COLOFON

P5- GRADUATION THESIS
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INTRODUCTION

Abstract

The Galapagos Archipelago is a living lab of evolution and an iconic piece of natural heritage that is in danger. It is also the most preserved archipelago of the world and therefore has to be seen as a global problem and as an opportunity to develop a system that can demonstrate that nature and humans can live in harmony.

The unique range of endemic species of flora and fauna that inhabits the islands is being threatened by the unsustainable way of living of local communities. The growing economy based on tourism has generated a lot of migration that carries side problems like expanding urban areas, poor waste management systems, over-fishing, energy shortage and pollution due to fossil fuel consumption.

Local government efforts towards sustainability are lacking on consistency. Big projects with low effectiveness from governmental institutions are the core of change. The patriarchal way of execution of this projects intends to give a universal solution for various endemic problems that deserve more specific attention and local participation.

This project would try to create local strategies towards an integral energy system that can be taken as the core of the sustainable development of the Islands. Thus an energy potential study base on the community participation and the protected environment has to be done as the starting point to ensure a local and more concrete design.

This project wants to add energy to this living lab of evolution as part of the human adaptation for the islands in order to preserve the existing.
Graduation: Sustainable Design Studio

This report is the result of a sustainable energy study for the island of Santa Cruz in the Galapagos Archipelago as part of the Sustainable Design Graduation Studio within the Building Technology track. This project pursues a sustainable development based on renewable energy and the balance between consumption and production.

Subject: Sustainable Island

Local energy strategies towards a sustainable development of Santa Cruz Island in the Galapagos Archipelago

Problem Statement

The Galapagos archipelago ecosystem is in danger and its conservation is essential for the sustenance of local communities. Their growing economy, overall life and nature depend on a sustainable way of development. The Ecuadorian government is trying to solve every issue towards that goal separately, without a clear vision of the big picture, and by the exclusion of the local community in these processes of change the results can be something to be concerned about.

Research Question:
- How can Santa Cruz Island in the Galapagos achieve a sustainable development by applying the “new stepped strategy” of reduction, reuse and production of energy and by taking into account water and waste cycles?

Sub-questions:
1. What is the Galapagos situation?
2. Which are the location properties of climate, landscape and population?
3. Which is the energy demand and potentials of the island?
4. How can the “new stepped strategy” be implemented?
5. Which scenario is most suitable for the Santa Cruz Island?
6. Which are the suggested interventions? (principal solutions)
7. How can these interventions be feasibly planned over time?

Project Goal:

To propose suitable local strategies of reduction, reuse and production of energy based on a bottom-up approach for a sustainable development in Santa Cruz Island.

Specific Goals:
1. To define the actual energy situation in Santa Cruz
2. To establish the location properties of climate, landscape and population.
3. To define energy demand in the island for today
4. To determine energy potential of the island
5. To implement the “New stepped strategy” in Santa Cruz.
6. To implement the reduction step strategies for Santa Cruz Island.
7. To establish how much renewable energy can be produced in Santa Cruz Island and if it is possible to achieve an energy neutral balance.
8. To establish scenarios in which this strategies are used
9. To propose interventions for the proposed scenarios
10. To develop a master plan of interventions
11. To develop the most strategic intervention into visual designs

Relevance

The Galapagos is a living lab of evolution and an iconic piece of World Natural Heritage that is in danger. This has to be seen as a global problem and as an opportunity to develop a system that can demonstrate to the entire planet that nature, humans and their economy can live together in balance in the world of today and tomorrow..
ANALYSIS

2. Context

The Galapagos Islands are – because of their nature, location and history – a unique living lab of evolution and an iconic piece of natural heritage for the world. But since their discovery in the early 16th century these fragile ecosystems have been exploited and destroyed by diverse human activities like farming, hunting, fishing and building in the islands. Today more than 25,000 people live there compared with the few hundreds 40 years ago and more than 180,000 tourists visit every year threatening more and more the local species and their habitat, therefore minimizing natural resources that are essential for local communities to exist.

The Galapagos are home of an unique range of endemic species of flora and fauna that have evolved in isolation for millennia. Almost no natural predators on land and an abundance of food in the ocean because of the Humboldt current have created a majestic but fragile ecosystem. Animals and plants are extremely vulnerable to introduced species, diseases, pollution and territorial loss, all related to the human presence in the islands in question.

The Galapagos are a series of volcanic islands and islets in the Pacific Ocean at the Equator line. From the 14 islands just 4 have fresh water that can allow human settlements, and even there this resource is limited and shared with the rest of the fauna and flora. The small volcanoes and mountains trap clouds and generate rain in the highlands; this water drains to the underground and reappears in constant springs in the dry volcanic lowlands. Because of farming and cattle the soil in the highlands has being eroding and during the dry season the springs bring less and less water each time. This is one of the most important problems that the Galapagos population has to face during the next years.

Up until 7 years ago [2007] all the electrical energy provided to the islands was generated by fuel thermal stations placed in different locations in the populated islands. The islands have no oil production of their own, so all the fuel is imported by ships from the continent. In 2001 an oil ship ran aground just outside of Santa Cruz Island and spilled 900 tons of diesel, resulting in the death of 90% of the iguanas of the region and the overall serious damage of the local ecosystem.

At that time UNESCO declared the islands in danger. Over-tourism, over-fishing, poor waste management, expanding urban areas, lack of fresh water and pollution due to fuel consumption are just some of the big prob-

Figure 2.1; P.Calle (2014), Economy cycle in the Galapagos.

Figure 2.2; P.Calle (2014), Imported goods, food and fuel.
lems that the islands were exposed to according to the UNESCO’s report.

Local and international entities like the ministry of renewable energies have started to question energy management and urban systems and responding to the UNESCO statement of endangerment have launched a campaign that focuses on renewable energy sources and sustainability. However there is little organization behind the already running projects and it seems like every one is heading towards a different direction. The government of Ecuador and the municipalities on the islands are willing to support every such initiative but they are missing the know-how, a master plan, a proper energy potential mapping study, a smart macro design that connects demand challenges and potential and can really show integral solutions.

Today various projects on renewable energy are running and the government of Ecuador has set the goal for eliminating the use of fossil fuels in the island for 2020. However, the dominant solution placed over the table is to change the fossil fuel matrix to biofuel with the same production pattern and transportation risks.

It is important to realize the unique situation of the Galapagos where the environment, economy and social welfare are closely linked. This happens because locals really depend on tourism and tourism exists because of the nature, in terms of sustainability it is clear that the local communities have to take care of nature to maintain their livelihood. Sustainability in one of these areas will create sustainability in the other areas.

This project will focus on just one island that can be used as model for the rest. The chosen island of Santa Cruz; the most populated one and the biggest in area and thus has more of the qualities and issues than the rest of the inhabited islands. Moreover Santa Cruz municipality has created a new housing project that doubles the urban area which is expected to create a huge migration wave in the coming years; the actual population of 18000 inhabitants can easily double in the next 15 years. Therefore the island demands inmate intervention and planning plus the municipality has shown the interest on this thesis subject. Besides this island is also house of the Charles Darwin Research Station that contains local meteorological data that can be used for the background research of this project.

There are a lot of things to be done in order to establish priorities, and most important to create a guideline/framework that can bring all the initiatives together and guide them towards a sustainable future.
• GALAPAGOS •

**tourism**

Photo 2.1; Atalaya (2014). galapagos intenso, Atalaya.

Photo 2.2; nexttripnaturism (2013). “Galapagos Island Amazing.”

Photo 2.3; P.Calle (2006), Puerto Ayora Port.

Photo 2.4; Udasin, S. (2013). “Galapagos Island Amazing.”

Photo 2.5; Galapagos, P. N. (2001). “buque Jéssica.”

• GALAPAGOS •

**Life, threats**

Photo 2.4; Udasin, S. (2013). Basurero en la Isla San Cristóbal.

Photo 2.5; Galapagos, P. N. (2001). “buque Jéssica.”

Photo 2.4; Udasin, S. (2013). Basurero en la Isla San Cristóbal.
2.2 Location

This archipelago is located in the Pacific Ocean 1000 km from the continental land of Ecuador. They are placed exactly on Equator line meaning that they belong to both hemispheres north and south.

There are two main currents that clash in this region creating unique climate conditions. The Humboldt current that comes from the south straight from Antarctica lowers the ocean’s temperature from April to October, and the cocos current coming from the north brings heat to the Galapagos the rest of the year.

Figure 2.4: P.Calle, (2014) Location of the Galapagos Archipelago
2.3 Santa Cruz

Santa Cruz, island, is located in the middle of the Galapagos archipelago and it is the centre of human activity of the islands since the National Park Headquarters and the Darwin Research Station are placed there, but more important has the largest settlement in the Galapagos, Puerto Ayora, with 14,000 people and a total population in the entire island of 18,000\(^{(1)}\).

The main airport of the archipelago, originally an air base built by the US Navy during WW II, is located on Baltra, a small island separated from the Northwest corner of Santa Cruz by the narrow Itabaca Channel, which is the only island that does not belong to the Galapagos National Park, the institution that controls and preserves the natural environment.

Santa Cruz is the only island that has a road that crosses the interior from the itabaca channel and the Airport to southern city of Puerto Ayora. The road also connects rural towns\(^{(2)}\).

This island is a shield volcano that overcame the ocean surface with a wide crest that divide the island in two zones a dry northern half and a more heavily vegetated windward southern part\(^{(3)}\).

Santa Cruz has a total area of 986 sq km. Form which 88 sq km belong to the national park, that has placed strict regulations in the island in order to maintain the natural territory. Inhabitant’s lands are divided in two regions: the agricultural zone or rural zone and the urban area of Puerto Ayora.

Santa Cruz is the most developed in comparison with the other 3 inhabited islands, and can be used as a reference of how the other island will develop. For this reason it is important to create a sustainable development plan for that particular island, so that the rest will follow its example.


2.4 Environment

For billions of years, nature has flourished in The Galapagos relatively undisturbed. The volcanic activity that formed the first Galapagos Islands continues to shape the landscape today, providing habitat for unusual fauna and flora found nowhere else on earth.

The Galapagos Islands are home to some of the highest levels of endemism (species found nowhere else on earth) anywhere on the planet. About 80% of the land birds, 97% of the reptiles and land mammals, and more than 30% of the plants are endemic. More than 20% of the marine species in Galapagos are found nowhere else on earth, like the giant Galapagos tortoise, marine iguana, flightless cormorant, and the Galapagos penguin—the only penguin species to be found in the Northern Hemisphere.

Since humans arrived for the first time to this islands in the 17th century the natural environment has been threatened by their predatory activities and introduced species brought in ships.

Since a few decades ago the Galapagos Islands have experienced accelerated human development due to recent rapid growth in both tourism and population. Santa Cruz Island, and more specifically the town of Puerto Ayora, has withstood the brunt of this growth. In addition to the problem of introduced species and the ever-greater probability of introductions, this growth has put increasing pressures on local resources and municipalities – in terms of health, education, waste management, and many other aspects of daily life.

This natural environment has a fragile ecosystem in which men has stepped on and now is also their home, this new inhabitant have to behave sustainably in order to not disturb the this amazing place.
2.5 Climate

Situated at the Equator, latitude 0, this island has a steady climate that fluctuates very little. Seasons are a subjective way of expressing wet or dry climate. Hot and cold currents change the ocean temperature creating more or less evaporation that creates the seasons, winter and summer. That is why in winter - or rainy season - temperatures can be warmer that in the dry summer.

The ocean evaporation creates clouds that are blown mainly from souther winds into the mountains inside the islands, this clouds get trap and rain is dropped. This phenomena creates different climatic zones layered latitude inside the island, generally the south slopes are humid and have created rain in the souther high lands generating different climatic zones depending the altitude of the mountains. (Fig.122)

Sun shines approximately 12 hours each day for the entire year, with a very little variation in angle to north in June and to south in December between 68 degrees and straight up 90 degrees twice a year in March and September. This creates a constant sun radiation that can only get affected by cloudy days.
2.6 Energy demand Study

This study has been developed to establish the demands of the island regarding energy, waste, and water. This information is essential for any further study, the base line for understanding of how the island works in terms of energy. How much is consumed? How is produced? And who is used? Basic information that is needed in order to create a sustainable energy strategy.

To compare and quantify all the energy demands the Joule has been established as the measuring unit into a year based time period.

The study is divided into 2 sectors of consumption, transportation and the build environment (residential and non residential) and each sector has been explored by different energy demands for more detailed results.

As start is important to realize how dependent to fossil fuel this Island is. All the energy produced comes from fossil fuel generation, even tap water depends on fuel to be pumped into the city.

Unit:
Joules per year
2.6.1 Transportation energy demand

**Air:** Planes are the main way of transportation between the islands and the continent. All flights come directly from the continental Ecuador with a full tank that allows them to go both ways with out fuelling on the island. These flights operate with an average capacity of 70% in which 90% of the passengers are tourists visiting the islands and 10% are local flying to mainland for family matters, paperwork or health issues (1).

There are 3500 commercial flights per year with an average distance of 1250 km. The most common plane used is the Airbus(2) 320 with a fuel consumption of 5.7 l/km meaning a total of 7150 l per flight. The energy content in airplane fuel is 35GJ per liter(3). As result total energy consumption of planes is 900.000 GJ per year.

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**Water:** There are 3 types of boats used for transportation, speedboats for inter-island transport, ferries, and tourist cruisers.

Speedboats are mainly used by locals to travel between nearby and populated islands and they use them with a frequency of two times a year for paperwork and/or family matters. There are about 5 trips per day that takes 2 hours each way a total 1800 trips per year. This kind of boats have 2 engines of 250hp with an estimated fuel consumption of 3.6 l of petrol per 10hp per hour. As result the fuel consumption is 720 litres per trip.

Cruisers have dual function they serve as transportation but also as home for 70% of tourists. In this kind of ships 85 % of fuel is used for motion and 15% for operation and guest appliances, lights, heating and cooling. There are about 80 Cruisers operating in the islands, 8 big ships with a total capacity of 600 passengers operating 321 days a year and 72 smaller ships with a capacity 1200 passengers operating 211 days a year. The amount of diesel used for this 80 boats in 2011 was 16380000 liters. This ships are based on Santa Cruz but they tour around the islands so they have to be picture as part of the entire archipelago.

There are 2 ferries that serve to cross the Itabaca channel for locals and tourist. This channels of 400 m width separates Baltra island where the airport is from the main island of Santa Cruz. For this crossing the ferries use 550 liters of fuel per day and function the entire year. As result they use a total of 400.000 liters per year.

**Land:** There are 1600 vehicles in the Island of Santa Cruz and the most common are pick-up trucks and scooters.

To calculate the total annual consumption of fuel of transportation in Santa Cruz Island some assumptions where made for the annual mileage and the efficiency of the vehicles.

<table>
<thead>
<tr>
<th>Type</th>
<th>Mileage</th>
<th>Efficiency</th>
<th>Quantity</th>
<th>Annual Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trucks Diesel</td>
<td>60000 km/year</td>
<td>7 km/l</td>
<td>55 units</td>
<td>475,000 liters</td>
</tr>
<tr>
<td>Buses (diesel)</td>
<td>80000 km/year</td>
<td>7 km/l</td>
<td>35 units</td>
<td>400,000 liters</td>
</tr>
<tr>
<td>Cars (petrol)</td>
<td>20000 km/year</td>
<td>8 km/l</td>
<td>180 units</td>
<td>430,000 liters</td>
</tr>
<tr>
<td>Taxis 2200cc (petrol)</td>
<td>80000 km/year</td>
<td>7 km/l</td>
<td>350 units</td>
<td>4,000,000 liters</td>
</tr>
<tr>
<td>Scooters (petrol)</td>
<td>20000 km/year</td>
<td>27 km/l</td>
<td>950 units</td>
<td>700,000 liters</td>
</tr>
</tbody>
</table>

**Transportation energy demand:**

- **Planes:** 900,000 GJ/yr
- **Cruisers:** 590,000 GJ/yr
- **Speedboats:** 47,000 GJ/yr
- **Ferries:** 14,000 GJ/yr
- **Cars:** 220,000 GJ/yr

**TOTAL 1,770,000 GJ/yr**
2.6.2 Cooling Energy Demand

In the Galapagos there are 2 seasons: the "garua season" or rainy season and the "dry season", which result in an average temperature difference between them of 6°C, from 20°C to 26°C. In order to calculate the cooling load, we assume that in the cold season there is no cooling load and in the hot season the extra energy load represents the cooling load. Furthermore, energy used for cooling is not just related to the Air-conditioning units, but also related to fans and fridges that increase the consumption of energy.

Santa Cruz = 25000 MWh/yr
Santa Cruz cold season
1700 MWh/month x 12 months = 20400 MWh/yr
Cooling load
25000 MWh/yr - 20400 MWh/yr = 4500 MWh/yr

Electricity to Cooling: Air-conditioning units have a coefficient of performance (COP) that represents how many units of energy are used per unit of heat extracted. For this calculation, we assume the average COP from a standard new system is 3.2.1


**Actual Cooling Energy Demand:**
16,500 GJ/yr

![Figure 2.13. P.Calle (2014) Cooling Demand Santa Cruz](image-url)
2.6.3 Heating Energy Demand

The Galapagos have a relatively hot climate that never goes below 16 degrees, and even that temperature only happens just some times in the dawn. This allows the population to be non-dependent of heating systems, meaning that the use of heating is just limited to hot water for showers and sinks rather than for controlling building thermal comfort. Also it is important to realize that just 15% of the population actually uses hot water, but that percentage has been growing because of the increase of income and the change of customs.

On the Fig.12 Assumptions based on Isabela study(1) and calculations made from formula(2).

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Actual Heating Energy Demand:
9.700 GJ/yr

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HEATING LOAD

**Hot Water**

- Local residents: 15%
- Tourist: 96%

**Assumptions:**
- 5 min shower by 61 per minute flow = 30L
- 5 L of sink hot water.
- Water temperature 18°C
- (25%) 4500 persons uses hot water

\[ E = m \times c_p \times \Delta T \]
\[ E = 35000 \, g \times 4.18 \, J/g \times 42 K = 6140000 \, J = 6.1 \, MJ \]
- efficiency 85% = 7.1 MJ per day per user

**TOTAL year**
4.500p x 7 MJ/d x 365 d = 115000000 MJ = 11500 GJ

Because of climate conditions 16°C lowest temperaute no building heating is required. Heating is just used for water for shower and sinks.

**Figure 2.13** P.Calle (2014) Heating Demand Santa Cruz

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*Energy losses in system pipes and storage heating tanks*
2.6.4 Electricity Demand

In Santa Cruz 99% of the electric energy demand is generated by 4 diesel generators that operate almost in full capacity. According to the Galapagos electric company data from 2013 the total amount of diesel used to generate energy was 6425000 liters that delivered 90000 GJ of energy to the island\(^1\). Since 2014 four windmills are going to start functioning and delivering 30% of the total demand.

Based on the table 2.2 the residential sector uses 40% of the total energy demand and the non residential sector 60%.

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\(^1\) CONELEC (2013). Detalle de Centrales Thermoelectricas Santa Cruz. Ecuador, Conelec.
2.6.5 GAS Demand

In Santa Cruz GLP its used mainly for cooking [85%] and for heating water for showers and sinks. That is because in the Galapagos 95% of stoves are powered by gas. Also in Ecuador gas is commercialized in cylinders, so for the Galapagos those cylinders have to be shipped from form mainland. According to the table 2.3 from January to August of 2011 (8 months) a total of 41000 gas cylinders were consumed in Santa Cruz from which 31000 were domestic (15kg) and 10000 industrial (45kg).

GLP Demand

90000 GJ/yr

Residential 40% = 36000 GJ/yr
Non Residential 60% = 54000 GJ/yr

Figure 2.15. P.Calle (2014) GLP Demand Santa Cruz

TABLE 2.3 Austrogas (2011). GLP cylinder consumption in The Galapagos

GLP consumption

2011 Sales data
- Domestic 4000 u
- Industrial 1250 u

Domestic 48000 u of 15 kg = 720.000 kg x 40MJ/kg = 29000 GJ
Industrial 15000 u 45 kg = 675.000 kg x 40 MJ/kg = 27000 GJ
Total of 1'400.000 kg x 40 MJ/kg = 56000 GJ
With a 8% annual consumption growth from 2011 to 2013
Demand 2013 = 65.000 GJ/yr

GCL - Gas

Hot Water
Cooking

15% 85%

cooking and water heating

45% 20%

42000 GJ 10800 GJ

fuel heat fuel heat

1'900.000 kg 210.000 kg
76500 GJ 13500 GJ

42000 GJ 10800 GJ
2.6.6 Water demand

Water is really an issue in the island of Santa Cruz. The main source of water comes from the cracks in the ground. In which the problem radiates because of the lack of sewage system 90% of the houses use septic tanks that are not sealed and connect to the underground, at that level every tin-horn is connected to the cracks, where the water sources get contaminated with septic waters. As a result this water is not suitable for human consumption even though the municipality applies treatments it seems not manageable to reach healthy standards.

The main drinking water comes from private desalination plans that sell water in plastic containers. The daily amount of production is 30m³ per day for the entire island. So for a quick calculation the average energy used to obtain sweet water from brackish water is 2.3 kwh/m³ and for ocean water 3.4 kwh/m³ (30 m³/d by 365 d = 11000 m³/yr by 3kWh/m³ = 33000 kWh/yr translated to Joules is 118 GJ/yr).

There is no information about the quantity of tap water consumed in Santa Cruz so the assumed data is taken from the ideal water consumption per day per person of 140 l. (2)

The only data obtain is the data from the pumps used to pump water into the treatment plants. There are a total of 7 pumps that work during the night with a capacity of 125 kW (assumption 365 by 8 hour = 365 MWh per year = 1300 GJ/yr. (3)).

2.6.7 Waste production

From the total waste produced in Santa Cruz 40% is organic, 3% plastic, cardboard 8%, 7% glass and 5% dippers. According to WWF study every 10 years waste production doubles in the Galapagos. Luckily in Santa Cruz there is a recycling program running that manages to recycle 50% of the waste, by focusing in organics, plastics and glass. (1) The transportation sector also has an import waste production in terms of burned oil from ships and cars, the same with used rubber tires.

If the daily waste production is 13 tons the total year production reaches almost 5000/yr tons from residential, commercial and rural waste, in which 40% is organic waste 2000 tons/yr. In terms of energy organic waste can be turn into biofuel with bacteria and inorganic waste burned.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Kg/per/day</th>
<th>%</th>
<th>Organic 40%</th>
<th>Non organic 60%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per person</td>
<td>0.617</td>
<td></td>
<td>0.2458</td>
<td>0.3702</td>
</tr>
<tr>
<td>comercial</td>
<td>2.900</td>
<td>25</td>
<td>1.160</td>
<td>1.740</td>
</tr>
<tr>
<td>residencial</td>
<td>0.600</td>
<td>58</td>
<td>2.600</td>
<td>3.900</td>
</tr>
<tr>
<td>rural</td>
<td>1.800</td>
<td>16</td>
<td>0.720</td>
<td>1.080</td>
</tr>
<tr>
<td>Sub-TOTAL</td>
<td>1.1210</td>
<td>100</td>
<td>4.484</td>
<td>6.726</td>
</tr>
<tr>
<td>cruisers</td>
<td>0.200</td>
<td>100</td>
<td>0.840</td>
<td>1.260</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1.3310</td>
<td>200</td>
<td>5.324</td>
<td>7.986</td>
</tr>
</tbody>
</table>

Table 2.4 W.Calle (2014). Plan para el manejo de desechos para las islas Galapagos. Ecuador, WWF.


1 WWF (2010). Plan para el manejo de desechos para las islas Galapagos. Ecuador, WWF.
3.6.8 Energy demand Results.

This chart creates the picture of consumption in the island were it shows clearly how energy is being consumed by every sector and the demand of energies.

The energy demand show clearly that most of energy consumption goes to transportation, planes, cruiser and cars, 80% of the total. Moreover residential and commercial energy consumption is really low with just a 20%.

What is also important to remark is how much energy is lost into producing electricity. And how inefficient is to burn fossil fuel for this reason. Just 40% of energy is delivered.

Heating and cooling loads inside the built environment (residential and non residential) represent just a 25% of the total energy demand of this sector, a really low in comparison with the housing demands in developed countries.
This chart shows how tourism because of its directly related to transportation has the biggest impact in the demand. If tourism is not considered as local demand the energy consumption of the island becomes four times less even considering locals plane use.

Figure 2.17. PCalle (2014) Energy consumption by sector
2.6.9 Demand Per person per day

The graph above illustrates the amount of energy used per person per day in Santa Cruz and shows a comparison with the British consumption per person per day\(^1\). This allows one to understand that in the Galapagos the consumption of energy is extremely low. Furthermore if the tourist energy consumption is not counted a Galapagueno consumes 5 times less energy than a British. Meaning that energy wise Santa Cruz is already really sustainable compared to other places that consume a lot more.

But this does not happen because the inhabitants of Santa Cruz try to live sustainably, instead this happens because of the islands being in a underdeveloped country where climate is stable, where low incomes limit consumption and where cultural background plays a big role into the way of living. So if we picture this society moving forwards to be developed in a westernised way we can expect this numbers to rise substantially.

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\(^1\) Mackay, D. J. (2009). SEWTHA: 300.
2.7 Energy Potential

2.7.1 Energy potential mapping

The method of energy potential mapping (EPM) analyses the spatial plans of land based on the energy production techniques that can occur.

2.7.2 Renewable energy production techniques

Renewable energy equals space, every energy generation technology uses space. But that is also different generation technology because it relies in different sources and can share the same space without affecting other activities, this can be called layered energy production.

For this study 6 different renewable energy sources will be analysed that could be utilized in this island: solar photovoltaic, solar thermal, wind, geothermal, tidal and biomass.

2.7.3 Energy potential Areas

Three main areas in Santa Cruz island, not part of the national park, represent the only potential places available to generate renewable energy without big environmental impact. These areas have been occupied and affected by men already so they are considered human lands even though they still need to guard nature’s balance, birds reptiles and other species are still frequent in these lands.

Baltra: Islands in the north is considered an appendix of Santa Cruz. This small island of 11km² holds the most important airport in the Galapagos and the only airport in Santa Cruz. These lands were used as a military based during the World War II form the United States army and after they left the Ecuadorian government converted it into an airport and a fuel port.

The agricultural land is located in the highlands in the south slopes of the volcano, the only place where soil is thick enough to allow agriculture to happen. This area is really humid and wet because of the “garua”, a foggy rain that gets caught by the height of the volcano. This is a total area of 114 km².

The Urban area occupies 3 km² at the southern coast of Santa Cruz. A total of 3700 buildings form Puerto Ayora city with about 14.000 inhabitants, 78% of the island population. Here space is limited by buildings, roads and infrastructure, but more importantly the land is fragmented by ownership. Applying energy generation programs here requires high involvement and organization of the citizens. But also awareness can be generated and sustainable thinking can be introduced to the users, to make them part of the problem and the solution.
2.7.4 Photovoltaic:

There are 3 areas from Santa Cruz not part of the Galápagos national park in which solar photovoltaic energy can be implemented: Baltra island, rural or agricultural lands and the urban areas.

**Urban Areas:** According to Puerto Ayora’s urban plans and foot print the total roof area of the existing building stock is 190,000 m² from a total of 2500 buildings, as result there is an average roof area of 76 m² per building. By assumption because of roof limitation of shape, use and structure (not because of sun angle, Equatorial latitude 90°) 60% of real roof area is suitable for solar panels, that means 45 m² per building or a total urban roof area available for photovoltaic generation of 115,000 m². Also there are some other small towns like Santa Rosa and Bellavista in the highlands that will be included in the rural area calculation.

**Agricultural Land:** It consists of 114 km² out of which 106 km² are used mostly for cattle and horticulture. A photovoltaic farm in this area competes directly with food production so this area will not be considered for solar photovoltaic energy production. But there is an extension of 8 km² planned as urban expansion that can be considered for this use in roofs, which would be 5% of the area, 0.4 km².

**Baltra** is considered an excellent spot for solar energy generation with 6.14 kWh/m².d solar radiation. It also has a flat landscape with low vegetation and an ecosystem already affected by the military base with no use for agriculture. But because of the airport and its restrictions it has a limited area of occupation of 4 km².

2.7.5 Solar Thermal

Water heating systems tend to be more efficient when the source and the user are close together, so less heat losses occur and material use like insulation and piping reduces so costs reduces too. Taking this into account it is easy to determine that the solar heat collectors need to be really close or attached to demand, the buildings, and the city, instead of being far away in open fields, for that reason I am going to analyse solar thermal energy just in the urban area.

Because at the equator the sun path that goes from East to West with a 70 to 90 degrees angle and by understanding that the sun energy power is at its maximum at 12 pm the best angle for the solar heat caption is at 0 degrees. So buildings rooftops are the most efficient surface to place collectors instead and not façades like northern and southern latitudes.

Global Solar radiation (G): 5.16 kWh/m²
Efficiency solar collector (Eff): 45% (ΔT 18C-50C)\(^{1}\).
Roof area (A): 115000m² (60% of total roofs area)

Calculation:
\[ E = G \cdot Eff \cdot A \]
\[ E = 5.16 \text{kWh/m}^2 \cdot 0.45 \cdot 365 \text{d} \cdot 115000 \text{m}^2 \]
\[ E = 97500 \text{MWh/yr} = 350000 \text{GJ/yr} \]

2.7.6 Biomass

Santa Cruz has 115 km² designated for agriculture and cattle. This area is situated in the highlands where the garua (foggy rain) and the thicker layer of soil allow corps and grass to grow.

At the moment 74 km² of that designated land is used for intensive cattle herding, in which 10,000 livestock are raised (8000 cows and 2000 pigs). But 65% of that territory is enough to raise 20,000 UC (cattle units) 4UC per hectare with a better use of the land. Cattle manure can be easily converted into bio-gas or bio-fuel by bacteria and used to power fuel engines. Furthermore capturing methane from manure reduces the impact of emissions released to the atmosphere to a twentieth of what it is now.

From each cow we can produce 5.4 GJ per year from its manure converted into Biogas.

There is an area of 9km² of timber plantation that can produce 68,000 GJ/yr of energy per km² just from its maintenance. But the landscape conditions and accessibility create a low harvest efficiency (assumption of 20%). This efficiency can gradually increase with more forest planning. Woody biomass can be converted into electricity by burning with an efficiency of 30%, because of heat looses.

From cuttings and organic remains from crops 17,000 GJ/yr can be obtained per km². A total of 31 km² from which 8 are considered urban expansion, so just 23 km² are used for horticulture and coffee plantations. Landscape conditions and accessibility create a low harvest efficiency (assumption of 50%). Organic waste from crops can be turned into electricity by burning with an efficiency of 30%.
2.7.7 Wind Energy

There is already a wind farm project being built in Santa Cruz. 4 wind turbines are being placed in Baltra near the airport that will deliver 21,000 GJ/yr. For this project, 3 sites in the island were studied, 2 in the highlands (Santa Rosa and Camote) inside the agricultural zone and in Baltra island (table). Even though the 2 sites in the highlands present good wind conditions the environmental impact, accessibility and slightly lower energy production compared to Baltra dismissed them. Anyway this energy potential study will take into account these 3 sites, knowing from beforehand that the sites in the highlands represent a threat to the environment and eventually will be dismissed too.

To calculate the wind energy potential the Enercon E48 turbines were used as reference because they are being used in the actual project. These turbines have a diameter of 48 m and by using the rules of thumb for the turbines spacing of 6D x 4D, giving an area of 55,000 m² per wind turbine.

Table 2.6 ERGAL (2007). Alternativas de Construcción de un parque eólico para suministro eléctrico en Santa Cruz. Wind potential Study for 3 sites inside Santa Cruz
2.7.8 Tidal barrage power

“Tidal barrage first allows water to flow into a bay or river during high tide, and releasing the water back during low tide. This is done by measuring the tidal flow and controlling the sluice gates at key times of the tidal cycle. Turbines are then placed at these sluices to capture the energy as the water flows in and out.”

Tidal barrage requires specific geomorphological coastal coves that allow dams to retain water from tides and that have big tidal range for more potential.

In the Santa Cruz the average tidal range is 2 m, a very low tide in terms of tidal energy potential. But this range can be compensated by the area of the tidal barrage. The island’s coastal silhouette suggests just one possible place that a tidal dam can be build that will allow a huge volume of water to be retained, that place is the Itabaca Channel that has an area of around 9 km². By creating 2 dams one in each side a huge amount of water could be reattain during high tide and released in low tide.

Itabaca channel will be used to set an example of the energy potential of a 2m tidal range in the Galapagos and the amount of space needed in ratio with the energy outcome.

But we have to realise that any dam creates important environmental problems and because of the Galapagos fragile ecosystem a project that will change landscape and flood land represents an ecological impact that certainly is not suitable for this place and furthermore not sustainable.

Tidal Energy

Itabaca Channel: 42.00GJ/yr

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![Potential Tidal](image)

Tidal Energy Potential

**Tidal Energy Potential**

**Itabaca Channel:** 42.00GJ/yr

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Figure 2.26. P.Calle (2014) Tidal energy potential of Santa Cruz
2.7.9 Urban Waste

Waste Water
Santa Cruz doesn’t have a sewage system at the moment but its planned to be built soon in the main urban areas, around 4500 house holds will be provided with this service. Waste water can be treated and by fermentation can produce biogas that can be used as fuel for power plants or compressed and used in vehicles. There are already some ships powered by gas. The potential energy production of biogas from waste water fermentation is 300 KWh/yr\(^1\).

Rain Water
The water supply in Santa Cruz is either very limited, has a high energy consumption to be purified or is not clean. Rain Water harvesting can help solve these issues. The amount of rain water per year is 300 mm\(^2\) that can be collected in building roofs (roof area in Puerto Ayora 190.000m2).

Organic Waste

According to the table 111 the amount of waste produce is 13.5 tons per day from which 40% is organic. Organic waste can be converted into biogas by fermentation in rate of 1 Ton of organic waste generates 150m3 of biogas\(^3\).

Inorganic Waste
In Santa Cruz 60% of waste is inorganic about 300 tons a per year. Normally this waste is recycled with a 50% rate and the rest goes to land field or back to the continent. But this waste can also be incinerated in a thermo-electric power plant to generate electricity. In average 1 ton of waste generate 500 KWh of electricity\(^4\).

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### 2.7.10 Energy Potential results

Santa Cruz shows great energy potential that has to be further developed in terms of space, viability, technology and the environmental impact.

Solar energy from far is the biggest potential in the island and in general in the world, but here at the at the equator the constant 12 hours during the year with a canicular sun maximizes the energy caption and creates a more stable potential.

![Figure 2.28. P.Calle (2014) Energy potential Study Results chart of Santa Cruz](image)

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>$U = 115,000$ GJ/yr</td>
</tr>
<tr>
<td></td>
<td>$B = 4'000,000$ GJ/yr</td>
</tr>
<tr>
<td></td>
<td>$R = 52,000$ GJ/yr</td>
</tr>
<tr>
<td>Heat</td>
<td>$LL = 350,000$ GJ/yr</td>
</tr>
<tr>
<td>Biofuel</td>
<td>$320,000$ GJ/yr (gas)</td>
</tr>
<tr>
<td></td>
<td>$100,000$ GJ/yr (elect)</td>
</tr>
<tr>
<td>Waste Water</td>
<td>$4,700$ GJ/yr</td>
</tr>
<tr>
<td></td>
<td>$57,000$ m$^3$/yr</td>
</tr>
<tr>
<td>Wind turbines</td>
<td>$B = 190,000$ GJ/yr</td>
</tr>
<tr>
<td></td>
<td>$R = 158,000$ GJ/yr</td>
</tr>
<tr>
<td>Rural 158 w/m$^2$</td>
<td>average wind speed 5.9 m/s</td>
</tr>
<tr>
<td>Baltra 189 w/m$^3$</td>
<td>average wind speed 6 m/s</td>
</tr>
<tr>
<td>Tidal energy</td>
<td>$42,200$ GJ/yr</td>
</tr>
<tr>
<td>Santa Cruz average tide difference 1.8 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tide frequency 2 times a day</td>
</tr>
<tr>
<td>Geothermal</td>
<td>$234,000$ GJ/yr</td>
</tr>
<tr>
<td>Isabela island</td>
<td>55km dist.</td>
</tr>
<tr>
<td></td>
<td>65000 MWh</td>
</tr>
<tr>
<td>Urban Waste</td>
<td>$5,400$ GJ/yr</td>
</tr>
<tr>
<td>3000 tons inorganic</td>
<td>$6,600$ GJ/yr</td>
</tr>
<tr>
<td>2000 tons organic</td>
<td>$E$</td>
</tr>
</tbody>
</table>

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**Figure 2.28. P.Calle (2014) Energy potential Study Results chart of Santa Cruz**
2.8 Governmental Energy plan

Islands such as the Galapagos that have isolated small grids face unique challenges because of their remoteness and dependence on fossil fuel generators for electricity. The contamination risk and costs of imported fuels create a dangerous and unsustainable scenario. Renewable energy, such as wind and solar, present a viable substitute for this dependency but at a cost to grid stability.

The actual energy plan for the Galapagos in order to get rid of fossil fuels is based on wind energy and imported biofuel. It seems amazing that located at Equator with such a good solar radiation and constant climate, solar energy has not been considered as the main energy solution.

Also the idea of replacing fossil fuels just by biodiesel has very little impact on the transportation risk and environmental pollution and actually does not address those risks. In short terms imported biodiesel will eradicate fossil fuel but not the problems of the entire fuel based matrix that loses a lot of energy by conversion into electricity and motion.
2.9 Reference Project

As a reference project, Tokelau atoll located also on the equator in the middle of the Pacific Ocean was facing similar problems regarding energy generation and the dependence on fossil fuel, but since 2013 they have converted into the first truly energy renewable nation.¹

With about a 10% of Santa Cruz island population they have created a solar PV farm that produces 150% of the energy they need. With similar climate conditions and similar solar radiation they are able to depend just on solar energy with battery energy storage. As a back up system for extreme climate conditions like storms they have biofuel generator power by coconut oil produced locally by themselves.

It seems a good idea to start thinking on solar energy for Santa Cruz instead of importing biofuel. Besides with a much bigger land territory and a bigger grid the system could work more efficiently. Well in a very basic way of thinking it is just a matter of scaling up the system and it looks possible.

2.6.11 Santa Cruz energy potential Island map

The energy potential mapping shows the available renewable energy in Santa Cruz considered for this study. The 3 main areas are layered by the different energy sources and their potential, illustrating how, the quantity and where energy can be produce inside the island of Santa Cruz.

Conclusion

The potential of energy inside the island is very big and could supply more energy that what is needed. The question now is how much this resources are we going to be used for each specific demand. Each energy source has specific potential that has to be explored strategically to achieve the balance with demand in the most efficient way. This means that using heat for heat, electricity for electricity and the same with bio fuel for fuel engines. Thus when the demand is not reached it needs to be supplied by the next most efficient source.
DEVELOPMENT

3 The new stepped strategy

3.1 Concept

Sustainable strategies are used as guidelines to follow in order to achieve sustainability in any type of project. For this study the “New Stepped Strategy” towards sustainable energy design will be followed tempting solve Santa Cruz scope of energy and sustainability.

Since the end of the 1980’s sustainable approaches to urban areas have followed the three step strategy:

01 Reduce consumption
02 Use renewable energy
03 Supply the remaining demand cleanly and efficiently

3.2 New stepped strategy

The New Stepped Strategy adds an important intermediate step in between the reduction in consumption and the development of sustainable sources, the reuse of waste, making optimal use of waste streams as energy supply, waste = food. By this addition the final step is expected to be unnecessary.\(^{(1)}\)

01 Reduce consumption (using intelligent bioclimatic design)
02 Reuse of waste by creating energy streams
03 Use renewable energy sources and ensure that waste is reused as food
04 Supply the remaining demand cleanly and efficiently (hopefully won't be needed in a near future)

There is an addition on step 3 concerning waste that can not be processed as energy that has to be delivered back to nature only if it can be degradable and if it is not toxic.

3.3 Layered new stepped strategy

For this project the “new stepped strategy” was applied for the build environment energy demands cooling, heating, electricity and transportation.

3.3.1 Transportation

Transportation is the most energy demanding sector, and depends on everyone to reduce the demand and to produce energy with strategic planning from the government to the user.

The most relevant interventions are on the engines of all motorized vehicles and ships, they need to become electric. In this way, cars, buses, boats, and trucks can directly be electric and could reduce their energy consumption by 60%. Plus electric boats do not spill engine fuel into the sea water and are more silent reducing sound contamination in pears and harbours. On the other hand ships at the moment have not been able to be 100% electric since the energy load is too big for energy storage on board but technology is getting there. The best alternative is to take the step in between fuel and electric and use new hybrid systems in cruise ships, a combination of a diesel electricity generator and electric engines. These new systems reduce the fuel consumption by about 30%.1

Another intervention on ships is to reduce the service energy required to power appliances for guests and crew that is calculated to be 15% of total fuel consumption. Most of the cruisers travel during the night while guests sleep and during the day they stay in their destinations without moving. Shore power from renewable sources could be provided on this “rest” points and thus fuel consumption could be reduced. This intervention could also eliminate air pollution and noise in harbours and pears and bays and may facilitate maintenance of the ship’s engines and generators, and reduces noise.2

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3.3.2 Cooling

Cooling is needed just during the hot season when the temperature in the coastal area surpasses 30°C for a couple hours a day. So, cooling should not be required. However, because of a bad bioclimatic design and precarious construction materials, most of the buildings required cooling even in lower temperatures when the sun shines during midday and in the afternoon over the metallic non-insulated roof sheets. Even though most of these buildings don’t use cooling systems because of the high costs, the internal conditions are not comfortable for the inhabitants.

By using simple bioclimatic concepts like cross ventilation, shadow, insulation, tall ceilings, evaporative cooling, vegetation, etc., the cooling load required inside the houses could be reduced, and almost eliminated.

Some smart combination of reduction and production can work, like solar panels shading metallic roofs.

As a result, the energy saving will not be achieved but the comfort conditions on the houses will improve.
3.3.3 Heating

Building heating is not needed in Santa Cruz because of the climate conditions, temperature does not fall under 16 C. Furthermore the average low temperature is 19 C. But heating is required for showering even though inhabitants are not used to showering with hot water, just a 15% of the populations uses it, but this number with time will rise because of the changing of society towards western standards.

Heating can be reduced but the amount of load is so little that just represents a 2 percent. Moreover, the installation of solar collectors in every building could increase the use of hot water, a bigger demand covered by a sustainable source.

The aim for solar collector water heating is not to reduce demand but to give this service in a sustainable way for the increasing demand and to achieve better living standards.

Figure 3.6. P.Calle (2014) HEating Stepped Strategies

Figure 3.7. Solar Premium(2012) Solar collector on roof.
3.3.3 Electricity

Electricity in Santa Cruz is the primary energy used in the built environment and mainly for appliances. The most important improvement to make is to obtain electricity from a renewable source to reduce the energy required to produce electricity from fossil fuels.

This layered scheme for electricity allows to see the possible actions and interventions in order to create a sustainable system from people to the government, and pointing out who is the actor and the action that has to be made.

The most relevant interventions are solar photovoltaic over the roof of the built environment in the urban areas and the construction of bio-digesters for biogas generation for the rural areas.

The reuse of waste from the built environment as an input into energy production has a lot of potential into electricity generation.
3.4 Reduce

This step focuses on the reduction of the energy demand by different layers of intervention form the people to the government. Each level responds to the specific reduction actions that can be made to reduce the whole.

Starting with the actual demand of the island it is important to specify which demands are directly related to the island and which not. In this case airplanes that have a huge energy consumption are tanked in the continent with enough fuel so they don’t have to fuel in the island. Even tough airplanes are part of the energy consumption of the island they transport mainly tourists (90%) so the discussion about who has to carry with this energy load is open but any how this fuel does not touch the island. So for this study airplane energy has to be charged and provided by the continent and not counted in the island.

The next layer are people, locals, islanders and how their behaviour can affect the demand. This study already showed how little the Galapagueno consume in therms of energy so there is not that much energy to save. But anyhow some strategies have to be applied in order to spread knowledge to maintain this austere behaviour and save a little bit more. Less taxis more walking, more cycling or more sweating and less AC.

The building layer has a similar situation with the previous layer, the energy consumption is really low. But it presents some other issues like comfort and living conditions. Common houses are build without any bioclimatic concepts, bad materials, bad designs and as a result they overheat, have no natural light, leak and have health issues. Any intervention in this layer will improve living conditions but will not reduce energy consumption for the moment. An important fact is that social economy is growing in the islands and the purchasing power allows some families to start buying AC units to level indoor climates, so in the near future buildings energy consumption will grow if bioclimatic and design strategies are not applied.

The next layer involves government, business owners and users. Here is where the big savings occur by changing from fuel to electric, by changing the matrix to electric based on renewable sources. In transportation electric cars and boats will save 60% of consumption, hybrid electric ships could save 30% and, by producing energy from renewable sources, the losses from the diesel thermoelectric generation get dismissed and represent savings of 60%, the same as sun heat collection for heating water.

In the final layer Government and municipality have to establish saving strategies in the main consumption sector, transportation. In land by creating better and more efficient public transport. On water fuel energy consumption could be reduced by making cruise pathways more efficient and shorter, and by providing shore electricity for docked ships’ operational demand.

After this filtering layers of reduction from 1’200,000 GJ per year of energy demand can be dropped to 565,000 GJ/yr. Energy demand has dropped to half, this is a big step towards sustainability.
NEW STEPPED STRATEGY

REDUCE

DEMAND 2,215,000 GJ

Actual Demand

Airplanes are fuel in continent
DEMAND 1,195,000 GJ

Behavior and Knowledge

DEMAND 1,195,000 GJ

Improving building and homes

DEMAND 1,195,000 GJ

Combination

direct heat and electricity
100% electric appliances
Transportation
electric and hybrid engines
DEMAND 700,000 GJ

Top Down

Better public transport
local services of health, education,
administration, etc.
Shorter cruisers paths
Shore energy supply
DEMAND 545,000 GJ

615,000 GJ

900,000 GJ

100%

-1.7%

-0%

-42%

-20%

Figure 3.11. P. Calle (2014) Reduction strategy step by step. Bottom-up
3.5 Reuse

Waste has an important potential that is being dismissed in the Galapagos. Reusing this waste from urban and rural areas could generate - in a very conservative way (rural agricultural land with more infrastructure could generate more) - 225,000 GJ per year.

Rural waste is mainly organic and comes from cattle manure, crops cuttings and forest maintenance. Biomass could, by bio-fermentation, create biogas (wet organic waste and manure) and by incineration of woody waste and dry cuttings generate electricity.

Urban waste has liquid and solid by-products that can be reused.

Liquid waste is divided in black water (sewage) and rain water. Rain water can by reused directly with local filtration methods for water supply and save energy required to obtain tap water. Sewage water contains organic waste that has to be treated before its reuse or release into the environment. This organic material can be treated by anaerobic bacteria that generates methane, that can be used as bio gas fuel.

Solid waste from Santa Cruz is 40% of organic and 60% inorganic. Form organic waste by bio-fermentation biogas can be obtain. Moreover from inorganic waste by incineration electricity could be generated but with some environmental considerations, burning materials that could be recycled or reused is not sustainable, so recycling processes should be filtering the waste material to be burned.
3.6 Produce

Production of energy by renewable sources is related to space and land use but because of limitations, space and production are not related in a proportional way.

The 3 areas of production theoretically can produce 1,720,000 GJ per year, that is more than enough to satisfy the demand of the island. Baltra solar generation could by itself supply the energy needed for transportation, residential and non residential activities, But this probably means a huge investment and to cover more than 1km² of land with photovoltaic panels and to find a way to convert electricity into fuel for the cruisers, the biggest energy consumers.

From an environmental point of view, some of these interventions represent medium and big threats. Wind turbines in the agricultural zone and probably in most of the island affect birds and bats, which is a huge deal in the Galapagos context. The tidal barrage is certainly a risky intervention with low energy outcome. Flooding lands and 2 dams will change the landscape and destroy a lot of animals’ and plants’ ecosystem.

Baltra is an island where the ecosystem already has been damaged, humans have transformed this landscape since USA placed a military base during World War II. The entire 11 km² have been intervened with houses, roads, pears and an airport. That is why this island is considered to be the one in which energy projects can be built without representing a big threat to nature, at least from the Government’s point of view this island will hold the energy generation.

At the urban zone energy production has big challenges, it will involve people like house and building owners that have to be part of the change in order to achieve a big energy outcome. Solar energy has a big potential: even if just building roofs are counted 116,000 GJ per year could be produced and that is 85% of the energy consumption of the build environment.

As a result there are 3 clear energy production approaches where people (bottom-up), government (top-down) or both (combination) are involved.

Figure 3.13: P.Calle (2014) PRODUCE sustainably energy diagram, step by step.
3.7 Storage

It seems inevitable to depend on energy storage when we talk about renewable energy, the energy production is strictly dependent on climate and its variations which create strong fluctuations on supply that most of the time do not match with the energy demand. Santa Cruz is not different in this sense but has an extra variable because of its small isolated grid that cannot share energy with others.

In big grids like in big countries or in continents where countries have connected grids with each other’s, the demand and production of energy generates smaller fluctuations because of the different sources or energy and because of fossil fuel that works as storage. Also different climates in different regions generate different outcomes that at the end are levelled out. But even in this cases there are some situations where over production of energy has to be stored or dismissed.

To calculate the amount of storage we used rule of thumb on energy storage for renewable grids. This is based on 3 days of zero energy production. This means that without any input the grid can satisfy the demand for 3 days, or with just 50% of production can give 6 days of energy. This amount of energy is considered to be enough.

There are multiple ways and systems to store electric energy with different limitations, costs, uses and environmental impacts. In the figure above there is small comparison showing the amount of space needed for each to store the 3 day energy load.

The most common storage systems used for renewable energy grids are:

- Pumped-storage hydroelectricity: The method stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation and used when is needed like hydroelectric energy.
- Rechargeable battery systems: Accumulate electricity by electrochemical energy storage.
- Flywheel works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy, so energy is extracted when needed.
Biomass. Because it can be burned at any time and can be stored for some period of time it can be considered a way of energy storage.

Fuel cell. Hydrogen used as storage medium, using energy to produce it and acquiring energy from it when needed.

3.7.1 Yearly based storage.

A really important consideration is that during 3 to 4 continuous months in the year wind stops running meaning that wind energy can not be counted and that the grid has to be covered by the other energy sources or by a big storage.

In this case wind production during the windy months can take over biomass energy production and biomass could be saved for the low wind months.

Daily based storage.

Solar energy is just produced during the day so at night time other sources of energy have to take over and compensate this fluctuations. Wind and biomass could be an option. Another alternative is to have daily storage capacity so the solar overload produced during the day can be used in the night.
4 Sustainable scenarios

4.1 Introduction

With the new scope of demand and production, after running the New Stepped Strategy, different scenarios with different approaches have been developed to show the possible ways to achieve an energy balance and a sustainable energy plan.

4.2 Approaches

Two ways to approach the scenarios have been established for this proposal. From the government, also called Top down, a centralized core of actions rule by concentrated easy to control and run intervention. And from the people, the user, also called Bottom-up, referring to the action, intervention or initiative coming from the mass, the public sector, in a decentralized way.

4.3 Scenarios

Five scenarios have been developed to expose different ways of dealing with the energy demand and production. One exposing the actual governmental plan but

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Figure 4.1. P.Calle (2014) island self-sufficiency
4.4 Zero fossil fuel based on actual government energy master plan.

**Description:** Like we saw before the government has created a master plan to get rid of fossil fuels in the Galapagos. This scenario represents this governmental approach over the new scope of demand. A small wind farm in combination with a huge load of imported bio-fuel would satisfy energy demand.

**Self-sufficiency penetration:** 14% Just a little bit of wind energy is being produced and the rest is imported fuel energy from the continent.

**Environmental impact:** High. A lot of risk on fuel transportation.

**Waste = energy:** None. Waste cycles are not being considered.

**Participation:** Low. Just governmental participation, no general public concern.

**Storage:** Low. Bio-fuel is used as energy storage but with a huge energy loses because of heat loses during energy production.

**Feasibility:** High. Has a very simple execution that makes it really possible to be set up.

**Conclusion:** For sure this is the cheapest and simplest way of eliminating fossil fuels in the island in a short term. But like we point out before the risk of fuel spills stays the same as do contamination in air and water. In the long term this scenario based on bio-fuel is not sustainable, the amount of biofuel that has to be produced competes directly with food production, besides just a little of the energy potential of the island is being used, this means that a lot of energy is being wasted which makes for a really inefficient system.
4.5 Solar and wind top down scenario

This Scenario adds solar photovoltaic generation to the government's approach so it can satisfy the energy demand of the inland without fossil fuel generation. The imported biofuel goes just to the Cruisers demand reducing already the previous scenario's demand. The solar generation comes from a PV farm in Baltra run by governmental institutions supporting the wind farm production. It's important to realize that this scenario has to work with out wind generation during the months of low wind.

- **Self-sufficiency penetration**: 55% because of the reduction of biodiesel imported.
- **Environmental impact**: Medium. A bigger area of baltra has to be covered by wind turbines and solar panels with some environmental impacts like bird ecosystem disruption, noise and transformed landscape. Also the imported biofuel risk remains but reduced.
- **Waste = energy**: 0%, waste is not being used as an energy resource.

**Participation**: Low. Just governmental participation, no general public concern.

**Storage**: High. 3 days of energy storage are needed specially in the low wind season when the wind load has almost no penetration.

**Feasibility**: High. Is a relative simple plan that just requires money. Government could run this project with out the concern of other parties.

**Remarks**: The incorporation of solar energy as the main renewable source is a big step, but this means also a bigger storage capacity, probably really expensive, if the biofuel gets out of the inland energy generation.

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Figure 4.3. P.Calle (2014) Top down energy master plan
4.6 Bottom-up scenario

Description

Driven by the people the main power supply comes form roof solar collectors and the biomass generated by agriculture. The already installed wind turbines will also add to the system. The direct use of biogas for cruisers engines increases penetration and more important the incorporation of the other populated islands into production of biogas to complete the entire demand. With this strategy cruisers have to tank biogas in the other islands while they are touring the archipelago. As result the importation of any fuel into the island becomes unnecessary.

Self-sufficiency penetration. High. 100% , 65% of which is self-penetration and 35% covered the archipelago

Local environmental impact: Low. Solar panels on roofs do not represent any threat to local environment. Plus waste streams are being used so no contamination is being inflicted onto nature.

Participation: High. Users are the main part of the energy generation system.

Waste = energy: High. 100% waste energy used.

Energy Storage: Medium. 30% of storage needed. 650 GJ batteries, medium size storage because of 10% biomass input can be used as storage.

Feasibility: low. Arranging 100% of building with solar collectors can be a difficult picture to achieve.

Remarks: The importance of the inclusion of the inhabitants into the energy matrix as producers could also save energy and result in a more conscious society. While it seems hard to achieve roof photovoltaic production the amount of energy to be gathered could supply 90% of the buildings energy consumption, meaning that they could become easily a self sufficient sector.

To create a bigger picture and include the rest of the archipelago into solving the energy demand of the cruise fleet is inevitable. This implies that biogas production has to be set up in other islands as well.
4.7 Combined Scenario

Description: by combining the best qualities of the previous scenarios a new fused approach appears, where people and government participate as a team. In this case the participation of the public sector remains as the core energy generation but the government executes also projects to support and sum up into the grid allowing to reduce energy storage and creates a much more diverse energy source than will create a more stable grid.

Self-sufficiency penetration: High, 100%, 70% of which is self-penetration and 30% covered the archipelago.

Local environmental impact: Low. Solar panels on roofs do not represent any threat to local environment. Plus waste streams are being used so no contamination is being realised into nature.

Participation: High. Users and authorities are part of the system.

Waste = energy: High. Waste is used as energy.

Storage: Low. Biomass used as storage.

Feasibility: Medium. If roof solar energy doesn’t reach the potential government’s solar farm can grow and overcome the demand.

Remarks: For this study this scenario represents the ideal situation. A bottom-up approach supported by the government clearly reaches the goal of a sustainable island based on renewable energy and the use of the waste as energy.
### 4.8 Ultimate Energy Self-sufficient Scenario

**Description:**

This scenario illustrates how to achieve energy self-sufficiency. The idea is to generate natural gas by an over production of electricity by renewable source, this process is named “Power to Gas”, the generation of natural gas by electric energy. (50% efficiency), or to use fuel cells to use in ships.

- **Self-sufficiency penetration:** High. 100% energy self-supplied.
- **Environmental impact:** Low. No biofuel used or imported, reducing the risk of spills and contamination.
- **Waste=energy:** High. Waste is used as energy.
- **Storage:** Low. Biomass used as storage.
- **Feasibility:** Low. Technological limitations and big investments.

**Remarks:** Is a very interesting concept but at the moment seems far from being available, plus the low efficiency of converting solar energy into gas to power an electric engine involves just to many loses and wasted resources. Also it seems to be a very expensive way of solving maritime transportation consumption, if more biogas is produced in other islands.
5 Proposal

5.1 Energy master plan

Based on the “combined scenario “where all parties collaborate into creating sustainability in the island a basic energy production master plan has been created.

The intervention of all renewable sources have been illustrated into the same picture into an urban master plan to have a better overlook of how the island could function and the facilities that need to created.

It is really important to create a diverse system that relies in different sources to achieve grid stability. But this also implicates more interventions and a much complex system to manage.

This master plan could work as a guideline for further designs and interventions that need to be developed into detail.

Figure 5.1. P.Calle (2014) Energy generation Master plan mapping
5.1 Baltra

The appendix island of baltra has being converted into the governmental energy production input to Santa Cruz island. It has the following interventions:

The wind park has been located as an extension of the actual wind park because of the wind potential study of baltra that shows that the east coastal area has more wind.

A bigger solar energy zone that is actually needed has been planned to support the future demand. It has been placed in an already affected and deserted area that was a military base camp. Inside this zone the proper area required for the actual solar plant has been placed.

The actual fuel port where cruise ships tank and passengers board has been converted into a biogas and bio fuel port with storage tanks related facilities. Besides floating dock platforms have been placed inside the bay where ships can connect into the shore grid while they are waiting for passengers.

The ferries over the Itabaca Channel have been converted to electric and have energy supply in both sides of the shore where they charge.

Baltra energy potential can hold more interventions in order to supply enough energy for the future demand, Therefore, Baltra’s participation into the system is essential.
5.2 Rural intervention master plan

The agricultural zone has the biggest biomass production. This bio waste converted into energy allows for the creation of a system with very little energy storage and for the supply of biogas for the maritime fleet. In order to provide this energy facilities have to be created.

Bio-digesters. A net of bio-digesters have been placed along the cattle fields to create centralized gathering places where farmers process the manure. The idea is to collect the biogas output with a gas pipe line that connects the bio-digesters with the compressed biogas plant.

Compressed biogas plant. This facility allows biogas to be filtered, purified and compressed to be bottled, so it can be used in ships as fuel. This plant has been placed in-between the bio-digesters and the sewage treatment plant to collect raw material from both sources.

Incineration power plant. This facility converts biomass, woody bio waste, into electricity. This energy source is being held as energy storage in the system, so space and proper conditions have to be created to harvest and store this biomass.

There are 2 small towns inside this area where solar photovoltaic panels have been placed over the roofs, and provide a big input to system.

Something really important to realise is that these fields have to become more efficient in terms of production and in terms of waste collection. A proper study on ecological agriculture and management has to be produced, this could help to increase the biomass production.
5.3 Urban intervention master plan

The urban environment is the most energy demanding area in the island but also has a big production potential and it has been used to produce energy. The interventions made, take advantage of the solar radiation and the empty roofs surface and the waste produced by the inhabitants. The following interventions have been made:

Sewage Treatment Plant. This facility takes advantage of the waste water that previously was thrown into septic wells polluting the underground water. The waste water is treated in anaerobic tanks functioning as biogester to produce biogas. Not only this produces energy but also purifies water before it is released into nature. The obtained biogas is piped to the Compress biogas plant so it can be used in ships.

Incineration power plant. This facility uses the non recyclable waste as energy source by burning it down with a 96% efficiency. This power plant has to be strictly regulated and planed with the latest technology so the pollution factor is minimized. This method is not the most sustainable, but keeps this kind of waste away from land fills that is a lot worst.

Solar roof panels. This master plan counts on the participation of every citizen to provide a big load of energy form solar roof photovoltaic panels and heat collectors, so it minimizes the space that would otherwise have to be used in non urban areas for this purpose.

Shore energy supply. Floating platforms connected to the shore grid by underwater cable along academy bay have been planed to be supplying energy to docked boats and cruisers. This reduces the fuel consumption while the ships are stationary in the bay.

Interventions on the urban area are key elements of this master plan because they will reduce contaminations and increase participation into the inhabitants.
5.4 Archipelago intervention master plan

Cruiser are the most energy consuming sector and because of technology limitations this vehicles can not be converted into electric. Therefore fuel seams the only way to power this ships and biofuels the only sustainable way. The bio gas produced in the Galapagos could be used for the cruisers by

Santa Cruz by it self can not produce enough biogas to satisfy the demand of the entire fleet but we have to understand that the most of the ships tour around the entire archipelago passing by other islands, so the energy demand should be supported just by the other populated islands too.

Figure 5.5 shows the archipelago master plan with the possible biogas stations and shore energy supply for stationary ships. Biogas stations are supply by local digester plants that process bio-waste form the islands helping also to achieve a sustainable management of waste.

Touring paths also should be developed shorter for fuel savings and taking into account each gas-station fuel availability and traveling distances.
6. Conclusions:

6.1 Introduction:

Addressing the main question of the research: yes! Sustainability can be achieved by applying the new stepped strategy.

This project has explored the energy demands of Santa Cruz in order to satisfy them in a sustainable way. As result the “Combined Scenario”, a combined approach, show how a sustainable energy production system can satisfy the energy demand. This supports the goal of achieving a sustainable development by applying the strategies of reduction reuse and production.

Even though energy self-sufficiency cannot be achieved at this moment the incorporation of the other islands into the renewable energy production matrix reaches a regional self-sufficiency. Any how in the “ultimate self-sufficiency” scenario is shown that technology will produce new ways of creating and storing energy that will erase the importation needs of Santa Cruz.

But more importantly, this research shows how and why the government has to include the population in the production of energy and needs to apply the new stepped strategy into their energy master plans in order to be more consistent with the intentions on turning the Galapagos into a zero fossil fuel archipelago. Furthermore, the importance of placing solar energy, the one with the more potential, into the picture and using waste as energy.

6.2 The New Stepped Strategy

This strategy really created a clear path of intervention in Santa Cruz that lead to sustainable scenarios meeting the demand with a sustainable production. And more importantly allowed the waste streams to become resources that not only helped to produce energy but also ensured no waste contamination into the environment. This is a very consistence way of achieving sustainability.

If this strategy suited for Santa Cruz case surely could be used for the rest of the archipelago and create a model with a bigger range of effectiveness.

6.3 Findings

During this research the calculation of demand and the strategies lead to very interesting facts.

The low local demand of energy is a result of climatic and socio-economical conditions and it amounts to one fifth of the European average energy demand. That shows an already very sustainable society.

Because of the low local consumption, the build environment energy can become self-sufficient with the energy produce from their roofs and waste.

The tourist sector is the most energy demanding because of transportation, ships and planes consume a lot of energy that at the moment can not be supplied without fuel.

Energy Storage load can be covered by biomass instead of using batteries or pumped storage, the energy stored on waste can be use at any time to support the grid fluctuation.

The entire archipelago has to convert into renewable for a regional energy balance.

By applying the reuse of waste and water into energy not only there is an important energy load added but also they enters into the a sustainable cycle. Therefore waste contamination threats disappear with this strategy.

6.4 Feasibility

All master plans have a level of complexity, in this case to convert every roof in town into solar energy producer can be a big challenge to accomplish. but not something impossible. With the right incentives and support from the government an economic scenario could create a new income for citizens.

Solar energy is at the moment expensive but prices are dropping down, creating an energy plan based on this source in this location is for sure a good option.

6.5 Further research

From this research some assumptions were made that have to be sustained with a more extended research.

Because this research focused on the demand and the strategy, the final products, the scenarios and the Energy Master Plan need to become more developed, precise and consistent, at the moment it is just a sketch proposal to picture how the island could hold this renewable energy production system in a sustainable scenario.

A field research also has been missing because of lack of time and resources this couldn't be done. This pro-
ject could get important inputs and more appropriate solutions from proper in situ study where local people and institutions express themselves towards this specific topic.

### 6.6 Future scenario

The island has a promising panorama for a sustainable future if tourism gets out of the picture, but at the same time we know that cannot happen because tourism is the primary economic resource for the inhabitants of the Galapagos and a big one for the country of Ecuador.

So it is clear that tourism has to continue growing but at least has to be controlled the unsustainable numbers visitors for 2030 will be 400% more something completely crazy. This energy demand is impossible to satisfy with the technology of today. But even if technology could solve energy requirements for this load the amount of visitors for sure will damage the environment. As humans we temp to destroy everything we touch.

With out new technologies that could eliminate fossil fuel from ships the only way to satisfy the demand is by managing with tourism just on land. This represents a good option but a big disappointment for tourists that wants to discover the archipelago as a whole.

Any how a more elaborate energy study for 2020 and for 2030 has to be performed in order to establish the exact strategies for the future sustainability of the Galapagos islands.

Figure 6.1. P. Calle (2014) 2030 energy consumption projection, based on population and tourism growth rate stabilize by the municipality of Puerto Ayora.
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ENERGY STRATEGIES TOWARDS A SUSTAINABLE SCENARIO

**REDUCED DEMAND**

- 45% HYBRID ENGINES AND REDUCED TRAVELING PATH 300,000 GJ/yr.
- 5% SHORE ELECTRICITY 20,000 GJ/yr.
- 55% ELECTRIC BOATS 24,000 GJ/yr.
- 55% ELECTRIC VEHICLES 90,000 GJ/yr.
- 55% ELECTRICITY GENERATED FROM A RENEWABLE SOURCE 135,000 GJ/yr.
- 0% WATER HEATING 14,000 GJ/yr.

**REDUCED DEMAND 550,000 GJ/yr.**

The energy demand of Santa Cruz Island can be reduced from 1,200,000 GJ/yr to 550,000 GJ/yr. The most important intervention is to get rid of fuel electricity generation and to convert transportation into electric.

**PRODUCTION MEETING DEMAND 550,000 GJ/yr.**

Using heat for heat, biogas for fuel and electricity for electricity. For a more efficient system cost could achieve balance.

**ARCHIPELAGO**
- BIOGAS 180,000 GJ/yr
  FROM ORGANIC WASTE
  FROM OTHER ISLANDS

**CATTLE MANURE**
- BIOGAS 105,000 GJ/yr
  ANAEROBIC BIOCONECTORS

**SEWAGE + URBAN BIOWASTE**
- BIOGAS 12,000 GJ/yr
  ANAEROBIC BIOCONECTORS

**AGRICULTURAL BIOMASS**
- 105,000 GJ/yr
  WOOD WASTE

**PRODUCE SUSTAINABLY**

- 23Kwh per person per day

**34,000 GJ/yr.**

**BALTRA WIND FARM**

- This island has a wind energy potential of 190,000 GJ/yr but just 30% is needed to help meet the demand 60,000 GJ/yr that occupies 1.5 km².

**BALTRA SOLAR PV FARM**

- Solar radiations: 6.14 kWh per day. With a designated area of 0.8 km² for a PV farm, Baltra could generate 100,000 GJ/yr.
- 6% is needed to meet the demand of 60,000 GJ/yr in an area of 50,000 m² (5 hectares).

**URBAN ROOFS**

- RSS BUILDINGS with a roof area of 180,000 m² from which 60% is assumed suitable for PV panels. Those panels could produce: 115,000 GJ/yr.

**RURAL ROOFS**

- One roof area are those buildings with a total roof area of 50,000 m², if solar PV panels are installed it could produce: 50,000 GJ/yr.

**85% of local consumption energy demand can be covered by photovoltaics solar PV panels and collectors.**

Pedro Calle (2014) MSC Building Technology Graduation Project TU Delft