Santa Cruz

Energy Strategies for a sustainable scenario

PEDRO CALLE

Main Mentor
Siebe Broersma
Second mentor:
Tillmann Klein
Galapagos

Location

Archipelago
Ecuador
18 main Islands
3 minor islands
107 islets
8000 km²
97% national park
2nd biggest maritime reserve
1600 m height volcano wolf
GALAPAGOS
Paradise
75% of food is imported
100% of goods are imported
100% fuel imported

99% fuel based energy
1% Renewable energy

GALAPAGOS
Economical model

Tourism

Nature

local businesses
GALAPAGOS
Problems

GOVERNMENT
Zero fossil fuel plan
Problem statement
- The Galapagos environment is in danger threatened by fossil fuels
- Their economy, overall life and nature depend on a sustainable way of development.
- The Ecuadorian government Zero Fossil Fuel plan failing

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?
CLIMATE - LANDSCAPE

"GARUA" Cloud band

Intra-Seasonal variability

Dry Lowlands

Dry highlands
Humid highlands
Soft boundary "transition" zone

Dry Lowlands
Humid highlands
Soft boundary "transition" zone

PREDOMINANT WIND DIRECTION

ANUAL AVERAGE

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec

- 0
- 5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45
- 50

Litoral
Arid
Transition
Humid
Actual Energy plan
Government

DEMAND

PRODUCTION
Wind farm  PV farm

built environment electricity

Locals transport
fuel cruisers transport turists
fuel planes transport turists

Transformation Fuel to energy

Energy Losses

Imported Biofuel
Toeklau-Santa Cruz

These islands are in the same latitude with similar climate conditions. They differ in the size and population Toeklau is about 10% of Santa Cruz in every sense if we consider habitable area. The big difference occurs within tourism where Santa Cruz hold 5000% more visitors. This project allows to believe that just relying on solar energy its possible and to scale 10 time don’t seem crazy.
SANTA CRUZ
Demand 2013

**Transport**
- Gas station
- Airplane
- Car
- Ship
- CO2

**Built environment**

**residential**
- Light bulb
- Oven
- Water heater
- CO2

**non-residential**
- Water faucet
- Toilet
- CO2
**Cooling Load**

**Cooling Demand**

- Average temp in cold 21°C months
- Average energy demand in cold months 1700 mWh
- Assumption: 1700 mWh per month energy without cooling.
- Total year electric energy consumption 26173 mWh
- Year consumption without cooling load 20400 mWh
- So year Cooling demand is 5773 mWh

\[
\text{COP} = \frac{42000 \text{ GJ}}{1150000 \text{ lit.}} = 3.65
\]

\[
16500 \text{ GJ} \times 60\% = 9900 \text{ GJ}
\]

\[
49500 \text{ GJ} = 3.2 \text{ units of heat energy are removed from indoors per unit of work energy used to run the air conditioner (COP).}
\]
SANTA CRUZ

Demand per person per day

- 37.0 kWh/p.d
- 9.5 kWh/p.d
- 24.6 kWh/p.d
- 1.2 kWh/p.d
- 2.6 kWh/p.d
- 0.7 kWh/p.d
- 2.6 kWh/p.d
- 0.5 kWh/p.d
- 0.7 kWh/p.d
- 2.6 kWh/p.d
- 0.1 kWh/p.d

1Kg

Residents + tourists

+125 kWh/p.d British

78 kWh/p.d

125 kWh/p.d British

23.5 kWh/p.d

82 kWh/p.d British

17 kWh/p.d

Residents (10% planes and ships)

Residents (no planes no ships)
The Galapagueno
SANTA CRUZ

Rural or agricultural Land

Energy Potentials Areas

Baltra

Layered use of space for more efficiency

Sustainable energy sources

Energy = Space

Urban land or Puerto Ayora

9500 GJ
Baltra
Solar radiation 6.14 kWh/m² per day
Efficiency pv 15%:
0.92 kwh/m² per day
336 KWh/m² per year
1.2 GJ/m² per year
Effective area (30%) 3300000 m²
Total energy generation = 4 000 000 GJ per year

Rural
Solar radiation 4.38 kWh/m² per day
Efficiency pv 15%:
0.65 kwh/m² per day
237 KWh/m² per year
0.850 GJ/m² per year
Rural area considering urban expansion zone
8 km² with a limitation of 99% = 80,000 m²
Total energy generation = 52,000 GJ per year

Urban
Solar radiation: 5.16 kWh/m² a\per day
Efficiency pv 15%:
0.77 kwh/m² per day
282 kwh/m² per year
1.01 GJ/m² per year
Total Roof area 190000 m²
Limitated roof area (60%) = 115000 m²
Total energy generation = 116000 GJ per year
to propose solutions in coherent sustainable way

New stepped Strategy

energy
water
waste

energy

waste

3.2 units of heat energy are removed from indoors per unit of work energy used to run the air conditioner (COP).
Sustainable scenario

1. REDUCE

2. REUSE

3. PRODUCE

ENERGY DEMAND,

WASTE = ENERGY

SUSTAINABLE ENERGY POTENTIAL
**NEW STEPPED STRATEGY**

**REDUCE demand**

**DEMAND** 2,115,000 GJ

- **Gas** 79,000 GJ
- **Build environment** 230,000 GJ
- **Fuel Locals transport** 5,000 GJ
- **Fuel cruisers transport turists** 615,000 GJ
- **Fuel planes transport turists** 900,000 GJ
### New Stepped Strategy

#### Reduce demand

<table>
<thead>
<tr>
<th>Source</th>
<th>Use</th>
<th>Demand</th>
<th>Gas</th>
<th>Build Environment</th>
<th>Fuel Locals Transport</th>
<th>Fuel Cruisers Transport Turists</th>
<th>Fuel Planes Transport Turists</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>230,000 GJ</td>
<td>220,000 GJ</td>
<td>60,000 GJ</td>
<td>615,000 GJ</td>
<td>900,000 GJ</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>90,000 GJ</td>
<td>60,000 GJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>615,000 GJ</td>
<td>60,000 GJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>220,000 GJ</td>
<td>60,000 GJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60,000 GJ</td>
<td>60,000 GJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airplanes</td>
<td>fuel</td>
<td></td>
<td>2115,000 GJ</td>
<td>900,000 GJ</td>
<td>615,000 GJ</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Demand** 2,115,000 GJ

**Actual Demand** 1,215,000 GJ

Airplanes are fuel in continent.
NEW STEPPED STRATEGY

**REDUCE demand**

### DEMAND
- **230,000 GJ**
  - **80,000 GJ**
  - **150,000 GJ**

### BUILD
- **230,000 GJ**
  - **80,000 GJ**
  - **150,000 GJ**

### FUEL LOCALS TRANSPORT
- **220,000 GJ**
  - **60,000 GJ**

### FUEL CRUISERS TRANSPORT TOURISTS
- **615,000 GJ**

### FUEL PLANES TRANSPORT TOURISTS
- **900,000 GJ**

**DEMAND**
- **2,115,000 GJ**

**ACTUAL DEMAND**
- **1,215,000 GJ**

**BOTTOM UP**
- **1,195,000 GJ**

- **Airplanes are fuel in continent**
- **Behavior and Knowledge**

**Better living conditions**

**-1.7%**
**NEW STEPPED STRATEGY**

**REDUCE demand**

- **Gas**
  - **Build environment**
    - **Fuel Locals transport**
      - **fuel cruisers transport turists**
        - **fuel planes transport turists**

**DEMAND**

- **2.115.000 GJ**
- **1.215.000 GJ**
- **1.195.000 GJ**
- **700.000 GJ**

**ACTUAL DEMAND**

- **1.195.000 GJ**
- **700.000 GJ**

**BOTTOM UP**

- **improving building and homes**
- **direct heat and electricity 100% electric appliances Transportation electric and hybrid engines**

**COMBINATION**

- **Better living conditions**
  - **100%**
  - **-1.7%**
  - **-0 %**
  - **-42 %**
**NEW STEPPED STRATEGY**

**REDUCE demand**

### ACTUAL DEMAND

- **DEMAND 2,115,000 GJ**
  - Gas: 90,000 GJ
  - Build: 230,000 GJ
  - Fuel: 200,000 GJ
  - Transport: 615,000 GJ
  - Fuel planes: 900,000 GJ

- **DEMAND 1,215,000 GJ**
  - Gas: 90,000 GJ
  - Build: 230,000 GJ
  - Fuel: 200,000 GJ
  - Transport: 615,000 GJ
  - Fuel planes: 900,000 GJ

- **DEMAND 1,195,000 GJ**
  - Gas: 90,000 GJ
  - Build: 230,000 GJ
  - Fuel: 200,000 GJ
  - Transport: 615,000 GJ
  - Fuel planes: 900,000 GJ

- **DEMAND 700,000 GJ**
  - Gas: 90,000 GJ
  - Build: 230,000 GJ
  - Fuel: 200,000 GJ
  - Transport: 615,000 GJ
  - Fuel planes: 900,000 GJ

- **DEMAND 545,000 GJ**
  - Gas: 90,000 GJ
  - Build: 230,000 GJ
  - Fuel: 200,000 GJ
  - Transport: 615,000 GJ
  - Fuel planes: 900,000 GJ

### TOP DOWN

- Better public transport
- Local services
- Shorter cruisers paths
- Shore energy supply

### BOTTOM UP

- Better living conditions
  - -1.7%
- Better living conditions
  - -0%
- -42%
NEW STEPPED STRATEGY

REUSE waste

Waste = Energy

Urban: 3 km²
Rural: 114 km²

Electricity  BIOGAS
NEW STEPPED STRATEGY

REUSE waste

Waste = Energy

Urban

- 57,000 m³ rain
- 3,000 tons non-recycl.
- 2,000 tons organic
- 600,000 m³ sewage

3 km²

Rural

- 60,000 tons crops and woody waste
- 12,000 tons manure

114 km²

680,000 tons waste

Electricity

BIOGAS
NEW STEPPED STRATEGY

REUSE waste

Waste = Energy

Urban

- 90 GJ
- 57,000 m³ rain
- 3,000 tons non-recycl.
- 2,000 tons organic
- 3 km²

Rural

- 114 km²
- 113,000 GJ sewage
- 60,000 tons crops and woody waste
- 12,000 tons manure
- 680,000 tons waste

Energy

- 225,000 GJ/yr
- 200,000 GJ/yr

Electricity

- 5400 GJ
- 100,000 GJ
- 108,000 GJ

BIOGAS

- 5700 GJ
- 11,300 GJ
NEW STEPPED STRATEGY

PRODUCE sustainably

AREA NOT PART OF NATIONAL PARK

Urban: 3 km²
Agricultural Zone: 114 km²
Baltra: 23 km²
NEW STEPPED STRATEGY

PRODUCE sustainably

BOTTOM UP
- 1'000.000 GJ
- 135,000 GJ
- 108,000 GJ
- 100,000 GJ
- 52,000 GJ

COMBINATION
- 1'000.000 GJ
- 158,000 GJ
- 108,000 GJ
- 100,000 GJ
- 52,000 GJ

TOP DOWN
- 1'000.000 GJ
- 135,000 GJ

ENVIROMENTAL LIMITATIONS
- 1'560,000 GJ
- 116,000 GJ
- 52,000 GJ
- 11,300 GJ
- 5,400 GJ

THEORETICAL PRODUCTION
- 1'720,000 GJ
- 116,000 GJ
- 11,300 GJ
- 5,400 GJ

AREA NOT PART OF NATIONAL PARK
- Urban: 3 km²
- Agricultural Zone: 114 km²
- Baltra: 23 km²
Potential energy storage

Off-grid Rules of thumb for storage: 3 days zero energy
3 days 0% energy = 4 days 25% energy = 6 days 50%

Electric energy daily demand: 680 GJ
3 days demand: 2,000 GJ

Energy storage capacity 2,000 GJ

- Standard batteries
  - 10 m³ = 2.7 GJ
  - 7400 m³ = 2,000 GJ

- Nas batteries
  - 10 m³ = 8 GJ
  - 2500 m³ = 2000 GJ

- 550 cars 20 kWh battery = 11 MWh = 39 GJ
- 1000 scooters 1.2 kWh battery = 1.2 MWh = 4 GJ
- 35 buses 85 kWh battery = 2.9 MWh = 10 GJ
- 55 buses 85 kWh battery = 4.6 MWh = 16 GJ
  - total = 70 GJ

- 10 m³ Total = 2.4 GJ
  - 8000 m³ = 2000 GJ

- h 10 m = 30,000,000 m³ = 2000 GJ
- h 100 m = 3,000,000 m³ = 2000 GJ
- h 200 m = 1,500,000 m³ = 2000 GJ

- h=200m
Scenarios

- **DIAGNOSTIC**
  - Context
  - Climate
  - Energy Situation
  - Energy Demand
  - Energy potentials

- **REDUCE**
  - Demand

- **REUSE**
  - Waste = Energy

- **PRODUCE**
  - Renewable Sources
  - Sustainably

- **PROPOSE**
  - Sustainable scenarios

**to propose solutions in coherent sustainable way**
People + government

<table>
<thead>
<tr>
<th>Component</th>
<th>Bottom Up</th>
<th>Combination</th>
<th>Top Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>160,000 GJ</td>
<td>72,000 GJ</td>
<td>20,000 GJ</td>
</tr>
<tr>
<td>Electricity</td>
<td>110,000 GJ</td>
<td>19,000 GJ</td>
<td>20,000 GJ</td>
</tr>
<tr>
<td>Electric transport</td>
<td>105,000 GJ</td>
<td>120,000 GJ</td>
<td>60,000 GJ</td>
</tr>
<tr>
<td>Shore supply</td>
<td>120,000 GJ</td>
<td>120,000 GJ</td>
<td></td>
</tr>
<tr>
<td>Santa Cruz</td>
<td>60,000 GJ</td>
<td>60,000 GJ</td>
<td></td>
</tr>
<tr>
<td>Other islands</td>
<td>60,000 GJ</td>
<td>60,000 GJ</td>
<td></td>
</tr>
</tbody>
</table>

**Deficit** 180,000 GJ

Bio fuel

**Demand** 545,000 GJ

**Energy Potential** 550,000 GJ

**Fuel Planes**

**Fuel Cruisers**

**Transport Tourists**

**Collector**

**PV**

**Biogas**

**Wind**

**Biomass**

**Self-sufficiency**

**Penetration**

**Participation**

**Storage**

**Waste=Energy**

**Environmental Impact**

**Feasibility**
Ultimate Selfsufficiency

**Deficit**
- 180,000 GJ
- Bio fuel

**Demand**
- 545,000 GJ

**Energy Potential**
- 550,000 GJ

**Combination**
- Heat: 18,000 GJ
- Electricity: 135,000 GJ
- Electric transport: 72,000 GJ
- Shore supply: 19,000 GJ
- Fuel cruisers: 300,000 GJ
- Fuel planes: 855,000 GJ
- 50% efficiency, 250 GJ loses

**Bottom Up**
- 18,000 GJ
- 116,000 GJ
- 105,000 GJ
- 58,000 GJ
- 120,000 GJ
- 60,000 GJ
- 60,000 GJ
- 50,000 GJ
- 34,000 GJ

**Top Down**
- 180,000 GJ
- 20,000 GJ
- Shore supply
- Power to gas / fuel cells

**Energy Network**

**Self sufficiency**
- participation
- storage
- waste=energy
- environmental impact
- feasibility
SANTA CRUZ

Energy generation Master Plan

**Biogas**
- 108,000 GJ

**Electricity**
- 100,000 GJ
- 52,000 GJ

**Solar PV**
- 116,000 GJ
- 90%
- 10%

**Solar Heat**
- 34,000 GJ
- 10%

**Electricity from Waste**
- 5,400 GJ

**Electricity from Biogas**
- 11,300 GJ
- 90%
- 116,000 GJ

**Electricity from Solar PV**
- 158,000 GJ
- 52,000 GJ

**Electricity from Wind**
- 60,000 GJ

**Electricity from Solar PV**
- 60,000 GJ

**Biogas from Waste**
- 180,000 GJ
 Intervention master Plan

- Wind farm area
- 2500 GJ/yr turbine
- Solar farm area
- Pv panels 60,000 m²
- 1GJ/m²/yr
- Cruisers port
- Biodiesel fuel station
- Shore energy supply platform
- Airport Track
- Roads
- Airport Terminal
- Electric ferry

Wind energy: 60,000 GJ
Solar PV: 60,000 GJ
Bio fuel: 180,000 GJ

2500 GJ/yr turbine

Pv panels 60,000 m²

1GJ/m²/yr

Shore energy supply platform

Electric ferry

Airport Terminal

Roads

Airport Track

Cruisers port

Biodiesel fuel station

Pv panels 60,000 m²

1GJ/m²/yr

Wind farm area

Solar farm area
Service roads for waste collection

50,000 m²

Roof PV panels

Bio digester

Compressed biogas plant

Bio gas 100,000 GJ

Bio mass 108,000 GJ

Rural land intervention master plan

Agriculture

Timber

Crops

Cattle

Urban
THE GALAPAGOS

Intervention Cruisers
fueling Plan

- Bio gas stations
- Shore electric supply
- Cruisers track
CONCLUSIONS

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

-Methodology

-Research

-Energy.

-Participation

-Scenarios

-Master plan

-Future

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy (GJ/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>0</td>
</tr>
<tr>
<td>2020</td>
<td>400000</td>
</tr>
<tr>
<td>2030</td>
<td>1200000</td>
</tr>
</tbody>
</table>

- SUSTAINABLE ENERGY USE:
  - Ships
  - Build environment
  - Cars and boats

BALTRA ISLAND
BELLAVISTA
SANTAROSA
PUERTO AYORA
The energy demand of Santa Cruz Island can be reduced 50% 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.

Santa Cruz generates 100% of their energy by imported fossil fuels. 4 diesel generators consume more than 6,000,000 liters to produce electricity. Furthermore, 2,800,000 m³ of gas are used for cooking. But the most consuming sector is transportation with 25,000,000 liters of fuel used mostly in cruisers ships (60%).

Anyway, the energy consumption in the island is low compared with the European demand of 1.25 KWh per person per day times five more.

Step 1: Hybrid engines and reduced traveling paths.

-45% reduction.

-5% reduction.

-55% reduction.

-55% reduction.

0% reduction.

Step 2: Water heating.

14,000 GJ/yr.

Step 3: Solar PV 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.

Step 4: Urban roofs.

Solar radiation: 6.14 kWh per day. With a designated area of 0.8 km² for a PV Farm, Baltra could generate 1,000,000 GJ/yr. 6% is needed to meet the demand, a total of 60,000 GJ in an area of 50,000 m² (5 hectares).

Step 5: Rural roofs.

In the rural area there are 700 buildings with a total roof area of 50,000 m², if solar PV panels are installed, it could produce 55,000 GJ/yr.

Using heat for heat, biofuel for fuel and electricity for electricity for a more efficient system could achieve balance.

The big solar energy potential of Santa Cruz could produce a lot more electricity and heat than is required, but the dependence to fuel into the maritime transportation sector imitates the island self-sufficiency. Biogas production can just meet the reduced fuel demand, and why reusing waste as energy is such an important input. Without biogas, the cruisers fleet fuel demand could not be met. Furthermore waste reused as energy helps resolve waste management creating a sustainability.

WASTE = ENERGY

85% of built environment energy demand can be covered by 60% of roof solar PV panels and collectors.

The energy produced in Santa Cruz is enough to cover 230 buildings.

PRODUCTION MEETING DEMAND 550,000 GJ/yr.

Using heat for heat, biofuel for fuel and electricity for electricity for a more efficient system could achieve balance.

The big solar energy potential of Santa Cruz could produce a lot more electricity and heat than is required, but the dependence to fuel into the maritime transportation sector imitates the island self-sufficiency. Biogas production can just meet the reduced fuel demand, and why reusing waste as energy is such an important input. Without biogas, the cruisers fleet fuel demand could not be met. Furthermore waste reused as energy helps resolve waste management creating a sustainability.

WASTE = ENERGY

85% of built environment energy demand can be covered by 60% of roof solar PV panels and collectors.

The energy produced in Santa Cruz is enough to cover 230 buildings.