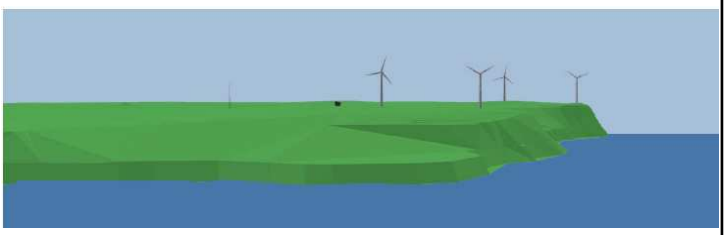
Operation Modes – San Cristóbal and Santa Cruz/Baltra (Galápagos Islands)

A comparison



Dipl.-Ing.
Benjamin Jargstorf
Factor 4 Energy Projects

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- Introduction
- Galápagos
- San Cristóbal
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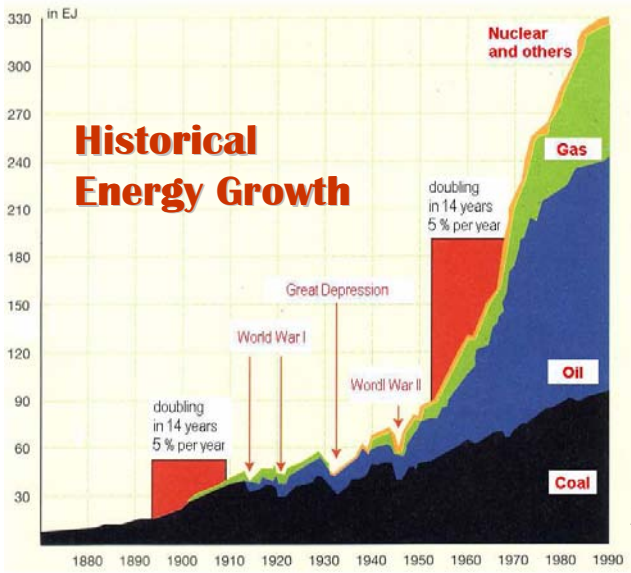
- Summary / Outlook

Factor 4 - World-wide Experiences

Introduction

Introduction



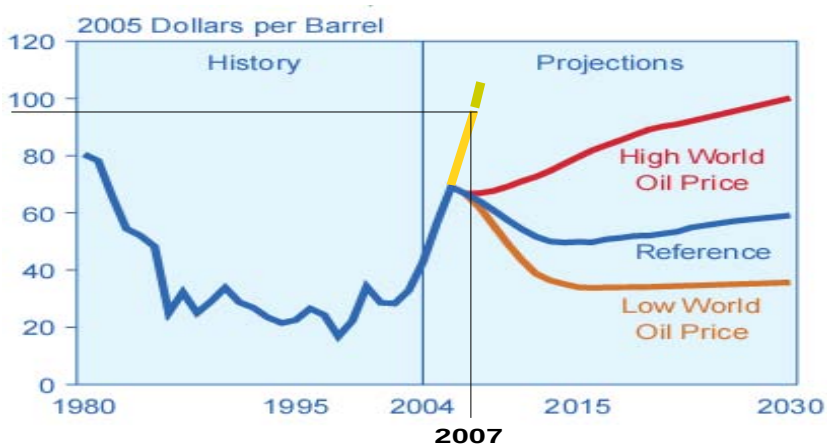
EJ:
1 Exajoule
= 10^{18} J =
227.8 mill.
MWh

Introduction

Oil Price (in US$ per Barrel) ...

Introduction

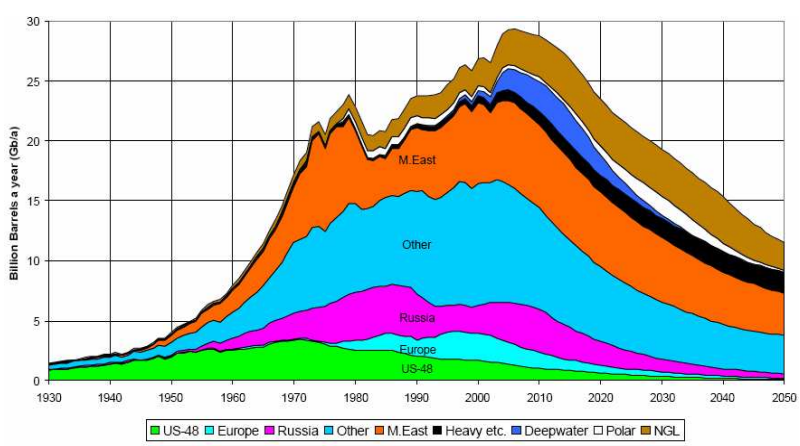
... and the Prediction of the Experts



Source: **Energy Information Agency of the Department of Energy, US Government**, "World Energy Outlook 2007", May 2007

Introduction

Peak Oil Production: today!



Source: ASPO – Association for the Study of Peak Oil (http //www.peakoil.net/)

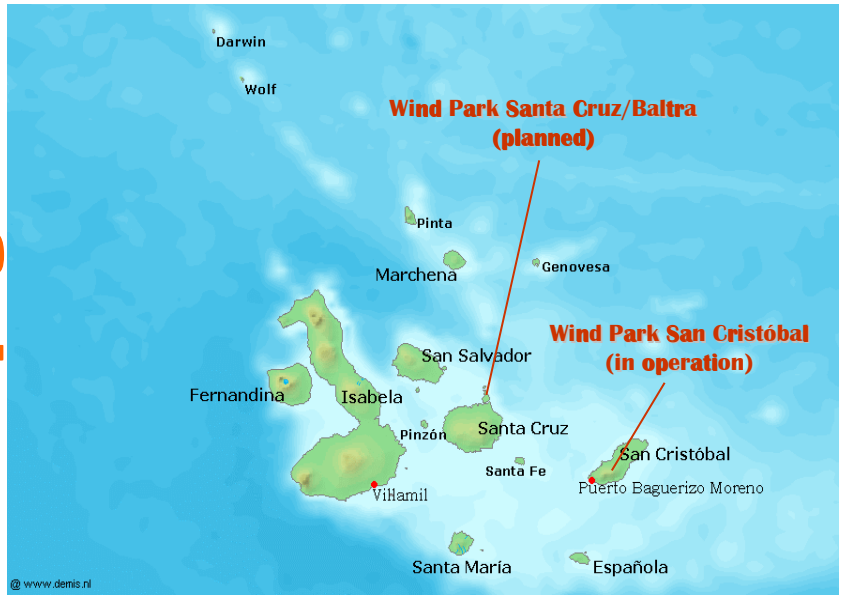
Galápagos

Galápagos

Overview

- archipelago 1,000 km to the West of the Ecuadorian mainland
- 20,000 inhabitants – ca. 180,000 tourists p.a.
- populated islands Santa Cruz and San Cristóbal
- electricity by diesel generators
- annual diesel fuel consumption
  - Santa Cruz ca. 5.3 million litres (1,400,000 gal)
  - San Cristóbal ca. 2.3 million litres (600,000 gal)
- in September 2007 commissioning of a wind/diesel project in San Cristóbal
- wind/diesel system for Santa Cruz/Baltra in 2009

Galápagos



San Cristóbal

San Cristóbal

Wind/Diesel System

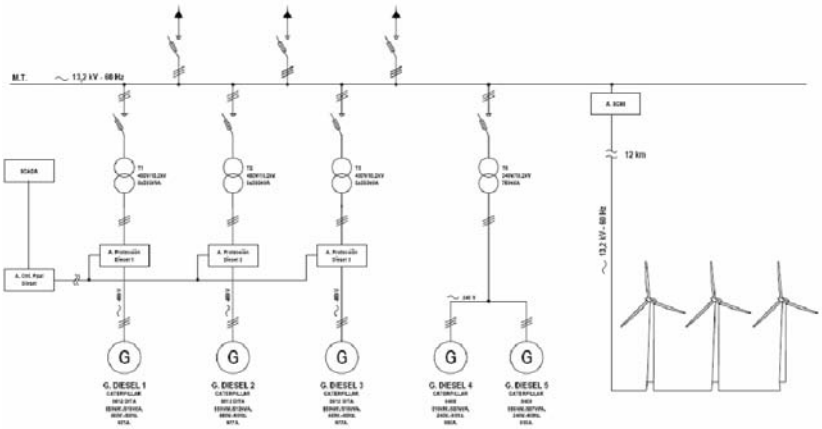
- type: ultra high-penetration
- designed by MADE, based on a cooperation with Sevilla University, Spain since 2003
- implemented by e8 - non-profit organization consisting of ten leading electric utility companies
- 3 wind turbines MADE AE 59 – 800 kW each
- grid load data:
  - minimum load – 600 kW
  - maximum load – 1,700 kW
- design criteria: diesel always on, no storage, supervisory control keeps minimum diesel load

San Cristóbal

Installation

San Cristóbal

Single Line Diagram



San Cristóbal

Main Components

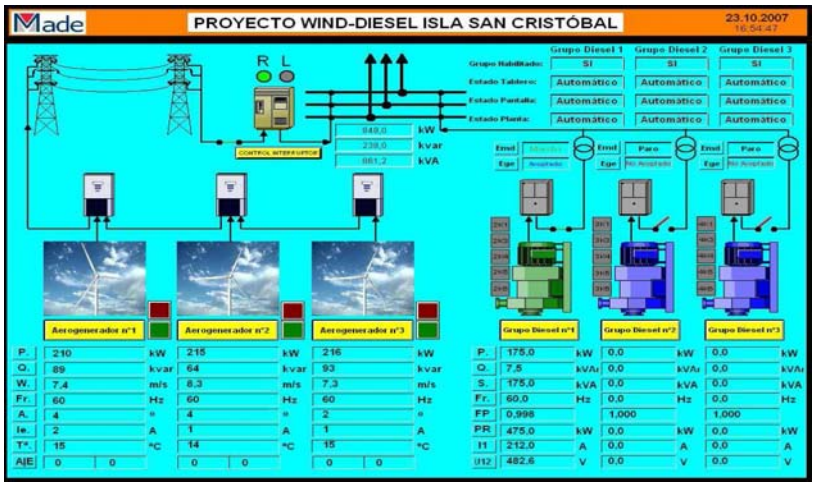
diesel generator protection

communication box

supervisory control and measuring unit

San Cristóbal

SCADA – Power Penetration 80 %



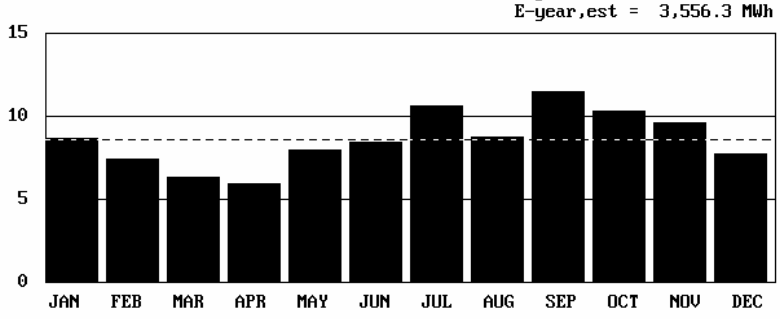
San Cristóbal

Wind Resources – V_{annual} = 8.4 m/s

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
Emonth	309	237	149	147	263	302	412	324	457	381	375	248	296.4 MWh
V-month	8.5	7.3	6.2	5.8	7.9	8.3	10.5	8.6	11.3	10.1	9.4	7.6	8.4 m/s
Weibull	3.8	2.8	2.5	2.2	3.1	3.4	3.6	3.5	3.5	2.9	3.6	2.8	2.70 {k}

MEAN MONTHLY WIND SPEED Vmonth in m/s

V-year = 8.38 m/s
E-year,est = 3,556.3 MWh



W I N D P L O T Cristobal Galapagos 50m * Anemometer * MADE AE59 800kW

San Cristóbal

Design Data – Wind Park Efficiency

theoretical Production per Turbine		3,350	MWh/a
Losses (Wind Data Insecurity, Park efficieny, electrical)	20%	670	MWh/a
realistic Production per Turbine		2,680	MWh/a
Production of Wind Park (three units)		**8,040**	**MWh/a**
Demand in the San Cristóbal Grid		6,800	MWh/a
of which to come from the Wind Park	50%	3,400	MWh/a
Wind Production to be curtailed (pitched away)		**4,640**	**MWh/a**
Energy Efficiency of the Wind Park		**42.3**	**%**

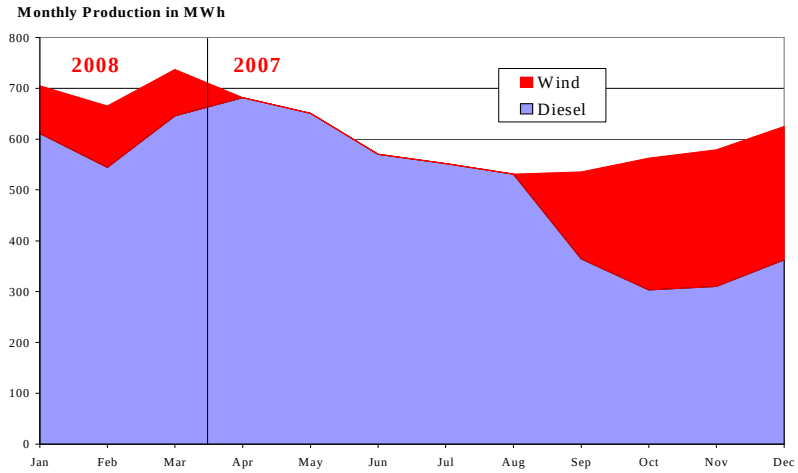
San Cristóbal

Penetration Rate - Projection

AÑO	DEMANDA (kWh)	Energía eólica para cubrir la demanda (kWh)	% Desplazamiento diesel
2008	7,981,087	4,126,164	52%
2013	10,186,114	4,887,240	48%
2018	11,808,498	5,375,724	46%
2023	13,689,286	5,932,941	43%
2028	15,869,634	6,626,638	42%

San Cristóbal

Production 2007/2008)



San Cristóbal

First Production Results (2007)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Diesel	697	655	681	682	651	571	552	531	364	304	310	362	**6,360**
Wind									172	259	269	263	**962**
Total	697	655	681	682	651	571	552	531	536	563	579	625	**7,322**
Wind Penetration									32 %	**46 %**	**46 %**	**42 %**	**45 %**
Fuel Efficiency	11.61	11.93	11.60	11.58	11.57	11.01	11.20	11.12	9.16	9.03	9.72	9.36	kWh per gal
spec. Consumption	0.326	0.317	0.326	0.326	0.327	0.343	0.338	0.340	0.413	0.419	0.389	0.404	litre/kWh
Effective Fuel Savings through Wind Energy									15 %	**32 %**	**37 %**	**29 %**	**33 %**

San Cristóbal

Interpretation of Results (2007)

- in the first 3 months: 45 % wind energy penetration
- however, specific fuel consumption in the diesels increased from 0.33 to 0.4 litres/kWh
- diesel generation efficiency went down from 11.45 to 9.31 kWh per gallon
- effective fuel savings therefore only 33 %

additionally:

- higher maintenance costs, shorter life time of diesels expected
- several complete black-outs in automatic mode

San Cristóbal

Current Situation

- customer (utility) disappointed/unhappy
  - island-wide black outs (10 in 3 months)
  - has IPP contract, pays for 45 %, but only gets 33 %
- today: no automatic operation allowed – manual operation with constantly 2 diesels in parallel
- specific fuel consumption now even higher
- advertised 50 % fuel savings unrealistic
- once again, not a good advertisement for wind energy and/or wind/diesel

San Cristóbal

Summary – Lessons Learnt

- integrate end-user (utility) in the planning and implementation process
- (ultra-) high- penetration wind/diesel systems not reliable without energy storage
- don't base IPP contracts on delivered kWh from wind, but on effective fuel savings
- effective fuel savings of 30 % also possible with a well designed standard grid-parallel wind system
- far too much efforts for (relative) little effects
- don't install newly designed system at an extremely remote location – test at home first

Photo Montage

Santa Cruz/Baltra

Santa Cruz

Current Planning 1

- wind park with 2 – 3 MW installed capacity
- site selection extremely difficult: Santa Cruz mainly Galápagos National Park
- thus, sister island Baltra (currently with airport, fuel storage and harbour facilities) wind park site
- problem: planned installation costs doubled on account of 50 km overhead line between Puerto Ayora and Baltra
- 2008: 8 million US$ available in the Trust fund
- tender procedure for wind park to start in July 2008

Santa Cruz

Current Planning

- type:
  - high-penetration (phase 1)
  - wind/diesel (diesel-off mode, phase 2)
  - wind/diesel with large industrial battery (phase 3)
- 3 phases to limit technical and operational risks
- for phase 2 current diesel power plant in Puerto Ayora is moved to Baltra, close to the wind park
- target penetration 25 % phase 1, 50 % phase 2 and > 100 % in phase 3
- target:
  - no low-load operation of diesel generators
  - always sufficient spinning reserve to avoid black-outs

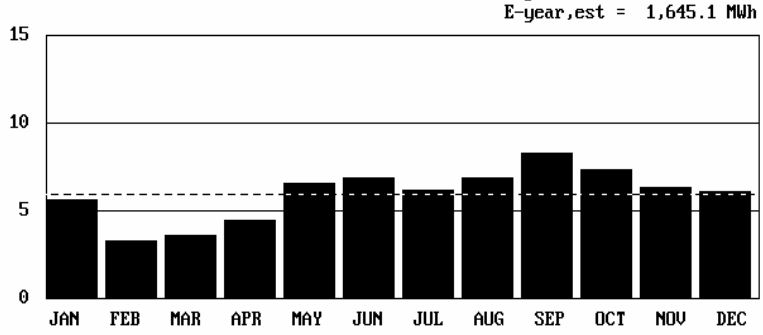
Santa Cruz

Wind Resource

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
Emonth	116	19	20	55	158	182	139	188	293	211	155	131	137.1 MWh
V-month	5.6	3.2	3.5	4.4	6.4	6.8	6.1	6.8	8.2	7.2	6.3	6.0	5.9 m/s
Weibull	2.7	2.5	3.0	2.9	3.8	4.5	3.2	3.7	4.8	4.0	3.3	3.3	2.68 {k}

MEAN MONTHLY WIND SPEED Vmonth in m/s

V-year = 5.88 m/s
E-year,est = 1,645.1 MWh



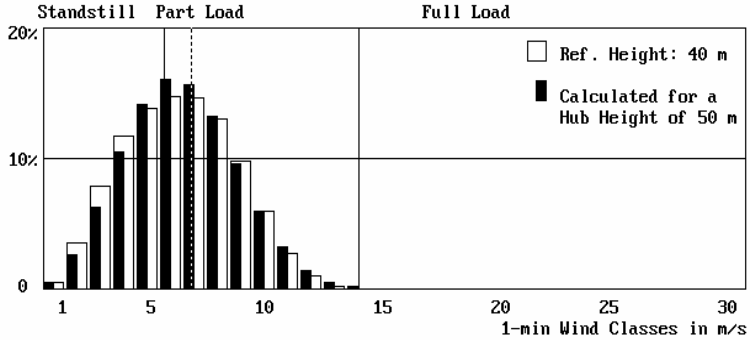
W I N D P L O T Baltra Galapagos 40m * Anemometer * MADE AE59 800kW

Santa Cruz

Output Prediction

V-year: 6.09 m/s
E-month: 146,671.2 kWh * E-year,est: 1,760.1 MWh * P-gen,mean: 203.7 kW
Standstill: 34.0 % * Part load: 65.3 % * Full Load: 0.8 % * CF-gen 25.5 %

FREQUENCY DISTRIBUTION f(v) in % (k = 2.80; c = 6.87 m/s)



W I N D P L O T Baltra Galapagos 40m R: .03 H: 50 m MADE AE59 800kW

Expected Layout for Wind/Diesel System

Santa Cruz

- synchronous condenser (rotating phase shifter) to allow diesel-off mode
- dedicated short-term energy storage to bridge time to start additional diesel(s)
- long-term (battery) storage to reduce start-stop frequency of diesel generators
- phase 1 will be tendered with a request for a proposal of phase 2
- proposed technical concept for phase 2 will be part of evaluation
- installed capacity 2-3 MW, 8-10 MW, 25-30 MW

1st Phase – Key Data

Santa Cruz

	3 x 800	
Installed Power	2.4	MW
Production (theo.)	5,500	MWh/a
Production (eff.)	4,300	MWh/a
Electricity Demand	**18,000**	**MWh/a**
Excess Energy	1,200	MWh/a
	22 %	
Cap-Fac Wind Park	20 %	
Penetration Rate	**25 %**	
Fuel Savings	1,161,000	litres/a
	322,500	Gal/a
Investment Costs	4.84	mio US$
Spec. Fuel Savings	0.24	litres/US$
spec. Gener. Costs	**0.15**	**US$/kWh**

Santa Cruz

2nd Phase – Key Data

	8 x 800	
Installed Power	6.4	MW
Production (theo.)	14,000	MWh/a
Production (eff.)	12,000	MWh/a
Electricity Demand	**24,000**	**MWh/a**
Excess Energy	2,000	MWh/a
	14 %	
Cap-Fac Wind Park	21 %	
Penetration Rate	**50 %**	
Fuel Savings	3,240,000	litres/a
	900,000	Gal/a
Investment Costs	10.00	mio US$
Spec. Fuel Savings	0.32	litres/US$
spec. Gener. Costs	**?**	**US$/kWh**

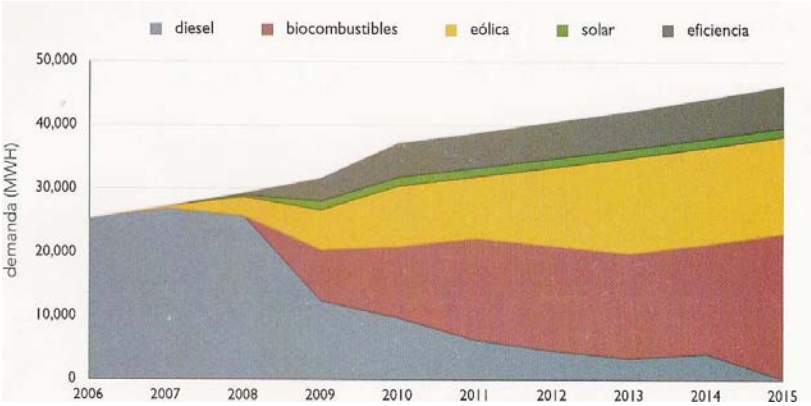
Santa Cruz

3rd Phase – Key Data

		40 x 800	
Wind	Installed Power	32	MW
Wind	Production (theo.)	68,000	MWh/a
Wind	Production (eff.)	68,000	MWh/a
Solar	Installed Power	20	MWp
Solar	Production (eff.)	30,000	MWh/a
	Electricity Demand	**24,000**	**MWh/a**
	Excess Energy	74,000	MWh/a
	to be used elswhere on the island		
	Cap-Fac Wind Park	24 %	
	Wind Penetration Rate	**283 %**	
	Fuel Savings from Wind	18,360,000	litres/a
	Fuel Savings from Solar	8,100,000	
	Total Savings	**26,460,000**	
		7,350,000	Gal/a
	Investment Costs	?	mio US$
	Spec. Fuel Savings	?	litres/US$
	spec. Gener. Costs	**?**	**US$/kWh**

Programa Cero Combustibles Fósiles

Santa Cruz



Source: Ministerio de Energía y Minas, "Cero Combustibles Fósiles en Galápagos", Proyecto Energías Renovables para Galápagos - ERGAL

Ample Space for Wind in Baltra

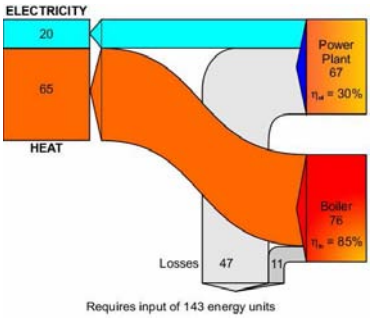
Santa Cruz

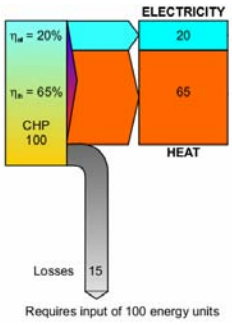
Santa Cruz

2nd Phase – New Diesel Power Station

Santa Cruz

New Diesel Power Station - Cogeneration





$$\eta_{separate} = \frac{85}{143} = 59.4\ \%$$

$$\eta_{cogeneration} = \frac{85}{100} = 85\ \%$$

Electric Scooters – Electric Boat

Santa Cruz

Electric Bicycle

Santa Cruz

CE-02605EA

Wheels: 24 inch I Battery: 24V/8AH NiMH GP or 24V 8.8AH Li-Ion Panasonic I Motor: 250W I Gears: 6 speed TX 50 Shimano I Thumb Shifter: TX 50 Shimano I Dual Pedal Assist/Throttle Control I Frame: Alloy I N.W/G.W: 23kg/30kg

Santa Cruz

Electric Scooter

CE-HS50QT-17

EEC Approval Number: E4*2002/24*0461*01 I
Wheels: 3.0-10 I Battery: 48V/38AH Silicon I Motor: 1500W I N.W/G.W 115kgs/136kgs

Santa Cruz

Electric Car (Citroen Berlingo)

Santa Cruz

Electric Outboard Motor (12 kW)

Summary

Summary

Comparison

	San Cristóbal	Santa Cruz
type	ultra high-penetration without storage	wind/diesel system with diesel-off mode
storage	none	a) short-term (flywheel?) b) long-term (battery)
implementation	one step	gradual, phase-wise approach, accompanied by intensive utility training
penetration	target ca. 50 % first 6 months 29.7 % real < 25 %	1st phase 25 % 2nd phase 50 % 3rd phase > 100 %

The End.

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