NEW AND RENEWABLE ENERGY SOURCES FOR SUSTAINABLE COMMUNITIES

by

M. G. Carvalho
L. Alves, A. Costa, N. Duic

VII Encontro Regional do Engenheiro
Angra do Heroísmo – Terceira – Açores
20 Julho 2002
CONTENTS OF THE PRESENTATION

- Characteristics of Sustainable Communities
- Types of Sustainable Communities
- Description of on-going projects for enhanced sustainability
- Conclusions
SUSTAINABLE COMMUNITIES

- Rio summit: Agenda 21
- EU White Paper for RES, Campaign for Take-off, ALTENER
- EU Green Paper on Security of Supply
- Kyoto Protocol
THE GOALS OF THE SUSTAINABLE COMMUNITY

- Integration of new technologies and concepts in socio-economic development
- Intensive use of RES
- Diversify energy sources
- Social and economic benefits
CHARACTERISTICS OF THE SOLUTIONS

- Competitive cost of NRET (when compared to conventional solutions)
- High percentage of NRES
- Decentralised generation
- Satisfy the needs of a community

→ INTEGRATION
Integration of NRES: Wind, Biomass, Small hydro, Geothermal, Distributed Generation, PV and solar heating, hydrogen, energy storage....

Rational use of energy (buildings, energy management, CHP...) is also important.
TYPES OF COMMUNITY

- Islands (small/medium)
- Isolated rural areas
- Non-isolate urban areas (blocks of buildings, neighbourhoods in residential areas, commercial / light industrial developments)
Islands
ISLANDS

- High economic dependence on imported energy sources – High energy costs

- Environmental fragility

- Seasonability of energetic, water and waste disposal needs - Tourism

- Small size of the local grids
Island projects
Metodology for the Evaluation of Renewable Energy Sources Potential
EVALUATION OF SOLAR POTENTIAL IN GIS

Clean sky
• Height
• Visibility
• Climatic zone
• Sun zenith
• Ground reflection
• Latitude

Spatial Model

Grid of global estimated global radiation with clean sky $G_h$

Typical day
Measurements of global radiation in meteorological stations

$K_p = \frac{G_p}{G_{hp}}$

Hourly maps of direct and diffuse radiation

(METHODOLOGY DEVELOPED BY INESC – PORTO)
MAP OF RENEWABLE RESOURCES - GEOTHERMAL

Temperatura Água (Superfície)

- 25.5
- 26
- 31
- 34
The potential for Clean Development Mechanism in Electricity Production
Regional GDP distribution for 3 economic scenarios, per island.
- Tourism sector
- Electrification rate
- Security of supply
ELECTRICITY SUPPLY

Baseline

30% wind

Combined cycle 30% wind

Business as usual economic scenario
Wind in all islands

Combined cycle only in Santiago

Business as usual economic scenarium

Medium CDM price scenarium – 15$/tCO₂
Renewable Energy Solutions for Islands
100% RES Island
PORTO SANTO
Madeira, Portugal
EQUIPMENT TO BE INSTALLED

PRESENT SITUATION
- 3.5 MW Diesel
- 3.4 MW Fuel Oil
- 1.1 MW Wind (4.4%)
- Peak Power – 5.6 MW
- Low Power – 2 MW
- Growth rate – 20%

SAVINGS
- 27 tCO₂/year

PILOT HYDROGEN SYSTEM
- 75 kW Electrolyser
- 300 kWh Storage
- 25 kW Fuel Cell

Cost: 830,000 € (33,000 €/kW)
H₂RES MODULES

WIND

SOLAR

LOAD

STORAGE
Hourly wind velocity data obtained
- Adjusted to the hub height
- Converted into hourly potential output

\[ v_z = v_{10} \left( \frac{z}{10} \right)^{0.14} \]

Example for VESTAS wind turbines, as installed on Porto Santo, Madeira, Portugal
H₂RES – SOLAR MODULE

- Hourly total radiation on horizontal surface obtained
- Adjusted to the inclined surface (RETSCREEN)
- Converted into hourly potential output by efficiency provided from supplier
H₂RES – LOAD MODULE

- Hourly load of power system obtained
- Limit to renewable intake
- Excess renewable rejected
Excess renewable taken to electrolyser
- If less than electrolyser capacity
- If hydrogen tank not full

The rest rejected – taken to desalination or other electricity dump
During peak hours (various definition) fuel cell is turned on using hydrogen stored until tank is empty.
Electricity delivered to power system
PORTO SANTO

- Population:
  5000 in winter ⇒ 20000 in summer
PORTO SANTO

- Power system (2000):
  - 13.8 MW thermal + 1.1 MW wind
  - 24.1 GWh thermal + 1.1 GWh wind
  - 5.6 MW peak, 2 MW base, 20% growth
Scenearia

1. Wind only
2. Wind as installed + solar

Up to 30% renewable at any time can be taken by power system

Excess to electrolyser

Fuel cell for peak shaving, optimised at 1.8% of electricity delivered
PEAK SHAVING SCENARIOS

The diagram illustrates the peak shaving scenarios for wind and solar power. The x-axis represents different energy sources: wind only and wind & solar. The y-axis represents power output in kW and energy in kWh.

- **Wind only**:
  - Wind: Higher kW but lower kWh compared to solar.
  - Solar: Lower kW and kWh.
  - Electrolyser, Fuel cell, Storage vessel: Low kW and kWh.

- **Wind & solar**:
  - Wind: Lower kW and kWh compared to wind only.
  - Solar: Higher kW and kWh compared to wind only.
  - Electrolyser, Fuel cell, Storage vessel: Similar to wind only.

Legend:
- Wind
- Solar
- Electrolyser
- Fuel cell
- Storage vessel
**PEAK SHAVING SCENARIOS**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Output (GWh)</th>
<th>Peak Serving Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind only</td>
<td></td>
<td>53%</td>
</tr>
<tr>
<td>Wind &amp; Solar</td>
<td></td>
<td>62%</td>
</tr>
</tbody>
</table>
100% RENEWABLE SCENARIAS

- Scenaria
  1. Wind only
  2. Wind + solar
  - Up to 100% renewable at any time can be taken by power system
  - Excess to electrolyser + desalination
  - Fuel cell to cover load when no renewable available
  - Optimised on no Diesel
100% RENEWABLE SCENARIOS

Wind only
- Wind: 25 MW
- Solar: 0.5 MW
- Electrolyser: 5 MW
- Fuel cell: 0.5 MW
- Storage vessel: 0.5 GWh

Wind & solar
- Wind: 22 MW
- Solar: 1.5 MW
- Electrolyser: 10 MW
- Fuel cell: 5 MW
- Storage vessel: 1.5 GWh
100% RENEWABLE SCENARIOS

<table>
<thead>
<tr>
<th></th>
<th>Wind only</th>
<th>Wind &amp; solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>solar output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wind output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Wind only</th>
<th>Wind &amp; solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>excess</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ren. taken</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Wind only</th>
<th>Wind &amp; solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>desalination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>electrolyser</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ren. taken</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Wind only</th>
<th>Wind &amp; solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>excess</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ren. taken</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Wind only</th>
<th>Wind &amp; solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>fuel cell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Wind only</th>
<th>Wind &amp; solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>fuel cell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>fuel cell serving time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind only</td>
</tr>
<tr>
<td>Wind &amp; solar</td>
</tr>
</tbody>
</table>
- For peak shaving wind & solar takes smaller storage and electrolyser
- For 100% renewable better wind only
A model for optimising integration of hydrogen storage with intermittent renewable energy sources (wind and solar) was devised.

Storage module can be upgraded to work with batteries or pump storage.

The model was applied to Porto Santo.

The results were intriguing.
AZORES ARCHIPELAGO
OBJECTIVES OF THE WORK

- To look at ways to increase the penetration of Renewable Energy Sources in Corvo and Graciosa Islands
- To test the potentiality of the developed H2RES model devoted to this kind of work.
- To build and fully model scenarios for the Corvo and Graciosa islands to increase security of supply, and reduce pollution, based on existing load and meteorological data and envisaging the following technologies: wind, solar PV, and batteries and hydrogen storage.
THE TARGET ISLANDS FOR THE CASE STUDIES
MG.1 - An already planned enlargement by the local utility (EDA) of the wind park up to 530 kW with an imposed wind energy limit of 30% of the “instant” load in the system.

MG.2 - The same conditions as in MG.1 + 2,000 m² of installed PV.

MG.3 - 30% RE contribution: wind power 1,200 kW, no restraints on the percentage of renewable energy with variable output placed into the grid.

MG.4 - 45% RE contribution to the annual consumption: 1,200 kW of wind power + 20000 m² of PV, in the same conditions as in MG.3.

MG.5 - 100% RE penetration: 9,000 kW of wind power + electrolyser with 8,900 kW power + 74 days hydrogen storage + fuel cell 1,600 kW power, allowing no renewable energy excess in the system.

MG.6 - 100% RE penetration: 5,000 kW of wind power + 80,000 m² of PV + electrolyser with 8,500 kW power + 31 days hydrogen storage + fuel cell 1,750 kW power, allowing no renewable energy excess in the system.
## RESULTS FOR GRACIOSA ISLAND

<table>
<thead>
<tr>
<th></th>
<th>MG. 1 (30% limit)</th>
<th>MG. 2 (MG.1 + 2000 M² PV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind (kW)</td>
<td>530</td>
<td>530</td>
</tr>
<tr>
<td>Solar (kWp)</td>
<td>0</td>
<td>170</td>
</tr>
<tr>
<td>Renewable (kW)</td>
<td>530</td>
<td>700</td>
</tr>
<tr>
<td></td>
<td>MG. 1 (30% limit)</td>
<td>MG. 2 (MG.1 + 2000 M² PV)</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Wind output (GWh)</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Solar output (GWh)</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>Ren. output (GWh)</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Ren. taken (GWh)</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Dump (GWh)</td>
<td>0.2</td>
<td>0.3</td>
</tr>
</tbody>
</table>
RESULTS FOR GRACIOSA ISLAND

MG.1 simulation, January 1
RESULTS FOR GRACIOSA ISLAND

MG.1 simulation, January 1. The source of electricity taken by the power system.
# RESULTS FOR GRACIOSA ISLAND

<table>
<thead>
<tr>
<th></th>
<th>MG. 3 (30% RE)</th>
<th>MG. 4 (MG. 3 + 45% RE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind (kW)</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>Solar (kWp)</td>
<td>-</td>
<td>1700</td>
</tr>
<tr>
<td>Renewable (kW)</td>
<td>1200</td>
<td>2900</td>
</tr>
<tr>
<td>Wind output (GWh)</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Solar output (GWh)</td>
<td>-</td>
<td>1.7</td>
</tr>
<tr>
<td>Ren. output (GWh)</td>
<td>2.8</td>
<td>4.5</td>
</tr>
<tr>
<td>Ren. taken (GWh)</td>
<td>2.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Dump (GWh)</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>MG. 5 (100% RE)</td>
<td>MG. 6 (100% RE)</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td><strong>Wind (kW)</strong></td>
<td>9000</td>
<td>5000</td>
</tr>
<tr>
<td><strong>Solar (kWp)</strong></td>
<td>-</td>
<td>6800</td>
</tr>
<tr>
<td><strong>Renewable (kW)</strong></td>
<td>9000</td>
<td>11800</td>
</tr>
<tr>
<td><strong>Electrolyser (kW)</strong></td>
<td>8900</td>
<td>8500</td>
</tr>
<tr>
<td><strong>Storage vessel (GWh)</strong></td>
<td>2.8</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>H2 storage (days)</strong></td>
<td>74</td>
<td>31</td>
</tr>
<tr>
<td><strong>Fuel cell (kW)</strong></td>
<td>1600</td>
<td>1750</td>
</tr>
</tbody>
</table>
## RESULTS FOR GRACIOSA ISLAND

<table>
<thead>
<tr>
<th></th>
<th>MG. 5 (100% RE)</th>
<th>MG. 6 (100% RE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind output (GWh)</td>
<td>22.4</td>
<td>11.8</td>
</tr>
<tr>
<td>Solar output (GWh)</td>
<td>-</td>
<td>6.9</td>
</tr>
<tr>
<td>Ren. output (GWh)</td>
<td>22.4</td>
<td>18.7</td>
</tr>
<tr>
<td>Ren. taken (GWh)</td>
<td>5.8</td>
<td>6.3</td>
</tr>
<tr>
<td>Electrolyser (GWh)</td>
<td>16.6</td>
<td>12.4</td>
</tr>
<tr>
<td>Dump (GWh)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel cell (GWh)</td>
<td>3.2</td>
<td>2.8</td>
</tr>
<tr>
<td>Fuel cell serving time (%)</td>
<td>45 %</td>
<td>40 %</td>
</tr>
</tbody>
</table>
MG.5 simulation, January 1, for this particular day more hydrogen is stored than retrieved
RESULTS FOR GRACIOSA ISLAND

MG.5 simulation, hydrogen stored during the year
CONCLUSIONS FOR GRACIOSA ISLAND

- The choice among the different scenarios depends mainly on comparing the costs of PV installation and of the hydrogen storage and on the available space.
- Due to actual high cost of PV, the scenario involving only wind seems to be preferable.
SCENARIOS FOR CORVO ISLAND

MC.1 – 60% re contribution to the annual consumption: 6,500 m² PV + 150 kW (18h) battery power, no restraints on the percentage of renewable energy with variable output placed into the grid.

MC.2 – 80% re contribution: 10,000 m² PV + 150 kW (36h) battery power, in the same conditions as MC.1.

MC.3 – 100% RE penetration: 25,000 m² PV + 170 kW (6 days) battery power

MC.4 – 75% RE contribution: 300 kW wind power, Pão de Açucar, + reversible hydro power plant (RHPP, 150 kW pump, 150 kW turbine, 2x2000 m³ reservoir).

MC.5 – 96% RE contribution: 300 kW wind power, Morra da Fonte, + RHPP (100 kW pump, 150 kW turbine, 2x2000 m³ reservoir).
MC.2 simulation, January 1, the source of electricity taken by the power system.
RESULTS FOR CORVO ISLAND

MC.4 Pão de Açucar

- Diesel: 25%
- Wind: 62%
- Hydro: 13%

MC.5 Morra da Fonte

- Wind: 76%
- Hydro: 14%
- Other: 10%
For a small energy system, very high intermittent RE penetration can only be reached by energy storage.

PV needs large area – might be unacceptable for Corvo.

Morra da Fonte – excellent location for wind turbine, possible to achieve 90% RE penetration with 300 kW wind – need for MT grid connection.

Pão de Açucar – needs more study – with 300 kW wind turbine hard to achieve more than 75% RE penetration
ISOLATED RURAL AREAS
ISOLATED RURAL AREAS

- Variable energy demands (tourism)
- Low degree of grid connection
- Protected environments
- Difficult accessibility for maintenance
- High installation costs due to remoteness
Integrating Self Supply Into End Use For Sustainable Tourism
INTERFACE NETWORK / RES

Grid

RES

Community Needs

$P_{RES} > \text{Consumption}$
Send to the grid

$P_{RES} < \text{Consumption}$
Taken from the grid
INTEGRATED WATER SYSTEM

RES
Solar PV
Wind PP

Sea water
Pump
Desalination
Fresh water
Storage
Hotel & Marina

End Use

Rain water catchment
Runoff collecting
Watershed management
Landscape Treatment
Roofs (impermeable surfaces)
Runoff water
Storage

Irrigation
Boats and car washing

Irrigation

Storage

Sewage
Treatment

Solid Sludge
Dried material
Agriculture Compost
Sun (to dry)
INTEGRATED MOBILITY PLAN

Solar Trolleys and Cars

Funchal

UNIX

Airport

GPL Taxis and Fuel Cell Bus

Green Hotel

Fuel Cell bikes
...to go for a ride

Taxi boat
...between Funchal and the Hotel
VIEW OF THE HOTEL AND MARINA
RURAL TOURISM IN ALENTEJO
(EDEN PROJECT)
RURAL TOURISM IN ALENTEJO

- Sun
- Solar heater
- Fuel cell
- Electrolysis
- Heat
- Electricity
- Hydrogen storage
- Alentejo
- Wind Turbine
- Wind
- Biogas
- Gasifier
- Biomass
- Photovoltaic
- Reforming
NON-ISOLATED URBAN AREAS
Non-Isolated (Urban) Areas

- Innovative approach for increasing RES awareness in Communities
- New opportunities for showcase projects involving industry and consumers
- Opportunities for residential communities
- Integrate the users of energy services in the production
MADEIRA TECNOPOLO
(EDEN PROJECT)
MADEIRA SCIENCE AND TECHNOLOGY PARK

- Sun
- Solar Heaters
- Photovoltaics
- Fuel cells
- Electrolysis
- Electricity
- Heat
- Hydrogen storage
- Reforming
- GPL
- Park Tower
TAGUS PARQUE
(EDEN PROJECT)
TAGUS PARQUE
TAGUS PARQUE

- Heat
- Electricity
- Hydrogen storage
- Electrolysis
- Reforming
- Fuel cells
- Photovoltaics
- GPL
- Sun
- Tagus Park
- Sun (P.V.)

- IPL
- Instituto Superior Técnico
- EU Flag
CONCLUSIONS

- Combine diverse (renewable) energy sources and technologies to resolve in an integrated way the problems of energy, water and residues
  ➔ **Integrated solutions**

- Better integration between supply and demand

- Island and remote regions as pioneers of zero emission society (e.g. Iceland), following the prophecy of Jules Verne in “L’Île mystérieuse”.
FINANCING INSTITUTIONS

- European Commission
  - DG Research
  - DG Tren

- Direcção Geral de Energia – Portugal
- Ministério da Ciência e Tecnologia - Portugal