315	(3,000)
Dec-01	1,167,677	711,676	372,063	80,216	4,025	1,167,980	303
Jan-02	1,389,066	844,776	446,881	93,180	4,405	1,389,242	176
Feb-02	1,385,731	816,077	461,929	102,592	5,625	1,386,223	492
Mar-02	-	858,507	435,196	98,805	4,797		
Apr-02	1,426,251	877,642	435,463	108,502	4,624	1,426,231	(20)
May-02	1,405,231	839,852	456,958	103,610	4,811	1,405,231	-
Jun-02		796,586	431,551				

In Figure 4.5 we can observe the difference in energy consumption from one island to another. Though the difference in population is one of the main factors in this difference in energy consumption, an important consideration is that the kWh use per capita is higher in Sta. Cruz.

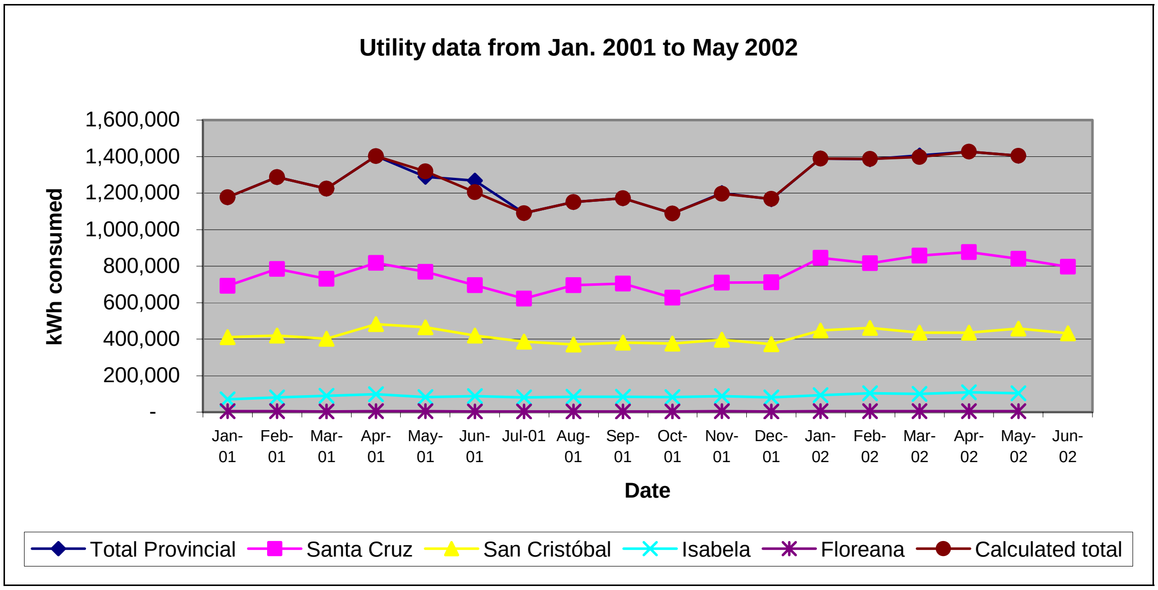


Figure 4.5 Energy Consumption of the Four Islands

For Figure 4.5, the values of March 2002 for 'total provincial' and June 2001 for Sta. Cruz were obtained by getting the average of the month before and after them, since the real consumption wasn't obtained.

Figure 4.6 indicates the energy consumption of Isabela since April 1999. Though there is an increment each year, we can distinguish the peaks in consumption during the hot season.

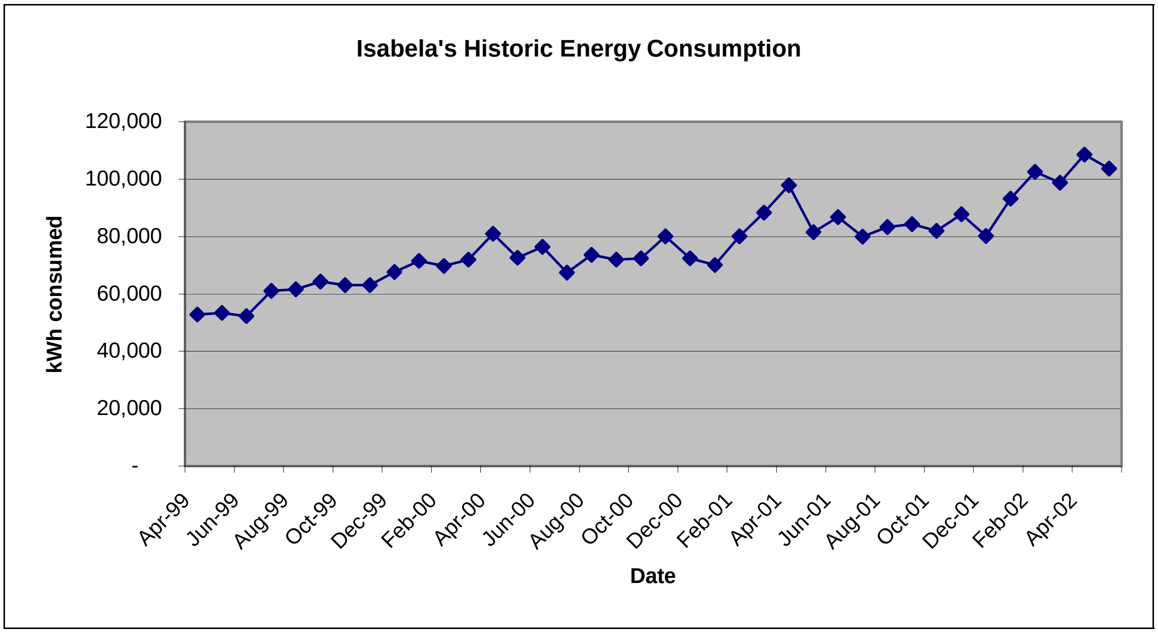


Figure 4.6 Historic Energy Consumption for Isabela

As mentioned previously, there are losses in the system, constituting the difference between the energy generated and the energy consumed. The example presented in Figure 4.7 is from the island of Sta. Cruz.

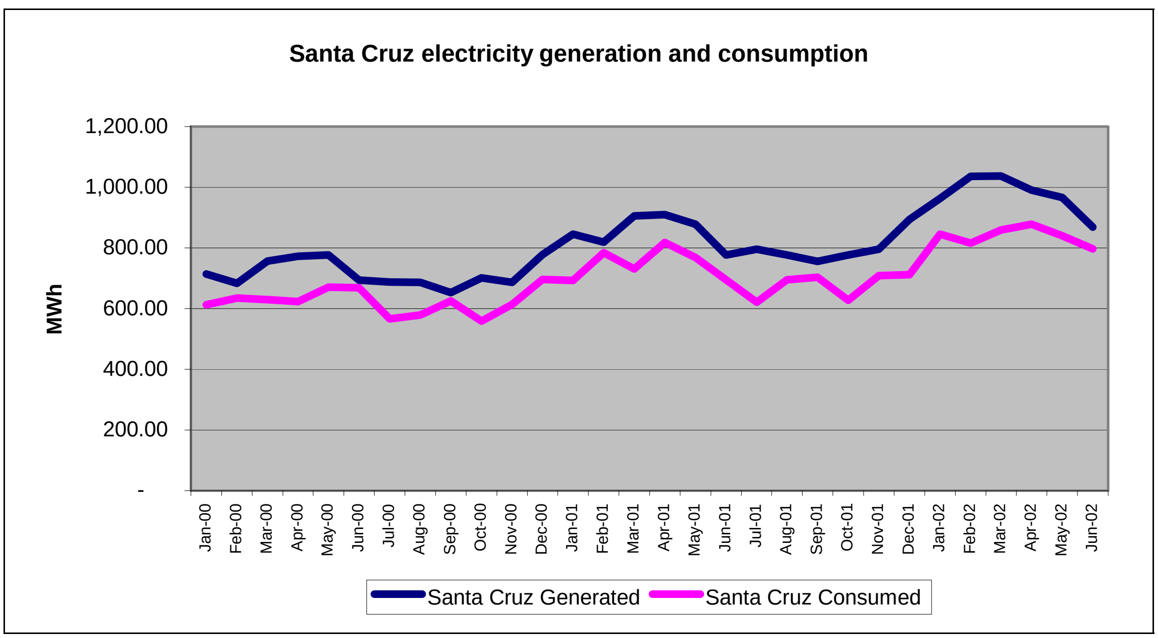


Figure 4.7 Generated and Consumed Energy in Sta. Cruz

There seems to be discrepancies in the information because some numbers (generation and consumption MWh values) are different depending on the information source. Again, there are mistakes in the mathematics. Some of the data received indicates that there seems to be more consumption than generation as can be seen in Fig. 4.8. This shouldn't be that surprising because there are errors in the consumption values. Many of the people surveyed complained of the way the utility company reads the meter. The utility company bills the cost per kWh according to the range in which the consumption falls. In some occasions, they bill more than 30 days so the consumption will purposely fall on the next range and they can charge more for each kWh. Some of the people surveyed actually complained about this to the utility company and got a reimbursement. However, those who don't complain or don't even notice these 'mistakes' don't receive any reimbursement. I believe this is one of the reasons for some of the differences that I found. When I was in the islands and asked about these discrepancies, the response was that it was a mistake when typing the number in or when reading the number from the meter.

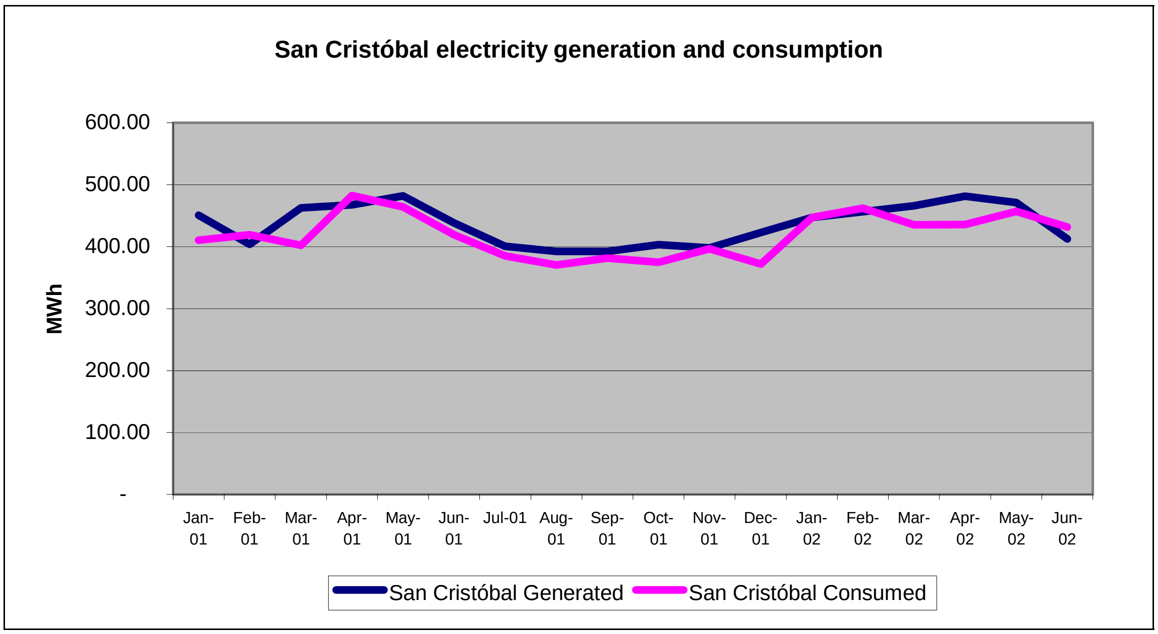


Figure 4.8 Generated and Consumed Energy in San Cristóbal

4.5.1 Residences

The residential energy consumption for the different islands is shown in Table 4.6 for the year 2002. This value is an average of the residences of the high land (rural area-villages) and the low land (urban area-towns).

Table 4.6 Residential Energy Consumption of the Galápagos Islands, in kWh

	Jan	Feb	Mar	Apr	May
Santa Cruz	193.96	182.43	185.05	197.76	187.98
San Cristóbal	156.06	156.80	148.93	145.10	154.05
Isabela	118.67	126.10	115.09	120.52	120.91
Floreana	70.77	90.05	78.50	81.44	89.22

The average consumption per residence in Sta. Cruz is much higher than the other islands, especially Floreana. During the surveys, I found that homes in Sta. Cruz have a wide variety of kitchen appliances.

It is very common in the islands to have the home (living area) in the back of the store (commonly the living room of the house), so the energy that is being consumed is for the store and the house. In some stores there were up to 5 refrigerators and freezers. The high level of tourism in Sta. Cruz and San Cristóbal is also a reason for their increased consumption.

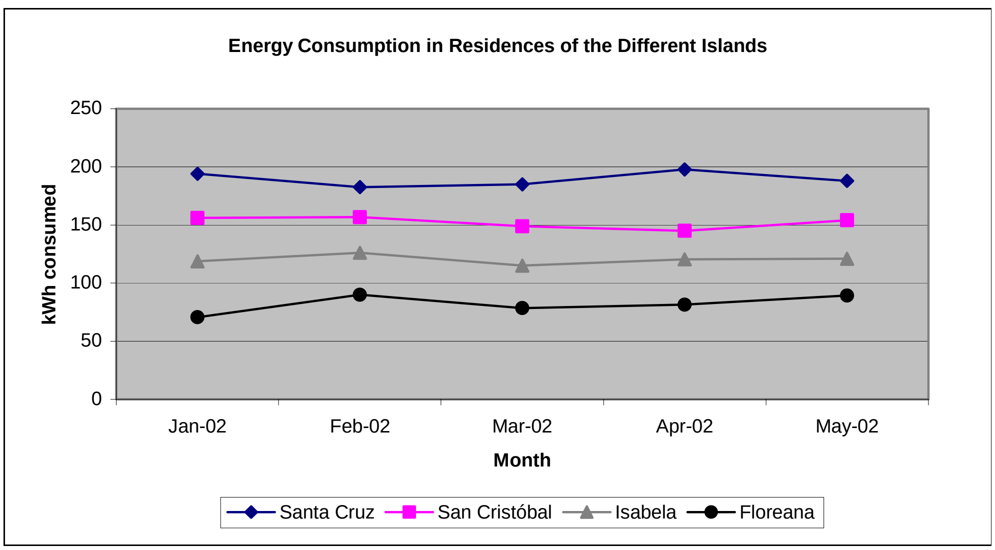


Figure 4.9 Residential Energy Consumption in the Galápagos Islands

The next table shows the loads that can be found in an average home.

Table 4.7 Loads for an Average Home

Equipment	Watts	kW	Hours of use per day	Days of use	Total kWh/month	Monthly Cost
1 light bulb in the living room	100	0.10	5	30	15.00	1.24
1 efficient light bulb in the dining room	23	0.02	5	30	3.45	0.28
1 fluorescent light in the kitchen	50	0.05	5	30	7.50	0.62
1 light bulb in the hallway	60	0.06	5	30	9.00	0.74
1 light bulb in the bedroom	100	0.10	4	30	12.00	0.99
1 light bulb in the bathroom	100	0.10	3	30	9.00	0.74
1 light bulb in the façade	60	0.06	11	30	19.80	1.63
1 color TV	100	0.10	12	30	36.00	2.97
1 ventilator	300	0.30	8	30	72.00	5.93
1 microwave	1000	1.00	0.5	30	15.00	1.24
1 computer	100	0.10	5	30	15.00	1.24
1 stereo set	50	0.05	5	30	7.50	0.62
1 iron	1000	1.00	3	4	12.00	0.99
1 refrigerator	200	0.20	8	30	48.00	3.96
TOTAL					**281.25**	**23.19**

As indicated previously, homes in Sta. Cruz (Pto. Ayora) have more appliances and equipment that consume energy than homes in other islands. Additional loads that some homes have are presented in Table 4.8.

Table 4.8 Additional Home Loads

Appliance	kW
Washing Machine	395
Drying Machine	400
Heater	1300
Blender	350
Coffee machine	850
Vacuum cleaner	1500

I found that in the three islands, on average, homes in the highlands consume one third of the energy that homes on the coast do.

It is also important to mention that 95% of establishments (stores, homes, hotels, etc.) use compact fluorescent lights.

4.5.2 Hotels

In the Appendix there is a complete list of hotels and the capacity of each one, as well as utility data. Table 4.8 summarizes some examples of hotels, all of them first class, with their respective capacities and energy and water consumptions. All of the hotels listed have air conditioning. One common complaint of hotel owners was the use of air conditioners by tourists during their winter season, which is from June to end of October or November.

Second and third class hotels don't have air conditioning and in some cases, don't have hot water, so their energy consumption is much lower. A first class hotel charges an average of 90 USD per night, while a third class hotel would charge either 10 or 15 USD.

Table 4.9 Water and Energy Consumption of Selected First Class Hotels

Hotel	Number of rooms	Water consumption (m^3/year)	Water consumption per room (m^3/year)	Energy consumption (kWh/year)	Energy consumption per room (kWh/year)	Solar Production (kWh/year)
Lobo de Mar	80	1,577	19.71	45,837	572.96	44,098
Las Ninfas	140	3,679	26.28	106,953	763.95	94,809
Fiesta	40	788	19.70	22,919	572.98	22,049
Angermeyer	44	1,799	40.89	52,288	1,188.36	52,288
Delfín	80	1,577	19.71	45,837	572.96	44,098

4.5.3 Schools

In general, most of the schools in the Galápagos Islands have light bulbs in their classrooms, and in some cases a ventilator. The exterior wall of most classrooms are made out of hollow brick, so there is natural light coming into the classroom. In some cases, there is a mesh outside the window to prevent insects from flying in. Air conditioning is used in administrative offices and computer labs. There is also a separate room for audiovisual, so one doesn't consider the use of a TV or VCR inside the classroom, thus, reducing the loads per classroom.

Figure 4.10 shows a sample of the monthly profile for a school. February and March are vacations, so the energy consumption is lower even though these are the hottest months of the year. Utility data of other schools can be found in the Appendix.

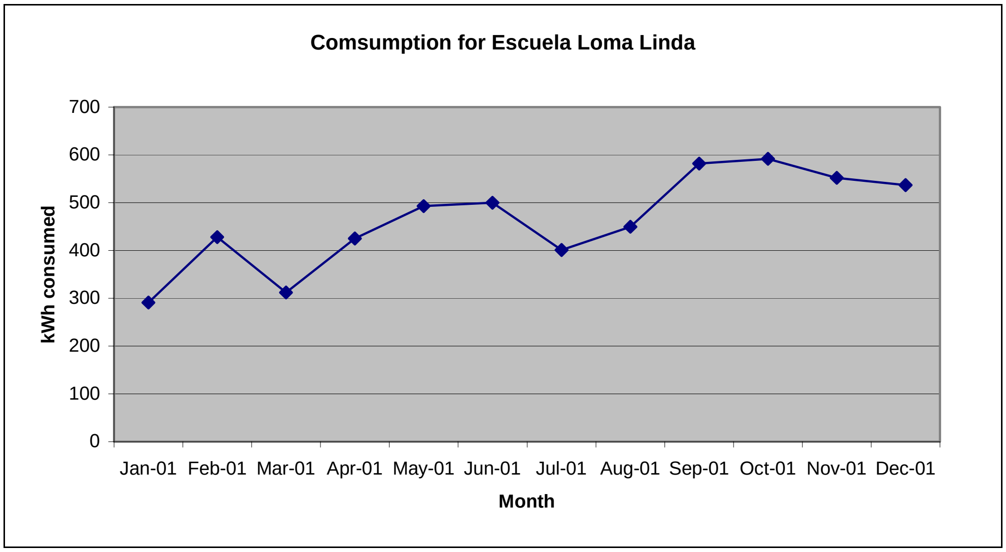


Figure 4.10 Energy Consumption of Escuela Loma Linda, Pto. Ayora, Sta. Cruz

5. RESOURCE DATA[38]

Wind speed and direction and solar radiation data, among others, were measured from July 1999 until May 2000 in the four populated islands[39]. There were eight stations distributed as follows: three in Sta. Cruz, two in San Cristóbal, two in Isabela and one in Floreana. The sites were chosen following specific technical and environmental criteria:

- Data was collected along the littoral and in the highlands, except for Floreana, where the only station was on the beach.
- The location of the sites was limited to the region of at most 10 km away from the grid because it would not be feasible to put long transmission lines in. We also have to remember that the grid in each island has a small capacity and the net power that will be integrated to the grid will not be of a big magnitude.
- The differences in wind velocity magnitude have more variations and are more unforeseeable than the ones for solar radiation, thus, the identification of measuring sites for wind data were predominant over the selection of sites for measurement of solar radiation.

Monthly averages for wind speed, solar radiation and additional weather data are shown in the following Tables.

Table 5.1 Wind Resource in Different Sites of the Galápagos Islands, in m/s

Stat.	Site	Aug-99	Sep-99	Oct-99	Nov-99	Dec-99	Jan-00	Feb-00	Mar-00	Apr-00	May-00*	Jun-00**	Jul-00**	Average
Gal-1	Floreana Costa	3.3	3.1	3.1	4.4	5.0	3.	1.5	2.0	2.6	2.2	2.6	3.5	3.0
Gal-2	Isabela Costa	3.9	3.4	3.8	3.9	3.8	3.4	3.0	3.3	3	3.5	4.1	4.1	3.6
Gal-3	Sta. Cruz Cerro	5.2	5.2	4.6	6.5	6.9	5.5	2.2	2.5	2	3.3	3.8	5.4	4.4
Gal-5	San Cristóbal Costa	5.5	5.1	4.9	6.6	7.7	5.2	2.3	2.1	1.8	3.5	4.1	5.7	4.5
Gal-6	San Cristóbal Cerro	8.1	7.8	7.5	10.6	9.6	6.4	4.2	3.7	3.5	5.7	6.6	8.4	6.8
Gal-7	Sta. Cruz Camote	3.4	3.4	3.2	4.3	4.3	3.1	2.3	2.8	2.2	2.4	2.7	3.6	3.1
Gal-8	Sta. Cruz Costa	3.9	3.5	3.8	3.4	2.8	2.7	2.8	3	2.7	3.2	3.7	4	3.3

[38] Electrificación Renovable de las Galápagos Eliminación de las Barreras que Impiden el Desarrollo de la Energía Renovable en el Ecuador, Informe Final, Lahmeyer International
[39] Complete resource data measured every 10 minutes, can be found in the Lahmeyer Study CD

* The availability of data was less than 30%
** The data obtained are estimates derived from the station and time of the year

Table 5.2 Solar Radiation in Different Sites of the Galápagos Islands, in W/m^2

Stat.	Site	Aug-99	Sep-99	Oct-99	Nov-99	Dec-99	Jan-00	Feb-00	Mar-00	Apr-00	May-00*	Jun-00**	Jul-00**	Average
Gal-1	Floreana Costa	203	211	199	190	200	181	175	223	222	201	174	183	197
Gal-2	Isabela Costa	223	218	231	210	206	220	274	293	281	258	224	201	236
Gal-3	Sta. Cruz Cerro	175	188	152	147	144	182	179	225	184	212	184	146	176
Gal-5	San Cristóbal Costa	238	233	236	213	218	203	222	263	238	208	181	215	222
Gal-6	San Cristóbal Cerro	163	157	149	147	151	153	213	237	189	143	125	147	164
Gal-8	Sta. Cruz Costa	173	187	198	186	188	211	266	289	260	249	217	156	215

* The availability of data was less than 30%
** The data obtained are estimates derived from the station and time of the year

Table 5.3 Weather Data in Galápagos Islands

	Temperature, °C			Temperature, °F			RH	Precip.	
	°C	*°C*	*°C*	*°F*	*°F*	*°F*			
Month	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*%*	*mm*	*in*
J	30	25	22.2	86	77	72	62	68	2.7
F	30	25.7	24.4	86	78	76	65	91	3.6
M	31.1	28.3	24.4	88	83	76	63	94	3.7
A	31.1	28.3	24.4	88	83	76	56	72	2.8
M	30	24.9	23.3	86	77	74	52	34	1.3
J	28.3	23.4	22.2	83	74	72	54	23	0.9
J	27.2	22.2	21.1	81	72	70	52	14	0.6
A	27.2	21.3	19.4	81	70	67	47	6	0.2
S	27.2	21.1	19.4	81	70	67	44	6	0.2
O	27.2	21.6	19.4	81	71	67	44	6	0.2
N	27.2	22.5	20	81	73	68	47	7	0.3
D	28.3	23.5	21.1	83	74	70	53	30	1.2
AVG	*28.8*	*24*	*21.8*	*83.8*	*75.2*	*71.3*		*37.6*	*1.5*

Some of the conclusions of the resource data analysis are:

1. The maximum wind velocity of all the sites is reached at noon, except for San Cristóbal Cerro, where it peaks between 6 and 8 am.
2. Low wind velocity can be found from December until May.
3. The highlands have higher wind velocities than the littoral regions, and the opposite occurs with solar radiation. High values are found in the littorals and lower solar radiation is in the highlands.
4. The best wind potential is in cerro San Joaquín, San Cristóbal.
5. The best solar radiation values are in the littorals of Pto. Baquerizo Moreno, San Cristóbal and Pto. Villamil, Isabela.

6. WATER

6.1 Introduction: Water Requirements and Availability

Galápagos is known for being dry and arid. During its discovery in early 1535, the bishop Tomás de Berlanga had reported to the King of Spain how inhospitable the islands were because of the lack of water sources added to the complicated wind and marine current system surrounding the Archipelago. It had been determined that the islands should be avoided in future expeditions. Pirates and whalers took advantage of this and used the islands as refuge and collected standing water from puddles, crevices and low tide collection areas.

Up until the middle of the century the population didn't surpass 1,000 inhabitants in the entire Archipelago. These people were able to sustain themselves with their own agriculture and cattle raising. During the last 25 years there has been a remarkable increase in population, reaching 10,000 habitants. The population and economical growth has produced several disparities. The excessive increase in residents and visitors can be self-destructive and the gradual improvement of infrastructure (ports, airports, roads, hotels, etc) hasn't been accompanied by a parallel improvement in obtaining potable water.

The lack of water is a limiting growth factor and the main social problem. Minimum quality and quantity requirements have to be met in order to avoid reaching difficult sanitary conditions. There have been different cholera outbreaks in the previous years and the risk of another one is a constant jeopardy.

Water is needed in three different sectors: population, agriculture and tourism. For population, an average of 200 l/person/day was used to obtain the annual water requirements.

Table 6.1 Water needed for consumption

Island	Population	Water needed (m^3/year)
Santa Cruz	9,920	724,160
San Cristóbal	5,682	414,786
Isabela	1,474	107,602
Floreana	88	6,424
Total	17,164	528,812

The land to be used for agriculture[40] was determined in 1979 and will remain the same because the rest of the territory is considered a National Park. The area of the land set for agriculture in each island is as follows:

Table 6.2 Land set for agriculture[41]

Island	Number of owners	Agriculture Surface (ha)
Santa Cruz	199	11,448.30
San Cristóbal	174	7,892.60
Isabela	209	4,783.10
Floreana	90	284.80
Total	672	24,408.80

Water demand for the tourism sector has been the hardest to define. Twenty years ago, it was estimated that 12,000 people visited the islands and stayed for an average of 5 days. By 2001, this value has increased to 45,000 visitors who stay an average of 7 days on the islands.

There are two types of tourism, one that visits the islands on a cruise boat and the other that visits the islands by flying from the Continent to the islands and using the local infrastructure. The number of visitors in each category hasn't been determined, even though it is a very important factor in determining the water demand that the islands would have for those tourists who don't take cruises. Tourists in both categories will consume water, with the difference that cruises usually depart from the Continent and get their water supply there.

In order to determine the water requirements for each island, some assumptions were made. The consumption per tourist is of 500 l/day and 70% of the tourists go to Sta. Cruz while the remaining 30% goes to San Cristóbal.

Table 6.3 Water needed for tourism[42]

Island	Total demand (m^3/year)
Santa Cruz	110,250
San Cristóbal	47,250
Isabela	27,000

[40] Only the total amount of water needed for agriculture will be given. The amount per ha will depend on the type of crop and the season.
[41] Bases para un Plan Hidrológico del Archipiélago de Galápagos, Consejería de Obras Públicas, Vivienda y Aguas.
[42] *Idem*

The total water requirements are:

Table 6.4 Water demand for the Galápagos[43]

Island	Urban Demand (m^3/year)	Tourism Demand (m^3/year)	Agriculture Demand (m^3/year)	Total (m^3/year)
Santa Cruz	724,160	110,250	500,000	1,334,410
San Cristóbal	414,786	47,250	600,000	1,062,036
Isabela	107,602	27,000	130,000	264,602

The main water source is groundwater, thus, a big well has to be designed to pump a certain flow of water. Table 6.5 presents a summary of the water extracted and the annual production of the current well.

Table 6.5 Water availability[44]

Island	Discharge to the sea (hm^3 x km of coast)	Maximum extraction flow (l/sec)	Annual production of well (m^3/year)
Santa Cruz	2 to 3	15 to 25	400,000 to 700,000
San Cristóbal	1 to 2	7 to 15	200,000 to 400,000

The Galápagos Islands have quality and quantity problems with their water supply. The main concerns are:

- San Cristóbal has a scarce supply, but good quality because it comes from surface water. On the other hand, this island is excessively dependant on the climate. Dry months and less abundant raining season cause water shortages.
- Santa Cruz has an acceptable supply in terms of quantity, but not of quality. There isn't enough surface water, and the water that is extracted from the well is affected by seawater pollution. The high chlorine concentration makes it necessary to have a desalinization plant.
- Isabela has a scarce water supply and poor water quality since it also has seawater contamination.

---

[43] *Idem*
[44] *Idem*

Samples from the sites indicated in Table 6.6 were taken to do a chemical analysis of the water content. Results[45] are presented in the table, as well as the standards to comply with quality requirements. Recent chemical analysis have not been performed.

Table 6.6 Chemical Analysis of Water Content for Different Sites

	Conductivity (μs/cm)	Chloride (mg/l)	Phosphate (mg/l)	Magnesium (mg/l)
Standards of the European Common Market	1,000	200	0.4	50
Alemanes Crevice, Sta. Cruz	4,510	1,322	1.4	79
Pampa Colorada Crevice, Sta. Cruz	3,159	971	3.1	70
Charles Darwin Catchment, Sta. Cruz	5,664	1,890	0.5	124
Barranco Catchment, Sta. Cruz	2,832	822	0.6	76
Galápagos Hotel Crevice, Sta. Cruz	6,220	1,899	-	163
PPSC-01, Sta. Cruz	2,129	776	-	-
Well 1, Sta. Cruz	1,780	525	-	57
El Chapín Crevice, Isabela	1,812	547	-	-

The following sections will detail the water conditions of each island visited.

6.2 Sta. Cruz[46]

Underground water pumping, managed by the municipality, has become a grave problem. They use 7 electric pumps with a capacity of 20 HP each, and one 40 HP bullet type pump to pump water that is 25 m. deep. The total pumping capacity is of 100 kW. Each pump has a flow rate of 12 l/s, but this value is not constant. Every day, the pumps extract a total of 26.7 l/s, which means that the seven pumps don't work all together, but alternately.

[45] *Idem*
[46] Information obtained from the Municipality of Pto. Ayora, Sta. Cruz

The water is pumped to the storage and distribution tanks, and there are approximately 2,600 users. Each house has a small pump with a capacity of 0.5 HP because the pressure in the water grid is not enough to reach the reservoir.

Water is only pumped during the daytime, from six in the morning until five in the afternoon; thus, the use of a reservoir is necessary.

The Island of Sta. Cruz has crevices all around it due to geological faults. Seawater filters into these crevices and is extracted at 800 m from the sea. There are two crevices that feed water into Pto. Ayora. The first one is called Grieta Misión Franciscana, and has a chlorine concentration is of 800 ppm, and the second one is named Ingala, with a 700 ppm chlorine concentration.

The water in Pto. Ayora has serious contamination problems, especially due to bacteria contamination. The amount of fecal coliforms in the Grieta Misión Franciscana is uncountable because the city doesn't have a sewer system. Under their public construction code, all establishments have to be built with a septic tank; however, there isn't a real follow up. It has been found that many residences living near the crevices discard their waste there.

Though it has not yet been confirmed, it is believed that in the highlands of the island there is a watershed of sweet water. During the raining season, it has been shown that the salinity concentration decreases, and during the dry season, the chlorine concentration can go as high as 1200 ppm. With the use of satellite images, it was found that the two crevices join at a certain point, and the chlorine concentration at this point is of 250 ppm. A productive well is pumping water in the intersection. The seven 20 HP pumps are used on the crevices and the 40 HP pump is used on its intersection.

Homes in the highland have a divided roof that permits them to collect water during the raining season and deposit it in a canal that will fill a hermetic reservoir. These homeowners will incorporate ultraviolet rays to the sweet water and produce potable water to sell to the lowlands. Pto. Ayora also has a purifying water factory with a capacity of 800 m^3 per day. The water purified is bottled and sold for drinking and cooking only.

Currently, there is a new project that consists of pumping water that is 180 m. deep with 40 HP pumps. This water would serve the populations of Pto. Ayora and Bella Vista, which is in the highland. Since the population is disperse, they require a higher pressure.

Santa Rosa, a village on the north end of the island, has a watershed coming from an altitude of 300 m. The water is discolored and during the raining season, it drags filth. The rainy season is from July to October, so the volume of water increases. December to March are considered the critical months because there is no rain, so the water volume diminishes. One interesting aspect, important for them because they export livestock, is that brackish water is good for cattle.

Something common within all the populated islands is that the piping system is not reliable since there are many leaks. The municipality destines 250 to 300 l/person/day in a rationale manner: three or four hours per district, depending on the population density of each district. In reality, the amount of water necessary per person is of only 120 l/day, so the amount of water pumped is much higher due to the many leaks that exist before the water actually reaches the household. It is estimated that 50% of the water pumped is lost throughout the distribution system.

One of the main problems is that the piping system is obsolete since it was installed at least 30 years ago. Other administrations put in flex piping and salt water is corroding and rotting the brackets. In the periphery of the island, some PVC piping is being installed as well as systems that will guarantee the supply of water to the population and a micro measuring system. Currently, five percent of the population doesn't get water from the municipality. Some families have access to the crevices and supply some water to their neighbors.

The water consumption of each establishment and residence is not measured (there aren't any measuring devices). Each customer is charged a monthly flat rate according to the sector; thus, a water conservation culture still has to be formed. For residential sector, the cost is of 3.6 USD/month, for the commercial sector it is of 5.83 USD/month and for the industrial sector the cost is of 15 USD/month. The cost per m^3 is between 0.2 to 0.5 USD. Water for human consumption adds up to 5 or 6 gallons per day in residences. Boats bring 2,000 to 3,000 gallons of water per trip, in these cases; there is a restriction on the amount of water used.

6.3 San Cristóbal[47]

An advantage that San Cristóbal has over Sta. Cruz is its supply of sweet water. Pto. Baquerizo Moreno and El Progreso are divided in districts, and according to the population density of each district, water is supplied for 2 or 3 hours every day.

Both population centers have a sewer system, but it's very old dated. The system is 25 years old and was designed for a population of 3,000 people. By the year 2000, the population had doubled, so the capacity of the sewer system is not enough. A new system would cost around one million dollars.

The municipality has a 1450 m^3 storage tank from which water is distributed to the population. According to calculations done by the municipality,

[47] Information obtained from the Municipality of Pto. Baquerizo Moreno, San Cristóbal

the daily supply of water for the entire populations of Pto. Baquerizo Moreno and El Progreso should not exceed 600 m^3, however, as there are considerable leaks in the secondary distribution system that are of near 50%, the entire 1450 m^3 are destined. Their distribution system does not have any measuring devices, thus, all residences are charged a flat rate of 2 USD per month that does not enhance a water savings culture. Since they pay the same amount whatsoever, they don't care how much water is saved or wasted.

6.4 Isabela[48]

Isabela has a recently inaugurated package type automatic wastewater treatment plant. The plant started working in March of 2002 and produces 5 l/s and works 24 hours a day with a total production of 400 m^3 per day. It has a sand filter, an activated carbon filter and a clarifier with the potassium chlorhydrate mix.

The plant uses four pumps:

- Two centrifugal water pumps of 6 HP each with a pumping capacity of 8 l/s
- Two chemical dosifiers of $^1/_3$ HP each with a pumping capacity of 1 to 3 gal/day.

Water is taken from two different wells that are formed by water accumulation - water from the highlands drips down through underground currents that lead to the sea. The volcanic lava produces underground tunnels and displaces the sweet water of the highlands (altitude ranging from 400 to 700 m) to mix with the seawater, so the water table is high and the land is porous. The water is taken from a maximum depth of 2 m., and if this depth increases, we would find seawater. There is a third well with sweet water, but this isn't used because all the water requirements of the population are met with the first two wells.

Their piping system reaches 98% of the homes and it does include measuring devices. The residential cost for water is between 12 and 16 cents of USD/m^3. The average consumption per household is of 15 m^3.

The sewer system only reaches 44% of the population, and even though there is a wastewater treatment plant, water coming out of it has a concentration of 160 ppm of fecal coliforms. Since the piping system is highly contaminated due to the high water table, water reaching homes has a concentration of 300 or more ppm of coliforms. Septic tanks are used in 56% of the homes.

[48] Information obtained from the Municipality of Pto. Villamil, Isabela

7. BOATS

Around 75% of the fuel brought into the islands is used for transportation purposes, and most of it is for boats. It has been found that 92%[49] of the pollution is caused by transportation, particularly boats, rather than electricity production. Some researchers and institutions have looked into the possibility of using renewable energy, especially photovoltaic panels, to power the boats.

So far, positive results for the use of photovoltaics haven't been obtained. The main reason for this is that the boats use 110 and 220 V, 60 Hz systems. A change to renewable energy would necessarily implicate a change in the entire system. Some boat owners have shown reticence to changing their whole system to be electrified with solar energy. However, they do believe that photovoltaics can still be used in boats, specifically for telecommunication purposes. The photovoltaic system would be used for the radio. In the case that they get lost and run out of fuel, they will still have the power of the photovoltaic system to get help.

The fuel consumption of each boat was very difficult to determine because it depends upon the distance the boat travels, the season in which it travels, and general weather conditions. In the case of fishing boats, the amount of fuel used also depends upon the type of specie it's fishing.

The following charts indicate the number of traditional fishermen and fishing boats authorized by the National Park, as well as the number of the three main different types of marine transportation: *fibra*, *panga* and *bote*.

Table 7.1 Number of Registered Traditional Fishermen[50]

Year	No. of Fishermen
1971	156
1980-1982	117
1982-1983	152
1983-1984	202
1984-1985	235
1985-1986	369
1992-1993	392
1996	455
1998	613
1999	795
2000	682

[49] Taller de Energías Renovables, July 23rd, 2002. Manual Sáenz, Environmental Ministry of Ecuador
[50] Informe Galápagos 2000-2001, Fundación Natura and WWF

There are three different types of boats in Galápagos: *botes*, *fibras* and *pangas*. The main differences between them are their size and the motor type and location. *Botes* have a stationary engine while *fibras* and *pangas* have an out of board engine. *Botes* and *fibras* have storage space for their capture, unlike the *pangas*. Also, a *bote* has more autonomy (can be in the sea for a larger amount of days).

Table 7.2 Evolution of Fishing Boats by Type and by Island[51]

	Panga			*Fibra*			*Bote*			Total		
	1999	2000	Increment Percentage	1999	2000	Increment Percentage	1999	2000	Increment Percentage	1999	2000	Increment Percentage
Isabela	43	54	26	28	32	14	9	9	0	80	95	19
San Cristóbal	52	148	185	8	33	313	29	32	10	89	213	139
Santa Cruz	31	52	68	32	35	9	22	22	0	85	109	28
TOTAL	**126**	**254**	**102**	**68**	**100**	**47**	**60**	**63**	**5**	**254**	**417**	**84**

The following table indicates the minimum and maximum HP, or displacement capacity, for each type of boat.

Table 7.3 Displacement Capacity of Boats in Galápagos[52]

	Motor (HP)	
Boat type	Min	Max
Panga	10	85
Fibra	25	200[53]
Bote	30	210

[51] *Idem*
[52] *Idem, pag. 53*
[53] Uses two motors

8. RENEWABLE ENERGY IN GALÁPAGOS

Different institutions are currently working on project proposals for the electrification of the Galápagos Islands with renewable energy. Some pilot projects using solar energy have been implemented both for electrification and for water heating. Monitoring of these systems is important to help determine the feasibility of using renewable energy on a larger scale. These systems have also aroused interest within the population about renewable energy technologies.

The following pages describe the different systems used in the Galápagos Islands and give an update of their current status and problems that have arisen.

8.1 Schools[54]

Colegio Nacional Galápagos in Pto. Ayora, Sta. Cruz and Colegio Alejandro Humboldt in Pto. Baquerizo Moreno, San Cristóbal have a photovoltaic system for electrification of part of the schools. Both systems were installed under a pilot program of the United Nations Development Programme (UNDP) and are exactly alike. The systems were installed in 1998 and have been working relatively well for the past four years.

The cost of each system was of 40,000 USD, and the UNESCO and the Energy and Mines Ministry of Ecuador financed them.

The characteristics of the systems are:

- Photovoltaic panels: 39 mono-crystalline silicon panels with a total area of 25 m^2 and a capacity of 3315 Wp.
- Batteries: 24 lead-acid stationary batteries of 2 V each one, produce a voltage of 48 VDC with an accumulation capacity of 900 Ah, enough to provide four days of energy.
- Data logger: It's a mini-computer connected to different sensors.
- Regulator: It has a capacity of 4 kWp, and it takes care of obtaining the maximum efficiency of the solar panels, by looking for the maximum power point.
- Inverter[55]
- Energy supervisor: Receives the signals coming from a group of sensors to measure the solar radiation, temperature of the batteries and energy production and consumption.

[54] Information provided by Luis Oña and Ricardo Gavilanes of Colegio Nacional Galápagos and Byron Fernández of Colegio Alejandro Humboldt.
[55] There wasn't additional information on the inverter.

- Other devices:
    - o Auxiliary charger
    - o Processor
    - o Visualization panel

The photovoltaic systems are given maintenance every two to three months. There are some months where there is larger load than what the system was designed for, thus, the school has to purchase electricity from the grid. However, during the seasons where the school produces more than it consumes, the surplus is not sold back to the grid.

Figures 8.1 and 8.2 show the energy generated by the photovoltaic systems and the energy consumed by the loads that are satisfied by it, for both schools.

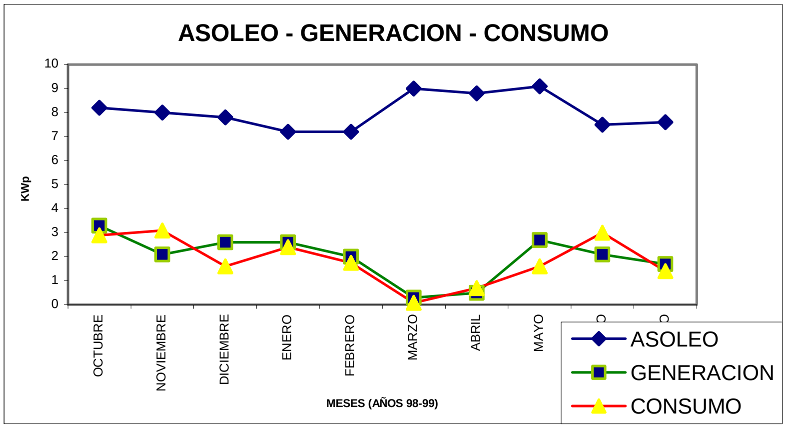


Figure 8.1 Energy Generation and Consumption
of the PV System of Colegio Nacional Galápagos, Sta. Cruz

Figure 8.2 is an output chart from the data logger of the Colegio Alejandro Humboldt.

	(kWh/m2)	(Wh)	(Wh)	(Wh)	(Wh)		Igualació
30/04/01	6.09	6781	0	11905	49	73%	0
01/05/01	7.96	6616	0	5212	48	76%	0
02/05/01	5.84	3572	2765	17066	48	32%	0
03/05/01	7.17	3693	9840	6395	48	38%	0
04/05/01	7.78	3789	11192	5225	49	55%	1
05/05/01	6.65	3507	0	3675	48	54%	0
06/05/01	8.16	6375	0	3994	48	59%	0
Total	49.65	34333	23797	53472	338		1

Figure 8.2 Data Logger Output of the PV System of
Colegio Alejandro Humboldt, San Cristóbal

Colegio Alejandro Humboldt uses from 65 to 70% of the energy they produce and their average solar radiation is of 511 W/m^2/day, equivalent to 4 or 4.5 hours of sun days.

The load that is satisfied with the photovoltaic system of Colegio Nacional Galápagos is described in Table 8.1.

Table 8.1 Loads Satisfied by the PV System of Colegio Nacional Galápagos

	Equipment	Quantity	Total Power (W)	Hours of use	Energy (Wh)
First Floor					
Classroom 1	Fluorescent lamps	2	100	0	0
Classroom 2	Fluorescent lamps	2	100	2	200
Classroom 3	Fluorescent lamps	4	200	0	0
Natural Science's Museum	Bullock's eye lamps	2	46	0	0
Hallway	Fluorescent lamps	2	100	3	300
Second Floor					
Computer Lab	Computers	9	900	8	7200
	Fluorescent lamps	4	200	3	600
	Bullock's eye lamps	2	46	3	138
Audiovisual Lab	Music and Audio-visual equipment	2	240	1	240
	Fluorescent lamps	4	200	1	200
	Bullock's eye lamps	2	46	1	46
Hallway	Fluorescent lamps	2	100	3	300
	Bullock's eye lamps	1	23	3	69
TOTAL			2301		9293

A similar load is satisfied for the Colegio Alejandro Humboldt, who uses the photovoltaic system for the administrative offices, and computer, audiovisual and music labs.

As mentioned previously, the systems have been working well, except for a few problems described briefly. The data logging system of Colegio Nacional Galápagos suffered some problems and is not collecting data anymore. However, the photovoltaic panels, as well as the batteries and inverters are working adequately. The main problems that the Colegio Nacional Galápagos has had are interruptions in the supply of electricity (three to four each year) and some of their loads being disconnected causing some of their breakers to go on. In Colegio Alejandro Humboldt a fuse burnt because of the humidity. Also, a general problem of the islands is the ground.

Students of the Humboldt school don't have the knowledge of the system's use and functioning, thus, the school has designed a project called *Let's Learn Together to Save Electric Energy* to spread awareness on energy efficiency and to learn the components, applications and maintenance of a photovoltaic system.

Starting with the following school year, the topic of Renewable Energy and Rational Energy Use will be incorporated into the curriculum of the Physics course. The program also includes a solar energy class.

8.2 Hotels

Three hotels in Pto. Ayora have solar water heating systems. They are Hotel Angermeyer, Hotel Palmeras and Hotel Fernandina. Hotel Lobo del Mar is currently installing their system.

The owners and employees of the hotels Angermeyer and Palmeras didn't have any information about their systems and couldn't refer me to the installer of the system. They don't have a clue of its performance nor have any maintenance schedule. One common aspect of these two hotels is that their tanks have a thermostat and they are connected to the grid, so in the case of having a day (or days) with low solar radiation, they heat the water with electricity from the grid. The amount of the times that they have to connect to the grid and the amount of water that is heated this way is unknown.

Fernando Ruiz[56], owner of Hotel Fernandina, gave all the details of the system installed in his hotel. He has six solar collectors and two collection tanks, of 500 and 600 l. One of the tanks is made of stainless steel and the second one is of steel, which avoids corrosion, but has infiltration problems. Mr. Ruiz mentioned that one of the main problems of the water supply is the high sulfur content, so there is a need to do some research for adequate materials for the tanks.

The system has two tanks just to ensure that the hotel will always have a supply of hot water. The water comes from the tank, circulates through the solar collectors, enters the 500 l tank and then goes onto the 600 l tank where it accumulates. The difference of this hotel with the two previous ones is that the backup is of gas rather than electricity. An additional feature of this system is that the pumps that feed water to the showers are of high pressure, decreasing the consumption of water.

Several years ago, electricity wasn't supplied from twelve midnight until six in the morning. Some researchers had the idea of installing photovoltaic systems, but due to the excessive charging and discharging the batteries would

[56] Information provided by Fernando Ruiz, owner of Hotel Fernandina

have to go through, added to the initial costs and the area required, the idea was discarded. Right now, with all the proposals of renewable energy projects in the islands, and a hybrid system being installed in the Island of Floreana, institutions have gained more interest in the use of photovoltaic energy for electrification purposes. Instead having a big amount of battery storage, the excess energy would be sold to hotels for their water heating. Hotels have said that one of their main concerns is the excessive demand of hot water between 5 and 6 pm, time at which all their customers seem to be taking a shower.

The tourism season varies every three months in average; this is, three month of high tourism, three months of low tourism, and so forth.

Hotels in Pto. Baquerizo Moreno and Pto. Villamil don't have solar water heating systems.

8.3 Stores[57]

Bodega Blanca, a hardware store in Pto. Ayora, has a photovoltaic system that is used mainly for four computers and part of the lighting of the store, equivalent to 20 W of fluorescent lights. It has 4 – 150 Amps. stationery batteries. They plan to double the capacity of the system for protection to their computers. The electricity from the grid has poor quality and ranges from 108 up to 140 V. This is due to two main problems: the power plant needs an overhaul that is long overdue and there is an imbalance on the phases.

8.4 Solar System of the Research Station of the Bolivar Canal, Galápagos National Park[58]

The control station in the Bolivar Canal, between the Islands of Isabela and Fernandina has a solar system as its main electric energy supplier.

The system consists of 12 Kyocera 120 W panels than can produce up to 60 A, 24 VDC, a Trace C60 charge controller and 12 deep cycle batteries with a 1050 A/hr capacity. The batteries weigh 320 lbs. and have three days of autonomy.

The current of the batteries goes through a sine wave Trace 4024 inverter with a capacity of 4000 W at a voltage of 120 VAC. There is also a converter from 24 VDC to 12 VDC for the communications radar and radios.

[57] Personal conversation with Jason Gallardo, owner or Bodega Blanca
[58] Personal conversation with Godfrey Merlen, designer of the system and researcher at the Galápagos National Park.

The load consists of lights, a refrigerator, a TV and VCR, radar and radios. During the months of July through December there are more days of sun than from January to June, where there is also rain.

The two main reasons for having a photovoltaic powered system are to avoid pollution and to have a reliable and permanent communication without having to bring fuel to the site.

8.5 Other uses

Small photovoltaic systems are used in the lighthouses of different populated and non-populated islands. Their capacity is unknown, but it must be around 2 kW. There is battery storage because they work during the night for protection of boats.

The navy also has photovoltaic installations for telecommunication purposes in Baltra's airport, and on their premises in Santa Cruz, San Cristóbal, Isabela, and Floreana. Information about the performance and technical specifications of these systems couldn't be obtained[59]. The specifications of these systems were not available.

8.6 Wind and Biomass

Wind energy is not being used in the Galápagos Islands up to now, since there is concern regarding the effect the wind turbines can have on the endemic birds. Research on the topic is currently being undertaken.

More details on the use of biomass on the Islands are presented in Section 9 of this report.

[59] The Armada de Ecuador has a registry of all the systems in Guayaquil, Ecuador, but special permissions need to be obtained to have access to them.

9. NEW PROPOSALS AND STUDIES

The Program Araucaria is the main instrument of the Spanish Cooperation for environmental protection and sustainable development in Latin America. Their scopes of work are projects that contribute to the conservation of natural resources and to the human development of the population. The Foreign Affairs, Environment, Education and Economy and Finances Ministries, who signed a Frame Convention of Collaboration in 1998, develop the Araucaria Program.

In terms of renewable energy, Araucaria will promote and finance technical assistance projects that will foster the development of minihydroelectric plants, wind and solar energy, and the use of biomass. It will also promote the development of small and medium enterprises and agriculture industries that will establish high energy efficiency standards in rural regions.

In the case of the Galápagos Islands, Cooperación Española has been working to keep the diverse environments as natural as possible by decreasing human impact on the ecosystems.

9.1 Floreana's renewable energy electrification project

Diverse institutions are working together in the design and installation of a renewable energy system for the electrification of Floreana. Floreana is the island with smallest population and lacks most of the basic necessities such as electricity and water supply.

The main goal of Floreana's renewable energy electrification project is to work towards the sustainability of Floreana by taking into consideration three priorities:

- Substitution of the current energy model and overcoming of existing social and cultural barriers
- Strengthening of local institutions and citizen associations as active members of this project
- Transcendence of this project to the entire Archipelago and other remote areas of Ecuador as a replicable model

The system designed for Pto. Velasco Ibarra is a solar-wind hybrid generation micro grid. The hybrid system will serve 44 electric connections, including houses, public lighting, interpretation center, services, etc.

Tables 9.1 and 9.2 give the technical specifications of the system to be installed in Floreana as well as the different system designs that will be used for agricultural purposes.

Table 9.1 Photovoltaic-Wind System for Puerto Velasco Ibarra

Photovoltaic Array	
Installed photovoltaic capacity	12.000 Wp
Tilt/Orientation	10º/180º North
Occupied surface (approx)	100 m^2
Batteries	
Type of battery	Lead-acid tubular stationary
Capacity (C100)	165 kWh
Tension of battery	48 V
Days of autonomy	3 days
Regulator	
Regulation capacity	12,000 Wp
Regulation mode	MPPT Tracking
Inverter	
Exit voltage	110 VDC
Nominal power	14 kW one phase
Harmonic distortion	Less than 2.5%
Reversible Inverter	
Data Acquisition	
Memory/frequency of entries	300 kbyte/hourly
Internal telephonic modem	Yes
Measuring Device	
Feed	110 VDC 60 Hz
Maximum intensity	10 A
Capacity of counter	100 MWh
Public Lighting	
Number of lamps	30
Lamp type	70 W double level electronic ballast
High level power	2,100 W
Low level power	1,365 W
Wind Generation	
Wind capacity	12,000 W

Table 9.2 Stand Alone Photovoltaic-Wind Installations for the Agricultural Regions

	Elemental Rate TD17	Basic Rate TD50	Productive Rate TD100
Photovoltaic Array			
Installed photovoltaic capacity	225 Wp	750 Wp	450 Wp
Tilt/Orientation	10º/180º North		
Batteries			
Type of battery	Lead-acid tubular stationary		
Capacity (C100)	3 kWh	10 kWh	20 kWh
Tension of battery	12 V	24 V	48 V
Days of autonomy	4		
Inverter			
Exit voltage	110 VDC		
Nominal power	400 W	1,200 W	2,000 W
Measuring Device			
Feed	110 VDC 60 Hz		
Maximum intensity	10 Amp.		
Capacity of counter	100 MWh		
Wind Generation			
Wind capacity	no	no	1,500 W

9.2 Waste Management in the Galápagos Islands

Among the projects to introduce the use of renewable energy in the Galápagos Islands, we find the ALTENER Program[60] of the European Commission to analyze the use of waste for energy recovery and the use of the resources contained within the waste.

The production of waste per person and per island has been determined as a first step. Predictions of waste production over the next 18 years have been calculated based on population growth data, as shown in the following tables.

[60] ALTENER is a program of the European Commission focused exclusively towards the development and promotion of renewable energy. This program helps in the creation of a framework for the use and development of renewable energy, providing assistance for pilot experiences, as well as for its implementation and commercialization.

Table 9.3 Waste production (kg/person/day/island)[61]

	Santa Cruz	San Cristóbal	Isabela	Floreana
Values for year 2000	0.74	0.93	0.52	0.52
Estimated values for year 2020	1.05	1.05	0.7	0.7

Table 9.4 Annual Production of Municipal Waste, in tons[62]

	Santa Cruz	San Cristóbal	Isabela	Floreana
Values for year 2000	3,511.30	2,186.35	283.61	22.78
Estimated values for year 2020	5,463.61	3,132.30	569.51	45.48

The composition of the waste also needs to be determined in order to identify the energy and/or resource recovery techniques. What seems strange in this case is that metal, textile and wood aren't common in the waste streams of the islands.

Table 9.5 Waste composition[63]

Percentages	Santa Cruz	San Cristóbal	Isabela
Organic Material	60	72	70
Paper and Cardboard	12	8.4	9
Plastics	9	6.3	6.8
Textiles			
Wood			
Glass	11	7.7	8.2
Inerts	8	5.6	6
TOTAL	100	100	100

[61] Propuestas para la Gestión Integral de los Desechos en las Islas Galápagos. Institut Catalá d'Energia, Barcelona, Octubre 2001, pag. 19
[62] *Idem*
[63] *Idem*

For the year 2020, the authors of the study assumed a moderate growth in the waste generation per person and a reduction in the percentage of organic materials in the waste.

Table 9.6 Estimate of the Composition and Production of Waste for 2020[64]

PERCENTAGES	Santa Cruz	San Cristóbal	Isabela	Floreana
Organic Material	55	60	65	65
Paper and Cardboard	13.05	11.6	10.15	10.15
Glass	11.25	10	8.75	8.75
Plastics	9	8	7	7
Metals	3.6	3.2	2.8	2.8
Textiles	0.9	0.8	0.7	0.7
Voluminous	1.35	1.2	1.05	1.05
Rubble, Debris	0.9	0.8	0.7	0.7
Special	1.35	1.2	1.05	1.05
Others	3.6	3.2	2.8	2.8
TOTAL	100	100	100	100

TONS	Santa Cruz	San Cristóbal	Isabela	Floreana
Organic Material	3,005.0	1,879.4	370.2	29.6
Paper and Cardboard	713.0	363.3	57.8	4.6
Glass	614.7	313.2	49.8	4.0
Plastics	491.7	250.6	39.9	3.2
Metals	196.7	100.2	15.9	1.3
Textiles	49.2	25.1	4.0	0.3
Voluminous	73.8	37.6	6.0	0.5
Rubble, Debris	49.2	25.1	4.0	0.3
Special	73.8	37.6	6.0	0.5
Others	196.7	100.2	15.9	1.3
TOTAL	**5,463.8**	**3,132.3**	**569.5**	**45.6**
Others				
Mineral Oil	50.0	10.0		
Wood and Thicket	800.0	500.0	100	25

Since Isabela and Floreana have a small population and thus, a smaller waste generation, energy recovery from waste will not be done. The organic fraction of the waste will be used for compost, hopefully with the help of experts from the Sustainable Agriculture Program of the Charles Darwin Research

[64] *Idem*

Station. Glass, plastics, metals and textiles are separated by the different families and set to recycle. The same thing is done with paper and cardboard. They are separated, compacted and transported to the continent, or used in compost with the organic material.

Santa Cruz and San Cristóbal, because of their population and high tourism, generate more waste. These two islands have the possibility of recovering energy from waste, and because of the amount generated, the project may be economically feasible and would help with the energy deficit of the islands.

The energetic potential of the waste is defined by its composition and the heating value of each of its elements, thus, we can find out the maximum energetic capacity of the waste. The percentage of recuperated energy will depend on the technology used and of the previous treatments that are done to optimize the efficiency. In the case of gasification, the pretreatment consists of decreasing the humidity percentage and extracting inert materials. The system will then produce a gas that will have approximately 75% of the original energetic potential.

The gas obtained will be cleaned and sent to gasoline engines that can have efficiencies near 36%. The results of using a gasification system are presented below.

Table 9.7 Energy Balance of Waste Gasification[65]

	Annual Production of Waste (tons/year)	Energy Contained in the Waste (GWht/year)	Consumption of the System and Losses (GWht/year)	Gas at the Entrance of the Motors (GWht/year)
Santa Cruz 2002	3,799.50	9.47	2.40	7.10
San Cristóbal 2002	2,434.00	5.08	1.30	3.80
Santa Cruz 2020	5,305.60	12.77	3.20	9.60
San Cristóbal 2020	3,128.60	7.06	1.80	5.30

	Electric Energy Produced (GWhe/year)	Expected Energy Demand (GWhe/year)	Percentage of Energy Satisfied	Estimated Capacity (MW)
Santa Cruz 2002	2,558.00	8.00	32.0%	0.30
San Cristóbal 2002	1,371.00	5.10	26.9%	0.20
Santa Cruz 2020	3,448.00	17.60	19.6%	0.40
San Cristóbal 2020	1,907.00	9.10	20.9%	0.20

[65] *Idem.*

9.3 Other Renewable Energy Activities and Proposals

The Ministry of Energy and Mines of Ecuador, together with the Environmental Ministry of Ecuador and the United Nations Development Programme (UNDP) have come up with a tentative system design (through Lahmeyer International) for the four islands, which is presented in the next table[66].

Table 9.8 Most Feasible RE Scenario

	Equipment						
Island	Wind (kW)	PV (kW)	Batteries (MWh)	Total Generation (MWh/year)	RE Generation (MWh/year)	Penetration Percentage	Initial Inversion
Sta. Cruz	6,250	2	10	10,300	6,324	61.20%	10,800
San Cristóbal	1,750	2	7	5,446	5,310	97.50%	6,200
Isabela	-	440	3	1,176	715	60.80%	6,800
Floreana	12	9	0	58	47	80.50%	760
TOTAL	8,012	453	20	16,980	12,396	75.00%	24,560

Even with the implementation of a hybrid system, the Islands will still have diesel consumption, but this will be reduced significantly, as can be seen in Figure 9.1

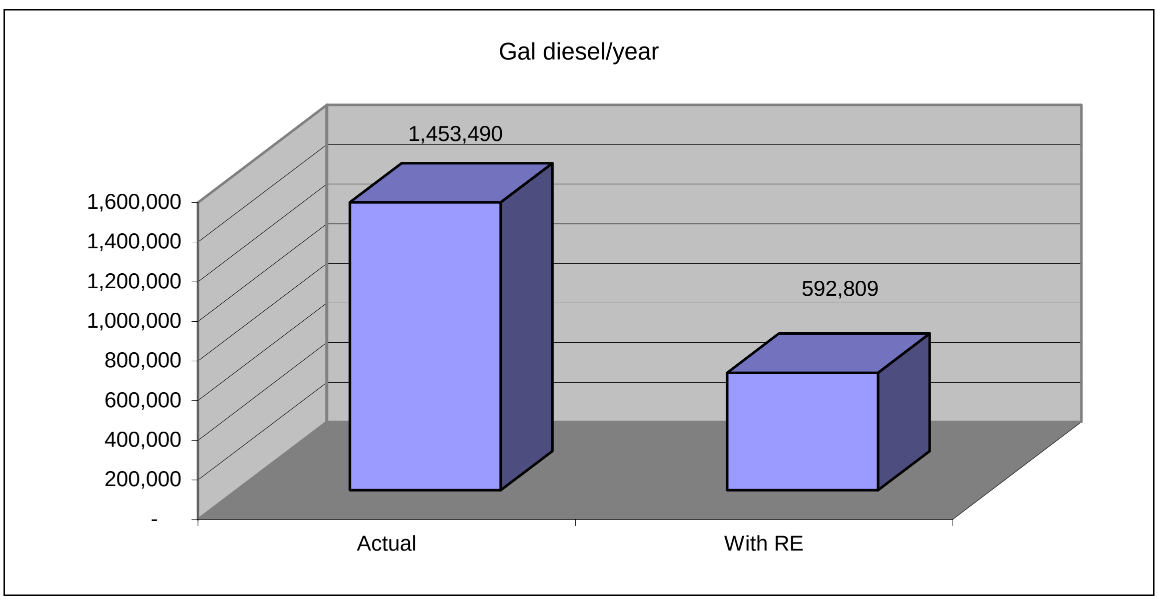


Figure 9.1 Reduction in Diesel Consumption with most Feasible RE Scenario[67]

[66] Electrificación Renovable de las Islas Galápagos. Ministerio de Energías y Minas. Power Point Presentation presented in a workshop in the Galápagos National Park, July 23rd, 2002.
[67] *Idem.*

CONELEC, the National Electricity Council, is the regulatory entity. One of their goals is to reduce CO_2 emissions, which they estimate are around 12,000 tons, by reducing diesel consumption on the Islands.

The cost of energy will be as follows:

Photovoltaic:	13.65 cents USD/kWh
Biomass:	10.23 cents USD/kWh
Wind:	10.05 cents USD/kWh
Geothermal:	8.12 cents USD/kWh

The additional cost for transportation is of 6 cents USD/kWh, with a maximum limit of 1.5 cents USD/kWh, if an extension of the transmission line is required.

These costs are in effect for 10 years from the time of installation for those systems installed after the year 2004.

The E7 Group also has a project for education and internet services through the use of renewable energy. Their project has already been approved and they are currently in the process of getting the equipment.

10. HOMER SIMULATION

With the population, load and resource data obtained from the Galápagos Islands, another simulation with HOMER was made to compare with the results of the design we had obtained in CVEN 4830. The simulation is done for Pto. Ayora, Sta. Cruz.

The component and optimization parameters remained the same.

10.1 Components

Five types of power generation components and their costs were identified and entered in to HOMER for economic optimization. The system components considered were PV panels, 2 types of wind turbine generators, diesel generators, storage batteries, and inverters. Table 10.1 shows the component models and costs used.

Table 10.1 Components Used and their Cost, in USD

Components	Model	Size (W)	Initial $	$/w	Replacement$	Maintenance $/yr
PV panels						
Solec		100	535	5.35	535	0.46[68]
Inverter						
Trace	SW4048	4,000	3,145	0.79	3,145	4
Storage Battery						
Trojan	L-16	2.1 (kWh)	189	90	90	10.5
Wind Turbines						
WTIC (Jacobs)	29-20	20,000	33,120	1.656	23,840	571
Atlantic Orient	AOC 1550	50,000	70,000	1.4	55,000	1,200
Diesel Generators						
Dayton	1N171	5,000	3,585	0.717	3,585	219
		9,000	10,475	1.164	10,475	394
		16,200	12,820	0.791	12,820	710
		22,500	13,240	0.588	13,240	986
		40,500	16,085	0.397	16,085	1,774
		45,000	16,440	0.365	16,440	1,971
		72,000	19,915	0.277	19,915	3,154
		81,000	21,000	0.259	21,000	3,548
		157,500	32,930	0.209	32,930	6,899

[68] Cost per watt

These components were chosen primarily for their reasonable cost but there were other specific criteria for some. The inverter was chosen for its pure sine wave output (not modified sine output) due to power quality issues. The two different wind turbines were selected to offer access to different wind regimes. The WTIC (Jacobs) 29-20 is a smaller turbine (20 kW) and works reasonably well in low wind speeds. The AOC 1550 is a larger (50 kW) turbine that works well at higher wind speeds and with larger loads. Since the price data for diesel generators does not appear to be linear, we chose several different models based on size and price to offer realistic cost options. The replacement costs are generally the same as initial costs except for the wind turbines since the tower can be reused. O&M costs are:

- $0.0025/kWh for PV,
- $1/kW for inverters,
- $5/kWh/yr for batteries[69],
- 2% of turbine and tower cost per year for WTG, and
- $0.01/kWh for diesel generators.

There were several general assumptions made about components:

- The life of PV panels was set at 20 years and a derating factor of 90% was used to account for various losses. The PV panels will be mounted with a 0.5-degree tilt with a north azimuth.
- The inverter is assumed to have a 5-year life and a 83% efficiency.
- The batteries are modeled with a 500 cycle life, 10 year float life, roundtrip efficiency of 80%, 40% minimum charge state, and a maximum charge rate of 0.1 A/Ahr unused.
- Both WTG's selected produce AC output and have a life of 20 years. The Jacobs 29-20 uses a wind speed scaling factor of 1.1682 to adjust for the height of the tower. The AOC 15/50 uses a 1.1716 wind speed scale factor since its tower is a little bit taller.
- Diesel generators are modeled to have a 15,000 hr life, 30% minimum load, fuel load intercept of 0.08 L/hr/kW rated, and fuel load curve slope of 0.25 L/hr/kW output, using clean, synthetic diesel.

[69] O&M cost for batteries can vary based on the use and treatment of the batteries. The O&M cost of $5/kWh/yr of battery storage used in this report was based on data from one of the developers of the HOMER software.

10.2 Simulation Parameters

I modeled with 0% and 10% unserved energy[70] allowance to see if significant savings could be achieved for a reasonable reduction in availability.

General optimization parameters were:

- $0.264/L for diesel fuel,
- Minimum of 70% renewable energy fraction and combinations between the two types of WTG's were not allowed.

The load profile and magnitude, as well as the resource data was changed in the following way:

1. Cooling loads were re-aggregated into the original load profile.

The load profiles used for the hotel, hospital, school, apartment and office building correspond to Honolulu and the cooling loads had been disaggregated. Since most office buildings and 50% of the residences and stores use air conditioning, the cooling loads were re-aggregated. Once we assign a magnitude input, the profile is adjusted, but the shape remains.

2. The annual load shape was adjusted to show the cooling season.

The load profile was plotted and adjusted to indicate the cooling season from December to May. In other words, the profile was displaced by six months.

3. The magnitude of the load profile was obtained with the utility data.

An annual average of the monthly utility data was obtained and used as the magnitude of the load profile. HOMER calculates the peak. The load profile generated by HOMER is shown in Figure 10.1.

[70] The unserved energy fraction is the proportion of the total annual electrical load that went unserved because of insufficient generation. A system is considered feasible (or acceptable) only if the unserved energy fraction is less than or equal to the maximum unserved energy fraction set by the user.

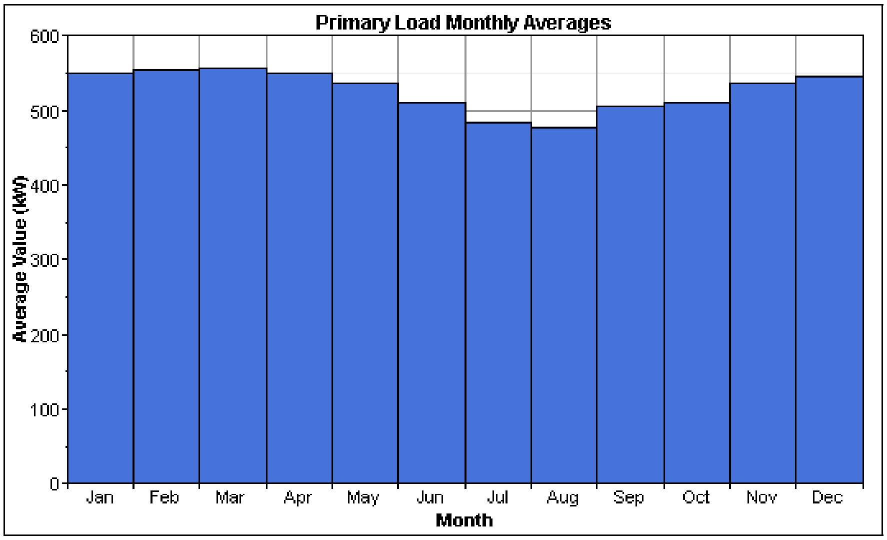


Figure 10.1 Load Profile Generated by HOMER

4. Resource data

The resource data that I got from the Galápagos Islands[71] has entries every ten minutes. To get the 8760 hourly file, the values had to be summed or averaged, depending if it was solar radiation or wind speed. The predominant wind direction is S and SE.

The resulting solar and wind monthly plots are shown in Figures 10.2 and 10.3.

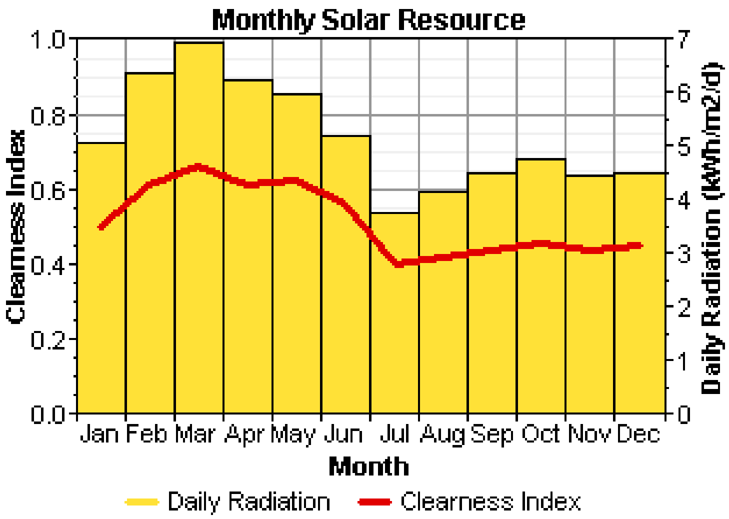


Figure 10.2 Global Solar Radiation Monthly Averages

[71] Information contained in the Lahmeyer Study, provided by Mauricio Velásquez of Galápagos National Park

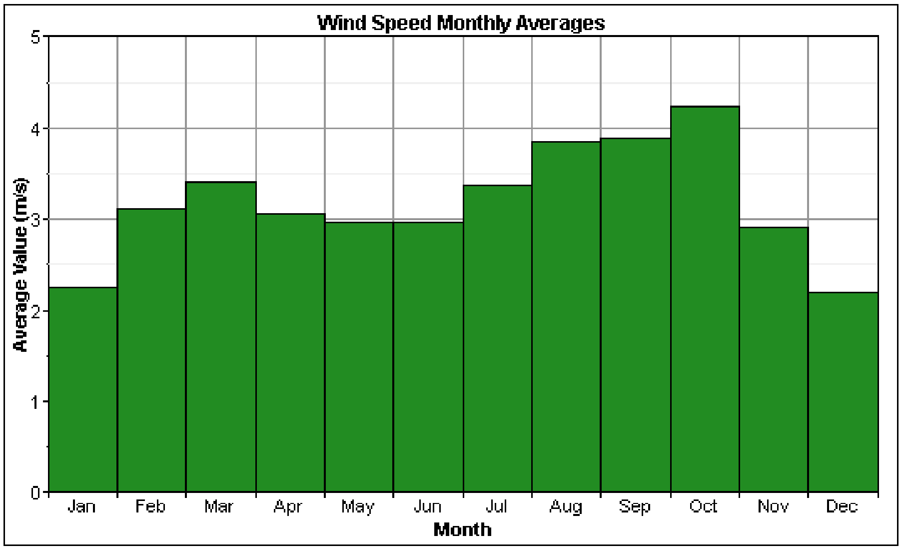


Figure 10.3 Wind Speed Monthly Averages

10.3 Simulation Results

The simulation output was similar to the system design proposed by the Ministry of Energy and Mines of Ecuador (shown in Section 9, Table 9.8), in the sense that both use a minimum capacity of photovoltaic energy and make more use of wind energy and batteries. The reason for this is the cost of the photovoltaic energy in comparison with the wind energy, having nothing to do with the resource. HOMER ranks the systems by their economic feasibility only, so if we want to see if a higher fraction of solar energy is technically possible, certain parameters have to be modified, such as indicating the minimum amount of photovoltaic kW we want in the system.

Since wind speed changed during the whole day, I added several sensitivities to the wind resource data. The average of the hourly data is of 3.19 m/s, but I considered the cases of having 5 and 8 m/s.

Table 10.2 shows us the outputs obtained from HOMER.

Table 10.2 Outputs from HOMER

Wind speed	% unserved	PV Array Capacity (kW)	Number of Wind Turbines	Generators Capacity (kW)	Battery Capacity (kWh)	Inverter Capacity (kW)	Rectifier Capacity (kW)	Total Capital Cost (USD)	Total Net Present Cost (USD)
3.19	0	-	1,000	750	2,500	500.0	375.0	19,607,410	33,074,552
		2.5	1,000	750	2,500	500.0	375.0	19,620,786	33,089,508
3.19	10	-	1,000	500	-	-	-	18,252,016	29,339,216
		-	1,000	500	10	5.0	3.8	18,256,946	29,346,334
		2.5	1,000	500	-	5.0	3.8	18,269,322	29,358,248
		2.5	1,000	500	10	5.0	3.8	18,270,322	29,360,856
5	0	-	300	750	2,500	500.0	375.0	7,615,686	15,315,324
		2.5	300	750	2,500	500.0	375.0	7,629,061	15,330,346
5	10	-	300	500	-	-	-	6,260,291	11,923,141
		-	300	500	10	5.0	3.8	6,265,223	11,927,811
		2.5	300	500	-	5.0	3.8	6,277,598	11,942,680
		2.5	300	500	10	5.0	3.8	6,278,598	11,942,841
8	0	-	150	750	1,000	500.0	375.0	4,446,031	9,117,652
		2.5	150	750	1,000	500.0	375.0	4,459,406	9,132,686
8	10	-	100	500	-	-	-	2,834,085	6,707,650
		-	100	500	10	5.0	3.8	2,839,016	6,712,246
		2.5	100	500	-	5.0	3.8	2,851,391	6,727,191
		2.5	100	500	10	5.0	3.8	2,852,391	6,727,278
		-	500	-	4,000	500.0	375.0	11,485,084	19,077,372
		2.5	500	-	4,000	500.0	375.0	11,498,459	19,092,420

Wind speed	% unserved	Cost of Energy	Renewable Fraction	Unserved Energy (kWh)	Unserved Energy Fraction	Battery Life (years)	Fuel Usage (L/year)	Generators Hours (hours)
3.19	0	0.56	0.72	4,206.4	0.00	10.0	936,036.7	5,186
		0.56	0.72	4,206.0	0.00	10.0	936,015.5	5,186
3.19	10	0.54	0.75	361,458.4	0.08	10.0	751,763.8	5,285
		0.54	0.75	360,598.9	0.08	4.7	751,608.8	5,283
		0.54	0.75	361,435.3	0.08	10.0	751,679.5	5,284
		0.54	0.75	360,575.9	0.08	4.7	751,524.5	5,282
5	0	0.26	0.81	-	-	10.0	721,849.3	4,302
		0.26	0.81	-	-	10.0	721,842.1	4,302
5	10	0.21	0.83	219,383.7	0.05	10.0	593,702.1	4,552
		0.21	0.83	218,515.6	0.05	4.6	593,159.8	4,545
		0.21	0.83	219,373.3	0.05	10.0	593,696.9	4,552
		0.21	0.83	218,505.3	0.05	4.6	593,154.4	4,545
8	0	0.16	0.89	3,482.1	0.00	10.0	499,982.1	3,092
		0.16	0.89	3,481.6	0.00	10.0	499,977.8	3,092
8	10	0.12	0.83	162,079.7	0.04	10.0	505,931.7	4,028
		0.12	0.83	161,237.3	0.04	4.7	505,389.3	4,021
		0.12	0.83	162,074.0	0.04	10.0	505,926.8	4,028
		0.12	0.83	161,231.6	0.04	4.7	505,384.5	4,021
		0.36	1.00	418,230.1	0.09	4.8	-	-
		0.36	1.00	418,220.8	0.09	4.8	-	-

11. CONCLUSIONS

The environment of the Galápagos is unique in the world and must be protected from man-made environmental hazards. Since humans have populated the Islands, energy production has evolved and stagnated at diesel generation, which present environmental hazards. Renewable energies represent a good option for reducing the risks of diesel generation, and would enhance flora and fauna diversity and growth. We are already aware of all the irreplaceable damage, both short and long term, that an oil spill can cause. The use of renewable energy will also support most international efforts in reducing greenhouse gas emissions and preserving the site as a protected area and as a Biosphere Reserve.

Each of the scheduled activities was carried out successfully – some were more successful than others because some information is simply not available at all. I would like to comment on each of the activities individually.

1. Survey of existing solar installations: I got to visit most of the photovoltaic and solar water heating systems on the Islands. I wasn't as lucky obtaining information about them because in many cases the data doesn't exist. It is common that systems are just 'abandoned' after its installation. Colegio Alejandro Humboldt was the only institution that had performance information on their photovoltaic system. Other places, such as Bodega Blanca and the Armada de Ecuador didn't have any information on their systems, other than its application. In the case of Colegio Nacional Galápagos, their data logging system broke down and nobody has been able to repair it. Hotels, except for Hotel Fernandina, don't have a clue of how their system is working, so it is difficult to make an assessment of how the current systems are functioning. Hotel Lobo del Mar is currently installing their own solar water heating system.
2. Resource data: Information from the Charles Darwin Research Station resource data monitoring station couldn't be obtained because the information is not public. However, Lahmeyer International collected resource data measurements (temperature, solar radiation and wind speed at different heights) on eight sites of the Galápagos Island. This information is included in their study. The measurements were carried out for one year (July 1999 to July 2000) and readings were taken every 10 minutes. Before using this data as an input for HOMER, a data check had to be performed because for a period of time all of the entries were –999, so these values had to be deleted. Also, for Gal8 (Sta. Cruz coast), which is the data set I used for my HOMER simulation, I obtained the hourly values by either adding or averaging the data (depending if it's solar radiation or wind energy). Grupo Araucaria also had to install

additional anemometers since the Lahmeyer wind speed data wasn't at the tower height that Araucaria had considered. This last data was not obtained. Data on predominant wind direction was obtained from the Water Study provided by the Municipality of Sta. Cruz.

3. Utility data: Most of the monthly utility data was obtained from different sources. The first one is Elecgalápagos, where I go monthly kWh generation and consumption by sector for the four populated islands. There were some months in which the information wasn't recorded or kept. I also performed a survey (and in some cases, brief energy audits) of different building types in the three islands and spoke with homeowners, store owners, hotel owners, school teachers and administrators, tour guides, researchers, doctors, and office assistants, among others. By doing this, I got an idea of how different the establishments are from one island to another and between the lowland and the highland. Speaking to the people also gave a better idea of the energy situation, what they feel is wrong and of what they need. I was amazed at the amount of residences, stores, schools and hotels actually kept their utility bills. In most cases, they only had the 6 previous months, but they do have knowledge of how much they have been paying and how the cost of electricity has been increasing. Some people were explaining how they have been slowly getting rid of their appliances and equipment because they can't afford their utility bill, and even though they are reducing their consumption, they still have to pay more every month. For the load profile of the town, one of the big changes I did was re-aggregating the cooling loads.
4. Population data: Population data for the Galápagos Islands as a province, and divided by islands, was obtained. However, exact population data divided by lowlands and highlands doesn't seem to exist, only approximate percentages or estimates made by the municipalities. In the case of San Cristóbal, the municipality didn't know the population of this island. There is no population between the lowlands and the highlands, and households from both regions were visited. The village and town assumptions were mostly accurate regarding what a village and what a town has (villages also have medical centers and schools). For the load profiles for HOMER, I increased the population because we had initially considered several towns with an average of 200 dwellings per town.
5. Visit existing power generation plants: Power plants in the three islands were visited and generation data was obtained for all of them, including O&M costs. Information on fuel consumption and transportation was also obtained. There are no wind or biomass systems currently installed.

6. Water: Water data was obtained in the municipalities. The municipality of Sta. Cruz had information on the three islands, and additional information on each of the other two islands was obtained in their respective municipality. In Sta. Cruz, the crevices and one of the pumps were visited, and in Isabela I went to their wastewater treatment plant. The municipalities provided previous water analysis and water projects, however, accurate and recent water analyses don't exist yet. While doing the utility data and energy use survey with the population of the three islands, I also inquired about water consumption habits, costs, problems and needs.
7. Tourism: High and low tourism seasons were defined, especially through hotels. A list of all tourism related buildings and their respective capacities was provided by the Tourism Ministry.
8. Boats: Tourism boat information was obtained at the Galápagos National Park (number of boats) and at the Chamber of Tourism (fuel capacities). Information on the number fishing boats and their technical description was obtained in the Galápagos National Park.
9. Oil spills: The Charles Darwin Research Station and the Galápagos National Park put together several studies on the events and the consequences of the Jessica oil spill.

I really didn't expect to get all this information because I didn't think they'd have it. Perhaps most surprising was to find that most places that I visited did have their utility data. People surveyed were very interested in learning more about renewable energy and in many cases they complained about the energy and water quality. I did find that their systems (for example, water piping, T&D lines, etc) were very old and their capacity hasn't been increased according to the increase in population, this is, the same systems remain since they were installed. The government is aware of this and is planning to modernize the systems according to the increase in capacity and population.

The high population growth rate is due to immigration and a lack of birth control, and according to some people who provided population information, it is easier for them to start controlling immigration rather than birth control.

The use of renewable energy is feasible there and is already occurring in Floreana. The government seems to support renewable energy projects and there is a lot of interest from the population. Though many are interested in renewable energy, they are also concerned of the impact these systems can have on the flora and fauna of the islands, so there are studies being carried out to determine, for example, how wind turbines may affect birds.

As for the system simulations, with the new load profile and resource data, the minimum requirement of 70% can still be met for the island of Sta. Cruz. It will mostly consist of wind energy because, as noted previously, HOMER ranks the systems by their economic feasibility only. I did manipulate HOMER into using a minimum requirement of solar energy, however, the cost increases considerably. Since there is concern about wind energy affecting the birds, and not too much space can be destined to a centralized hybrid system, I was thinking that perhaps rooftop systems might work well. Due to time constraints, I did not do those simulations in HOMER, nevertheless it may be worth modeling. Each establishment can have their own rooftop system for electrification and perhaps water purification (once the content of the water is determined and an appropriate treatment is designed for it). This way we can have a distributed generation system, in which one establishment can connect with another one. If there should be any surplus, this can be sold to the hotels for water heating purposes (just like one of the proposals that was mentioned in Section 8).

Something that became evident is that they need a lot of education regarding renewable energy technology. The population and authorities of the Galápagos Islands have many unanswered questions that, at this point, are a barrier for the inclusion of renewable energy. During a workshop I attended, one of the questions was, how much will it cost us to change all our appliances so that they can work with electricity produced from renewable energy. I think an education campaign would have to be carried out to ensure that the systems installed would be successful.

From this trip, it became evident how much human impact can affect an ecosystem. There have already been two oil spills and the long term effects are unknown. The use of renewable energy will help preserve the region, and fossil fuels will still be used – but in much lower proportion. It is often said that people don't know what they have until they loose it, and if this happens in Galápagos, then it will be too late.

I hope this report will be useful for other people for continued work in the Galápagos Islands.

Tierra y mar, un solo patrimonio en Galápagos.[72]

Land and sea, a single inheritance in Galápagos.

[72] My favorite phrase that I found on a poster I saw in the Galápagos National Park offices.

12. BIBLIOGRAPHY

Cardenas, S., 2001. A Study of Transport and Energy in the Galápagos Islands. World Wildlife Fund (WWF), Quito.

Programa de las Naciones Unidas para el Medio Ambiente, 2000. Perspectivas del Medio Ambiente Mundial, Madrid, PNUMA, 1999[73]

“Islas Galápagos." Enciclopedia Microsoft Encarta 2001. 1993-2000 Microsoft Corporation. Reservados todos los derechos

Foster, Robert E. 1998, Photovoltaic market development and barriers in México, Thesis to obtain the degree of Masters in Business Administration, New Mexico State University. Page 20

Andrónico, Adede O., 1995, Digesto de Derecho Internacional Ambiental. Secretaría de Relaciones Exteriores México. Page 27.[74]

Stoltenberg Blaise and Ley, Debora. Galápagos Distributed Generation Project. Final Report for CVEN 4830, University of Colorado-Boulder. December, 2001

Proyecto de Agua Potable y Alcantarillado Sanitario para la Cd. de Puerto Ayora, I. Municipalidad de Sta. Cruz, Galápagos[75]

Bases para un Plan Hidrológico del Archipiélago de Galápagos, República de Ecuador[76]

Propuestas para la Gestión Integral de los Desechos en las Islas Galápagos[77]

Programa Araucaria: Proyecto Integral de Infraestructuras para la Sostenibilidad de la Isla de Floreana, Ecuador. Fase I: Electrificación[78]

The Galápagos Chamber of Tourism, catastro de hoteles y pensiones, agencias de viajes, alimentos y bebidas, otros, y transporte por isla

Informe Galápagos 2000-2001, Fundación Natura-WWF

Distribución Relativa de Población por área y sexo, índices de masculinidad y porcentaje urbano según provincias, Censo 2001[79]

---

[73] United Nations Environmental Program. Perpsectives on the Global Environment.
[74] Digest on International Environmental Law. Foreign Relations Secretariat, México.
[75] Potable Water and Sanitary Sewer System Project for Puerto Ayora, Municipality of Sta. Cruz, Galápagos
[76] Basis for a Hydrologic Plan in the Galápagos Archipielago, Republic of Ecuador
[77] Proposal for the Integral Management of Waste in the Galápagos Islands
[78] Integral Infrastructure Project for the Sustainability of Floreana Island. Phase 1: Electrification
[79] Relative Population Distribution by region and sex, 2001 Census

Catastro de escuelas, 2001

Lista de Embarcaciones, 2002

The Galápagos Chamber of Tourism, Cupos de combustible[80]

Datos Poblacionales, Sta. Cruz, San Cristóbal e Isabela

Consumos de agua, San Cristóbal

Colegio Alejandro Humboldt, outputs from photovoltaic system

Lahmeyer Study, July 2002

PV System on Isabela, by Godfrey Merlen, photos and technical specifications

Embarcaciones Pesqueras, Parque Nacional Galápagos

Ministerio de Turismo, Catastro 2002 Galápagos de empresas y establecimientos turísticos

Utility data from Empresa Elecgalápagos

Biological Impacts of the Jessica Oil Spill on the Galápagos Environment, A Preliminary Report, August 2001. Charles Darwin Research Station and Galápagos National Park

[80] Fuel capacities of tourism ships

13. ACKNOWLEDGEMENTS

This trip was made possible thanks to many people, whom I'd now like to acknowledge.

To Irma Larrea, Communications Officer of World Wildlife Fund – Galápagos Program, I want to give a special thank you for all her help and for going out of her way with the logistics and preparatory details previous to, during and after the trip. I also want to thank her for contacting Edwin Yáñez of Servicios Logísticos Insulares. It was great working with her.

To Edwin Yáñez and William Vázquez of Servicios Logísticos Insulares, for their assistance and help during the stay in the islands. It was also great working with them.

To Dr. Jan Kreider for trusting and allowing me to work on this project and for his advice and guidance.

To Dr. Carlos Valle and Susana Cárdenas, of World Wildlife Fund – Galápagos Program, for their guidance and recommendations for the trip and insight on my report

To my parents, for their support and another special thanks to my Mom for accompanying me on the trip.

To Michael Ross, for his friendship, caring, support and all this advice.

To Sandia National Laboratories, because this work was done under their One Year on Campus Fellowship.

To all my friends and relatives, especially Carolina, Mike - Pizza Man, Hope, Sri, Zeke, Blaise, Xochitl, Sharon, Dale, Jackie and Christopher (I know there are names missing, and I apologize for that), for their caring and support and all the laughter.

To my aunts, uncles and cousins, especially Auntie Cha-cha, Auntie Jocele and Uncle Tecva, and all the people at Sandia for their trust in me and their continued support.

To Ron Swenson who provided contact information and all the wonderful people I spoke with and surveyed in the Galápagos Islands, for their time and their invaluable help to obtain good and accurate results for this report. It was also great to make friends there!

14. APPENDIX

14.1 People Visited

Institution	Person
Universidad San Francisco de Quito - WWF	Dr. Carlos Valle
Universidad San Francisco de Quito - WWF	Irma Larrea[81]
Universidad San Francisco de Quito - WWF	Susana Cárdenas
Estación Científica Charles Darwin	Dr. Howard Snell
Parque Nacional Galápagos	Mario Piu
Parque Nacional Galápagos	Edgar Muñoz
Parque Nacional Galápagos	Mauricio Velásquez
Parque Nacional Galápagos	Juan Vizcaíno
Parque Nacional Galápagos	Godfrey Merlen
Ministerio de Turismo	
Cámara de Turismo (Capturgal)	
Alcaldía de Pto. Ayora	Delio Sarango
Alcaldía de Pto. Baquerizo Moreno	Carlos González
Alcaldía de Pto. Baquerizo Moreno	Jefe de Avalúos y Catastros
Alcaldía de Pto. Villamil	Pablo Gómez
Alcaldía de Pto. Villamil	Jefe del Área Técnica
Oficinas de Elecgalápagos en Pto Ayora, Pto. Baquerizo Moreno y Pto. Villamil	Jefes de Agencia. Abraham Rosero Marino, Pto. Ayora
Electronáutica	Hans Scheiss
Hotel Fernandina	Fernando y María Fernanda Ruiz
Colegio Nacional Galápagos	Luis Oña
Colegio Nacional Galápagos	Ricardo Gavilanes
Colegio Alejandro Humboldt	Byron Fernández
Servicios Logísticos Insulares[82]	Edwin Yáñez
Servicios Logísticos Insulares	William Vázquez
Capitanías de Puerto en Pto. Ayora, Pto. Baquerizo Moreno y Pto. Villamil	
Bodega Blanca	Jason Gallardo

[81] Special thanks to Irma Larrea for arranging all the logistics and details of the trip and for helping me throughout the entire trip.
[82] Also, thanks to Edwin and William for all their assistance in Sta. Cruz (they were recommended by Irma Larrea)

14.2 *Inventory of Documents*

1. Fueling Facility Study and Remedial Plan for the Galápagos Islands, WWF
2. Proyecto de Agua Potable y Alcantarillado Sanitario para la Cd. de Puerto Ayora, I. Municipalidad de Sta. Cruz, Galápagos. - Potable Water and Sanitary Sewer System Project for Puerto Ayora, Municipality of Sta. Cruz, Galápagos.
3. Diagnósticos y evaluación de la situación de los sistemas de agua potable y alcantarillado, y disposición de aguas servidas de los municipios de Puerto Baquerizo y Puerto Villamil, Informe Final. - Diagnosis and evaluation of the situation of potable water and sewer system, and disposition of the waters serving the municipalities of Puerto Baquerizo and Puerto Villamil, Final Report.
4. Bases para un Plan Hidrológico del Archipiélago de Galápagos, República de Ecuador. - Basis for a Hydrologic Plan in the Galápagos Archipielago, Republic of Ecuador.
5. Propuestas para la Gestión Integral de los Desechos en las Islas Galápagos. - Proposal for the Integral Management of Waste in the Galápagos Islands.
6. Araucaria Project:

- Estudios y proyectos para la implementación de RES en el Archipiélago de Galápagos, Ecuador, diseñado por el Grupo de Implementación. - Studies and Projects for the Implementation of RES in the Galápagos Archipielago, Ecuador, designed by the Implementation Group.
- Energías Renovables en Pequeñas Islas Reserva de la Biosfera (Menorca, Lanzarote, Guadeloupe, Galápagos). - RE in Small Islands in Biosphere Reserves (Menorca, Lanzarote, Guadeloupe, Galápagos).
- Proyecto Integral de Infraestructuras para la Sostenibilidad de la Isla de Floreana, Ecuador. Fase I: Electrificación. - Integral Infrastructure Project for the Sustainability of Floreana Island. Phase 1: Electrification.
- Propuestas para la Gestión Integral de los Desechos de las Islas Galápagos, Ecuador. - Proposals for the Integral Management of Waste in the Galápagos Islands, Ecuador.
- Campaña de Marketing Solar en Islas. - Solar Marketing Campaign in the Islands
- Propuesta de proyecto: Iniciativas de ahorro, eficiencia y racionalización del consumo eléctrico en las Islas Galápagos, Ecuador -
- Instalación Solar Térmica para calentamiento de agua caliente sanitaria para:
    - Hotel Lobo de Mar
    - Hotel Las Ninfas
    - Hotel Fiesta
    - Hotel Angermeyer
    - Hotel Delfín

- Energía demo, tecnologías avanzadas en ahorro y eficiencia energética (artículo de revista) - Energía demo, advanced technologies in energy savings and energy efficiency (magazine article).
- Circular Informativa para proyecto de Floreana (electronic version)
- Convenio Junta Parroquial Floreana (electronic version)
- Proyecto Floreana (electronic version)

7. The Galápagos Chamber of Tourism, catastro de hoteles y pensiones, agencias de viajes, alimentos y bebidas, otros, y transporte por isla.
8. Informe Galápagos 2000-2001, Fundación Natura-WWF
9. Distribución Relativa de Población por área y sexo, índices de masculinidad y porcentaje urbano según provincias, Censo 2001
10. Catastro de escuelas, 2001
11. Lista de Embarcaciones, 2002
12. The Galápagos Chamber of Tourism, Cupos de combustible
13. Datos Poblacionales, Sta. Cruz, San Cristóbal e Isabela
14. Consumos de agua, San Cristóbal
15. Colegio Alejandro Humboldt, outputs from photovoltaic system.
16. Lahmeyer Study, July 2002
17. PV System on Isabela, by Godfrey Merlen, photos and technical specifications.
18. Energías Renovables, Colegio Nacional Galápagos, Power Point Presentation.
19. Embarcaciones Pesqueras, PNG, Excel Spreadsheet
20. Ministerio de Turismo, Catastro 2002 Galápagos de empresas y establecimientos turísticos
21. Colegio Alejandro Humboldt, Energía Fotovoltáica (Word document) and Proyecto Energía Solar (Power Point Presentation)
22. Biological Impacts of the Jessica Oil Spill on the Galápagos Environment, A Preliminary Report, August 2001. Charles Darwin Research Station and Galápagos National Park
23. Empresa Elecgalápagos, utility data:
    - Floreana, Jan-Dec. 2001
    - San Cristóbal, Jan-Dec. 2001
    - Total of Galápagos, Jan-Dec. 2001
    - Isabela: Jan 2000-Dec. 2001
    - Florena: Jan. 99
    - Isabela: May 99 and Dec. 99
    - Sta. Cruz-Isabela: Dec. 98, Jan 99
    - Catastro; Dec. 98 Jan to Mar. 99
    - Isabela: April-Nov 99
    - Sta. Cruz; Jan, Mar, April, May, Dec. 99
    - Floreana, San Cristóbal, Sta. Cruz, Isabela, Total of Galápagos; Jan-May 2002

14.3 Detailed Population Data[83]

	Total			Urban			Rural		
Age (years)	Women	Men	Total	Women	Men	Total	Women	Men	Total
0 to 4	4.88	5.62	10.50	5.45	5.99	11.44	2.78	4.19	6.97
5 to 9	5.07	5.53	10.60	5.60	6.19	11.79	3.11	3.08	6.19
10 to 14	4.57	4.77	9.34	5.01	5.23	10.24	2;93	3.05	5.98
15 to 19	4.32	5.05	9.37	4.77	5.34	10.11	2.69	3.98	6.67
20 to 24	4.66	5.11	9.77	5.17	4.83	10.00	2.78	6.13	8.91
25 to 29	5.04	5.72	10.76	5.32	5.40	10.72	4.04	6.97	11.01
30 to 34	4.53	5.29	9.82	4.94	4.66	9.60	3.02	7.63	0.65
35 to 39	3.89	5.17	9.06	4.20	4.45	8.65	2.78	7.81	0.59
40 to 44	2.57	3.57	6.14	2.71	3.26	5.97	2.03	4.72	0.75
45 to 49	1.58	2.53	4.11	1.48	2.17	3.65	1.91	3.89	0.80
50 to 54	1.43	1.81	3.24	1.27	1.49	2.76	2.00	3.02	0.02
55 to 59	1.00	1.36	2.36	0.71	0.89	1.60	2.09	3.14	0.23
60 to 64	0.80	0.83	1.63	0.56	0.58	1.14	1.70	1.76	0.46
65 to 69	0.68	0.76	1.44	0.47	0.46	0.93	1.44	1.85	0.29
70 to 74	0.35	0.42	0.77	0.20	0.32	0.52	0.90	0.78	1.68
75 to 79	0.24	0.26	0.50	0.22	0.20	0.42	0.30	0.48	0.78
80 to 84	0.12	0.16	0.28	0.09	0.12	0.21	0.24	0.30	0.54
85 to 89	0.08	0.09	0.17	0.06	0.09	0.15	0.15	0.12	0.27
90 to 94	0.02	0.04	0.06	0.01	0.04	0.05	0.06	0.06	0.12
95 to 99	0.03	0.05	0.08	0.03	0.02	0.05	-	0.09	0.09
TOTAL	**45.86**	**54.14**	**100**	**48.27**	**51.73**	**100**	**36.95**	**63.05**	**100**

[83] Informe Galápagos 2000-2001, Fundación Natura-WWF

14.4 Utility Data of Some Schools, Hotels, Stores and Offices[84]

All values are given in kWh.

<u>SCHOOLS</u>

Escuela Loma Linda	
Month	Comsumption
Jan-01	291
Feb-01	428
Mar-01	312
Apr-01	425
May-01	493
Jun-01	500
Jul-01	401
Aug-01	450
Sep-01	582
Oct-01	592
Nov-01	552
Dec-01	537
May-02	616

Pedro Pablo Andrade	
Month	Consumption
Feb-00	307
Mar-00	161
Apr-00	193
May-00	61
Jun-00	145
Jul-00	213
Aug-00	173
Sep-00	176
Oct-00	229
Nov-00	132
Jan-02	279
Feb-02	299
Mar-02	139
Apr-02	73
May-02	310
Jun-02	436

Liceo Naval Militar	
Month	Consumption
Feb-02	431
Mar-02	684
Apr-02	807
May-02	1209

Galo Plaza Lazo	
Month	Consumption
Jul-00	122
Oct-00	142
Jan-01	184
Feb-01	181
Mar-01	29
Apr-01	78
May-01	165
Sep-01	138

Alejandro Humboldt	
Month	Consumption
Jul-01	804
Aug-01	613
Sep-01	637
Oct-01	389
Nov-01	478
Dec-01	173
Jan-02	345
Feb-02	24
Mar-02	27
Apr-02	570
May-02	
Jun-02	786

Colegio San Francisco	
Mar-99	25
Apr-99	39
May-99	74
Jun-99	86
Jul-99	61
Aug-99	49
Sep-99	96
Oct-99	93
Nov-99	67
Dec-99	44

Colegio Técnico Ignacio Hernández	
Month	Consumption
Jun-01	367
Jul-01	289
Aug-01	285
Sep-01	327
Oct-01	353
Nov-01	429
Dec-01	405
Jan-02	738
Feb-02	286
Mar-02	196
Apr-02	318
May-02	504
Jun-02	297

Fray Agustín Azcunaga	
Month	Consumption
Jan-02	576
Feb-02	508
Mar-02	438
Apr-02	567
May-02	632
Jun-02	840

Galo Plaza Lazo	
Month	Consumption
Jul-00	122
Oct-00	142
Jan-01	184
Feb-01	181
Mar-01	29
Apr-01	78
May-01	165
Sep-01	138

Escuela Nacional Galápagos	Jun-02	2594

[84] Only representative cases are presented. Other utility data values can be found with the photos.

HOTELS

	Palmeras	Delfín	Red Mangrove Inn
Month	Consumption		
Jan-02	2,357	14,271	6,216
Feb-02	3,369	14,449	
Mar-02	3,383	14,580	5,585
Apr-02	3,028	14,556	
May-02	3,193	7,840	4,713
Jun-02	2,826	13,138	

Hotel Mar Azul	830
Hotel Chatham	1478
Hotel Casa de Marita	2072
Hotel Ballena Azul	662
Hotel Alexander	1149
Hostería Isabela del Mar	723

Hotel Islas Galápagos	
Month	Consumption
Dec-01	257
Mar-02	420
Apr-02	438
May-02	401
Jun-02	433

OFFICES AND STORES

Cantina Chayito	
Month	Consumption
Jan-00	248
Feb-00	191
Mar-00	211
Apr-00	267
May-00	212
Jun-00	191
Jul-00	164
Aug-00	107
Sep-00	99
Oct-00	92
Nov-00	99
Dec-00	123
Jan-01	124
Feb-01	151
Mar-01	136
Apr-01	100
May-01	135
Jun-01	126
Jul-01	100
Aug-01	56
Sep-01	103
Oct-01	101
Nov-01	106
Dec-01	108
Jan-02	160
Feb-02	157
Mar-02	135
Apr-02	
May-02	122
Jun-02	128

Comercial La Isla 523

INGALA	
Month	Consumption
Jun-01	1759
Jul-01	1487
Aug-01	1278
Sep-01	1339
Oct-01	1267
Nov-01	1855
Dec-01	1589
Jan-02	2296
Feb-02	2251
Mar-02	2305
Apr-02	2520
May-02	2079

Centro de salud Isabela 328

14.5 Electricity Generation

Month	Island	Energy Produced (MWh)	Auxiliary Units Consumption (MWh)	Other Auxiliary Consumption (MWh)	Available Energy (MWh)
Jan-00	San Cristóbal	405.77	4	2.95	398.82
Feb-00		390.88	3.19	3.1	384.59
Mar-00		408.38	8.45	3.16	396.77
Apr-00		411.32	8.45	3.28	399.59
May-00		451.61	0	2.84	448.77
Jun-00		394.56	0	2.28	392.28
Jul-00		391.65	0	1.7	389.95
Aug-00		382.93	1.83	1.1	380
Sep-00		380.36	3.24	1.3	375.82
Oct-00		401.2	3.35	1.83	396.02
Nov-00		394.09	2.85	1.92	389.32
Dec-00		434.86	2.82	1.99	430.05
Jan-00	Sta. Cruz	716.62	2.19	0.65	713.78
Feb-00		685.32	1.49	0.7	683.13
Mar-00		759.68	1.62	0.98	757.08
Apr-00		774.64	1.37	0.92	772.35
May-00		780.3	2.15	0.85	777.3
Jun-00		696.96	2.37	0.5	694.09
Jul-00		690.24	2.1	0.28	687.86
Aug-00		688.32	2.17	0.31	685.84
Sep-00		655.6	2.63	0.27	652.7
Oct-00		703.36	2.29	0.22	700.85
Nov-00		688.64	2.39	0.32	685.93
Dec-00		780.48	2.42	0.53	777.53
Jan-00	Isabela	83.92	0	0	83.92
Feb-00		82.77	0	0	82.77
Mar-00		92.16	0	0	92.16
Apr-00		94.17	0	0	94.17
May-00		95.45	0	0	95.45
Jun-00		83.92	0	0	83.92
Jul-00		85.6	0	0	85.6
Aug-00		82.56	0	0	82.56
Sep-00		83.42	0	0	83.42
Oct-00		86.41	0	0	86.41
Nov-00		84.71	0	0	84.71
Dec-00		90.89	0	0	90.89

Month	Island	Energy Produced (MWh)	Auxiliary Units Consumption (MWh)	Other Auxiliary Consumption (MWh)	Available Energy (MWh)
Jan-00	Floreana	4.28	0	0	4.28
Feb-00		4.79	0	0	4.79
Mar-00		3.3	0	0	3.3
Apr-00		3.6	0	0	3.6
May-00		4.8	0	0	4.8
Jun-00		4.48	0	0	4.48
Jul-00		4.59	0	0	4.59
Aug-00		4.08	0	0	4.08
Sep-00		5.02	0	0	5.02
Oct-00		4.2	0	0	4.2
Nov-00		4.48	0	0	4.48
Dec-00		4.64	0	0	4.64
	Total	**14,566.01**	**63.37**	**33.98**	**14,468.66**

Jan-01	San Cristóbal	454.08	3.34	0	450.74
Feb-01		407.4	3.55	0	403.85
Mar-01		465.89	3.24	0	462.65
Apr-01		471.36	3.58	0	467.78
May-01		485.76	3.52	0	482.24
Jun-01		438.72	3.52	0	438.04
Jul-01		406.4	0.68	0	400.77
Aug-01		395.26	5.63	0	392.33
Sep-01		395.07	2.93	0	392.46
Oct-01		409.02	2.61	0	403.46
Nov-01		401.77	5.56	0	397.86
Dec-01		424.85	3.91	0	422.89
Jan-01	Sta. Cruz	847.7	1.96	0	845.74
Feb-01		821.38	2.02	0	819.36
Mar-01		906.6	1.61	0	904.99
Apr-01		910.88	1.46	0	909.42
May-01		879.68	1.4	0	878.28
Jun-01		778.56	1.41	0	777.15
Jul-01		796.48	1.19	0	795.29
Aug-01		778.56	1.51	0	777.05
Sep-01		757.44	1.58	0	755.86
Oct-01		778.88	1.68	0	777.2
Nov-01		798.08	2.08	0	796
Dec-01		895.04	1.67	0	893.37

Month	Island	Energy Produced (MWh)	Auxiliary Units Consumption (MWh)	Other Auxiliary Consumption (MWh)	Available Energy (MWh)
Jan-01	Isabela	92.11	0	0	92.11
Feb-01		91.6	0	0	91.6
Mar-01		109.45	0	0	109.45
Apr-01		103.74	0	0	103.74
May-01		101.79	0	0	101.79
Jun-01		91.77	0	0	91.77
Jul-01		88.34	0	0	88.34
Aug-01		89.98	0	0	89.98
Sep-01		91.19	0	0	91.19
Oct-01		89.57	0	0	89.57
Nov-01		86.23	0	0	86.23
Dec-01		94.83	0	0	94.83
Jan-01	Floreana	4.36	0	0	4.36
Feb-01		4.36	0	0	4.36
Mar-01		4.48	0	0	4.48
Apr-01		5.08	0	0	5.08
May-01		4.76	0	0	4.76
Jun-01		4.84	0	0	4.84
Jul-01		4.8	0	0	4.8
Aug-01		4.4	0	0	4.4
Sep-01		4.6	0	0	4.6
Oct-01		4.56	0.15	0	4.41
Nov-01		4.96	0.17	0	4.79
Dec-01		4.88	0.11	0	4.77
	Total	**16,291.54**	**62.07**	**-**	**16,231.03**

Jan-02	San Cristóbal	450.62	3.34	0	447.28
Feb-02		459.45	3.01	0	456.44
Mar-02		468.48	2.48	0	466
Apr-02		484.03	2.65	0	481.38
May-02		474.07	2.98	0	471.09
Jun-02		412.53	2.33	0	410.2
Jul-02		0	0	0	0
Aug-02		0	0	0	0
Sep-02		0	0	0	0
Oct-02		0	0	0	0
Nov-02		0	0	0	0
Dec-02		0	0	0	0

Month	Island	Energy Produced (MWh)	Auxiliary Units Consumption (MWh)	Other Auxiliary Consumption (MWh)	Available Energy (MWh)
Jan-02	Sta. Cruz	964.8	1.85	0	962.95
Feb-02		1037.16	1.79	0	1035.37
Mar-02		1038.08	1.49	0	1036.59
Apr-02		992.32	1.63	0	990.69
May-02		968.32	1.52	0	966.8
Jun-02		869.76	1.86	0	867.9
Jul-02		0	0	0	0
Aug-02		0	0	0	0
Sep-02		0	0	0	0
Oct-02		0	0	0	0
Nov-02		0	0	0	0
Dec-02		0	0	0	0
Jan-02	Isabela	101.86	0	0	101.86
Feb-02		116.47	0	0	116.47
Mar-02		110.84	0	0	110.84
Apr-02		112.62	0	0	112.62
May-02		108.95	0	0	108.95
Jun-02		104.69	0	0	104.69
Jul-02		0	0	0	0
Aug-02		0	0	0	0
Sep-02		0	0	0	0
Oct-02		0	0	0	0
Nov-02		0	0	0	0
Dec-02		0	0	0	0
Jan-02	Floreana	5.04	0.15	0	4.89
Feb-02		5.96	0.13	0	5.83
Mar-02		5	0.14	0	4.86
Apr-02		4.72	0.14	0	4.58
May-02		4.98	0.17	0	4.81
Jun-02		4.84	0.14	0	4.7
Jul-02		0	0	0	0
Aug-02		0	0	0	0
Sep-02		0	0	0	0
Oct-02		0	0	0	0
Nov-02		0	0	0	0
Dec-02		0	0	0	0
	Total	**9,305.59**	**27.8**	**-**	**9,277.79**

14.6 Complete List of Tourism Facilities and Boat information