
# *Energy Sustainability: Island of Hvar, Croatia*

***Final Report – April 19th, 2006***

***ZERIC - UNEP***

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# Outline

- Objective/Purpose
- Energy Model
- Energy Consumption
- Renewable Sources
- Energy Planning
- Favored Concept – Homer
- Business Model
- Conclusions

# Objective / Purpose

- ZERIC – Zero Emission Remote Island Challenge
- Recommend a sustainable energy system for the island of Hvar, Croatia
  - “reasonable level” of energy sustainability max. 0.5 €/kWh
  - Use renewable sources for energy production
  - Storage should be considered (biofuels, hydrogen, etc...)
  - Suggest business model

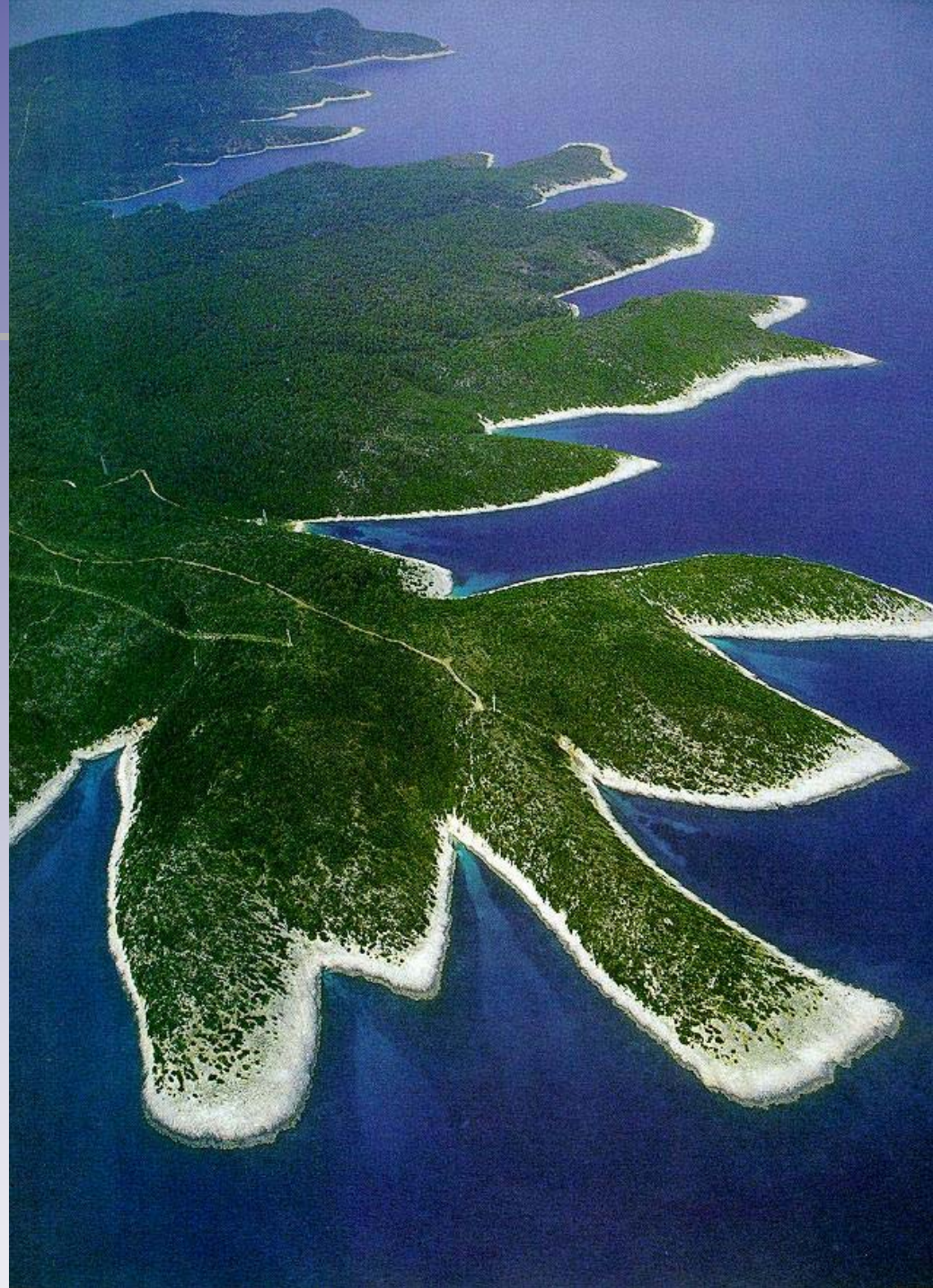
# Location


Hvar
Šćedro
Hvarski kanal
Neretvanski kanal


HUNGARY
Varaždin
Koprivnica
Zagreb
Bjelovar
Virovitica
Osijek
Karlovac
Sisak
Kutina
Slavonska Požega
Vukovar
Slavonska Brod
Vinkovci
Senj
Pula
Otočac
RAB
Adriatic Sea
BOSNIA & HERZEGOVINA
Zadar
Knin
Sarajevo
Sibenik
Sinj
Split
ITALY
Hvar
Dubrovnik
0 25 50 mi
0 25 50 km

# Statistics

- Total area of 297 $km^2$ with 270 km of sea coast
- Largest industry is tourism
- Population: 11 103
- Tourists (2005): 222 781
- Agriculture: Vineyards & Orchards
- Livestock: Sheep & Goats



# Energy Model

- Influential Factors: Tourism, Heating Season
- Thermal Energy Sources:
  - Electricity – Mainly for heating, hot water and cooking
  - Oil – Heating, hot water, other industrial and services use
  - Gas – Cooking
  - Wood – Heating and some cooking
- End-Users:
  - Locals – Usage in the home
  - Tourists – Usage in the lodging
  - Industry – Food processing & Chemical
  - Services – Restaurants, clubs, leisure facilities, pools etc...
- Transportation: Locals, Tourists, Farming & Waste

# Energy Consumption

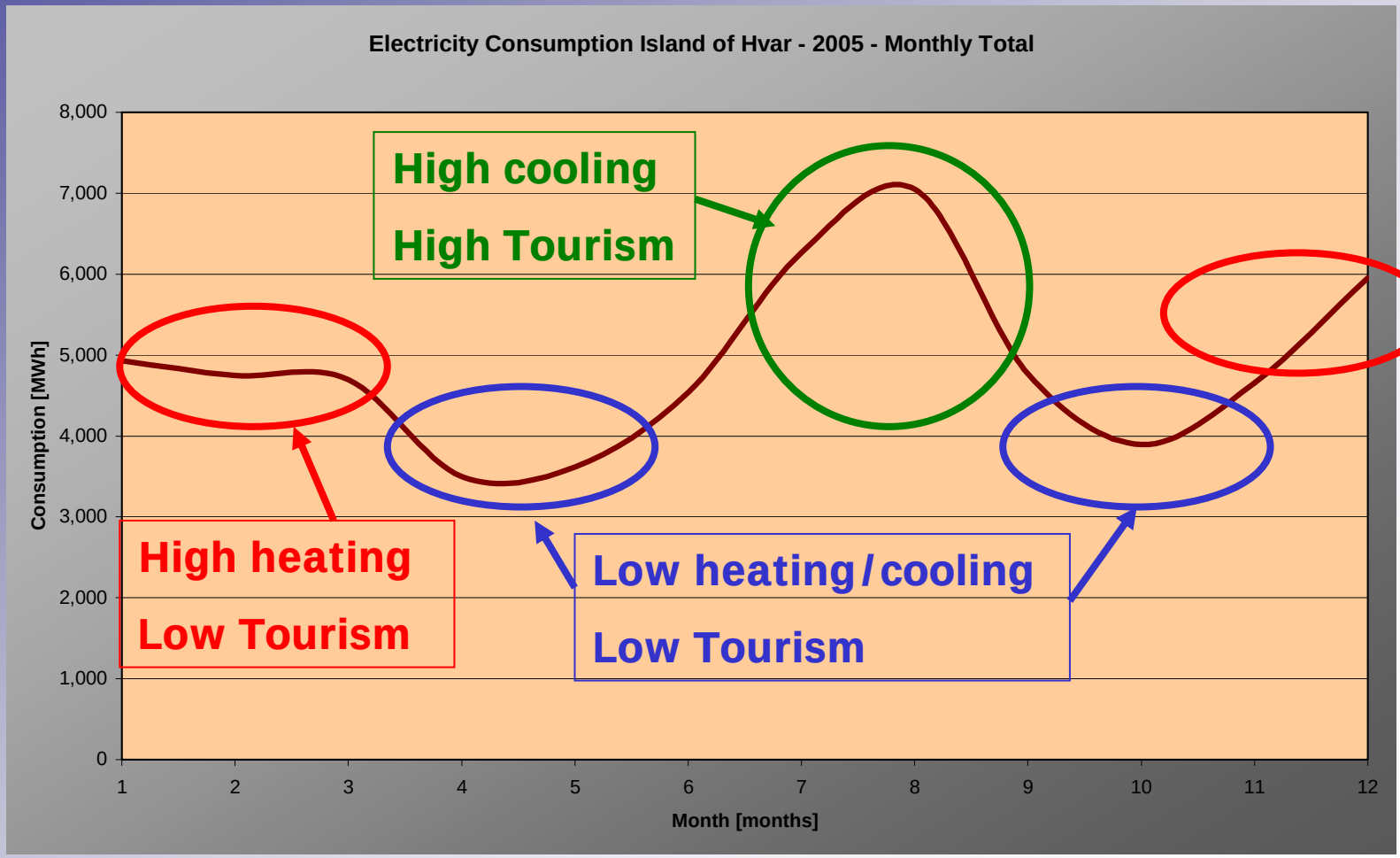
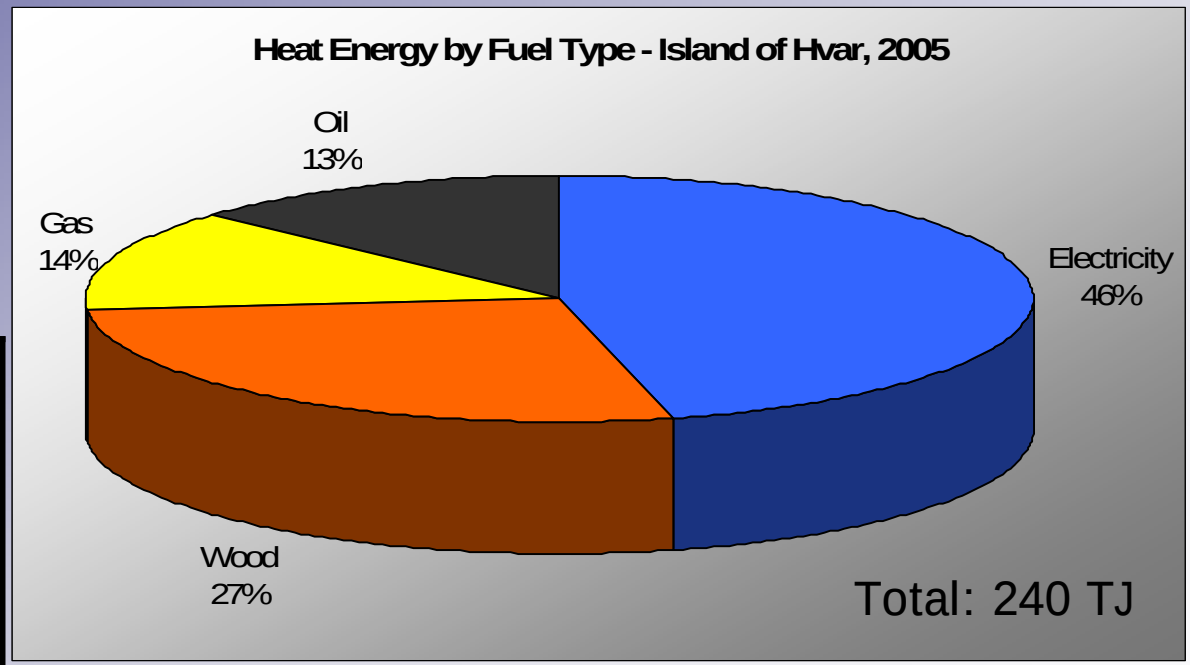



Figure: Hvar Electricity Consumption - Monthly Total, 2005

# Total Consumption

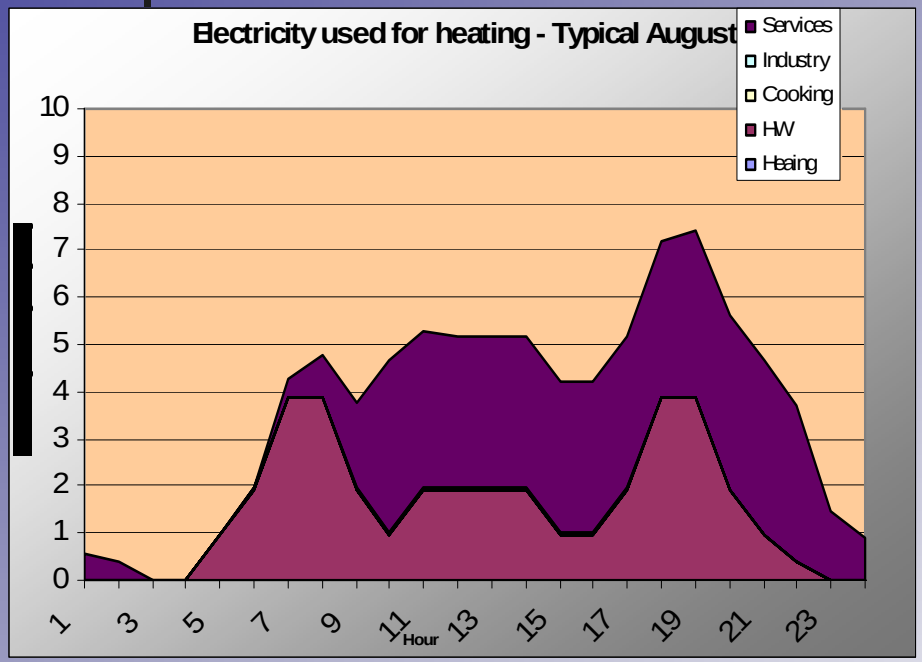
| | |
|---|---|
| Thermal – Elec. | 30,898,724 kWh |
| Thermal - Other | 35,991,699 kWh |
| Non-Thermal | 27,708,110 kWh |
| Total | 94,598,803 kWh |
| Fuel Consumption | 816,953 litres |

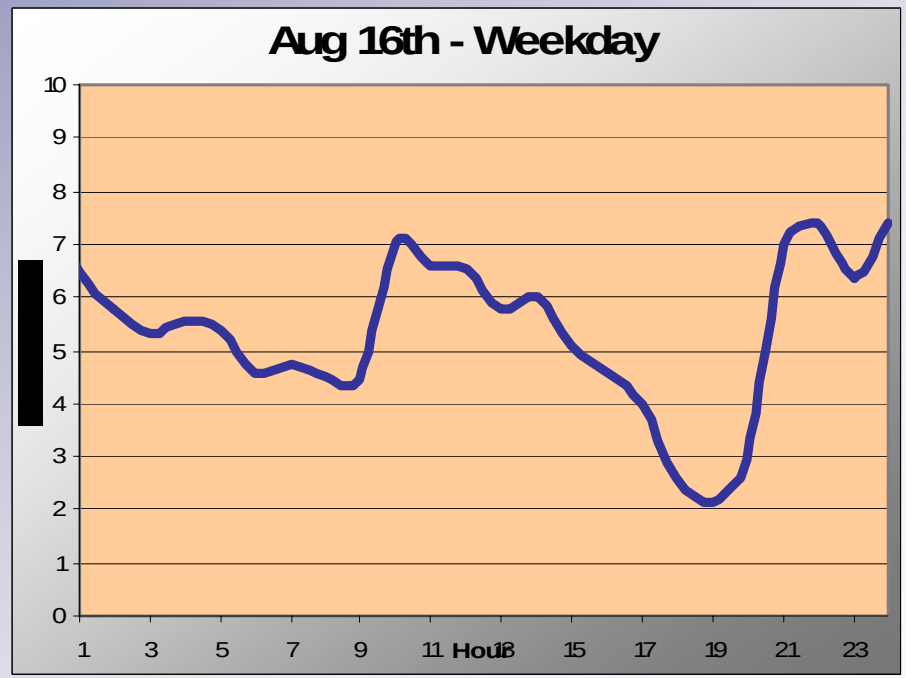


# Renewable Sources

- Potential:
  - Sun: 2718 hrs/year of sun
  - Wind: Speeds up to 8.5 m/s at mountain crest
  - Biomass:
    - 3,300 ton/y of Agricultural Waste
    - 4,243 ton/y of MSW & Sewer Sludge
    - 852 ha of Available Arable Land
- No-Potential:
  - Geothermal: 0.049$^{o}$C/m &Temperature too low
  - Hydro: 778mm rain per year
  - Wave, Tidal: Too little, 12cm
  - OTEC: no more than 100m

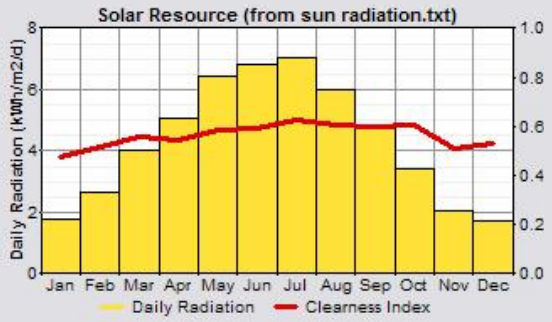
# Daily Electricity Trend



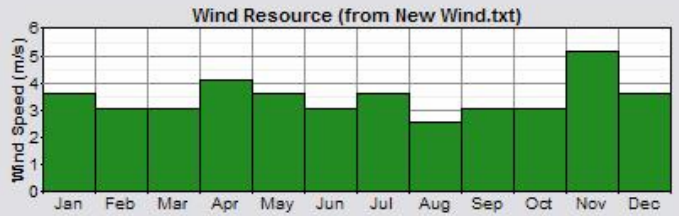



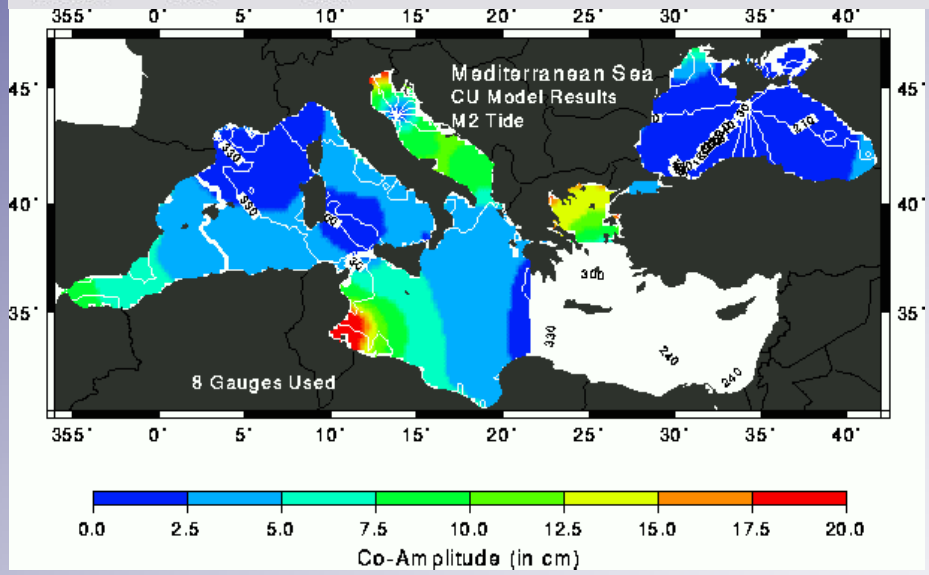
# Solar, Wind & Others

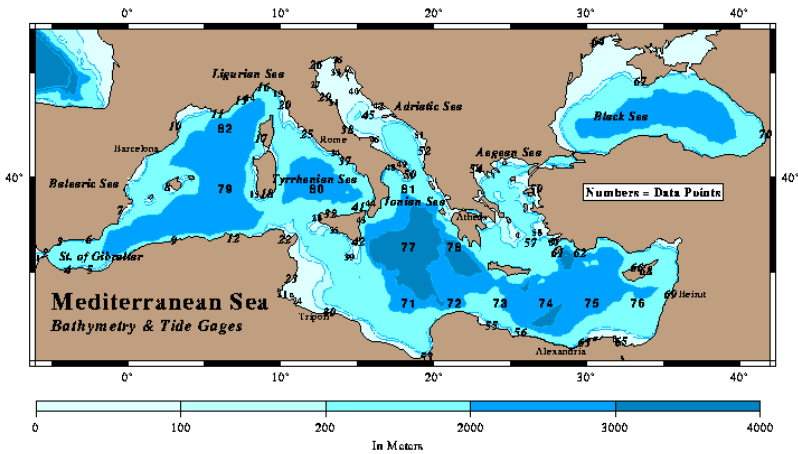
| Month | Clearness Index | Daily Radiation (kWh/m2/d) |
|---|---|---|
| January | 0.479 | 1.764 |
| February | 0.517 | 2.642 |
| March | 0.556 | 4.001 |
| April | 0.542 | 5.076 |
| May | 0.588 | 6.433 |
| June | 0.590 | 6.847 |
| July | 0.625 | 7.034 |
| August | 0.605 | 6.011 |
| September | 0.600 | 4.751 |
| October | 0.603 | 3.450 |
| November | 0.512 | 2.044 |
| December | 0.529 | 1.724 |
| Average: | 0.576 | 4.324 |




| Month | Wind Speed (m/s) |
|---|---|
| January | 3.601 |
| February | 3.087 |
| March | 3.086 |
| April | 4.089 |
| May | 3.599 |
| June | 3.088 |
| July | 3.601 |
| August | 2.572 |
| September | 3.086 |
| October | 3.087 |
| November | 5.143 |
| December | 3.601 |
| Annual average: | 3.469 |



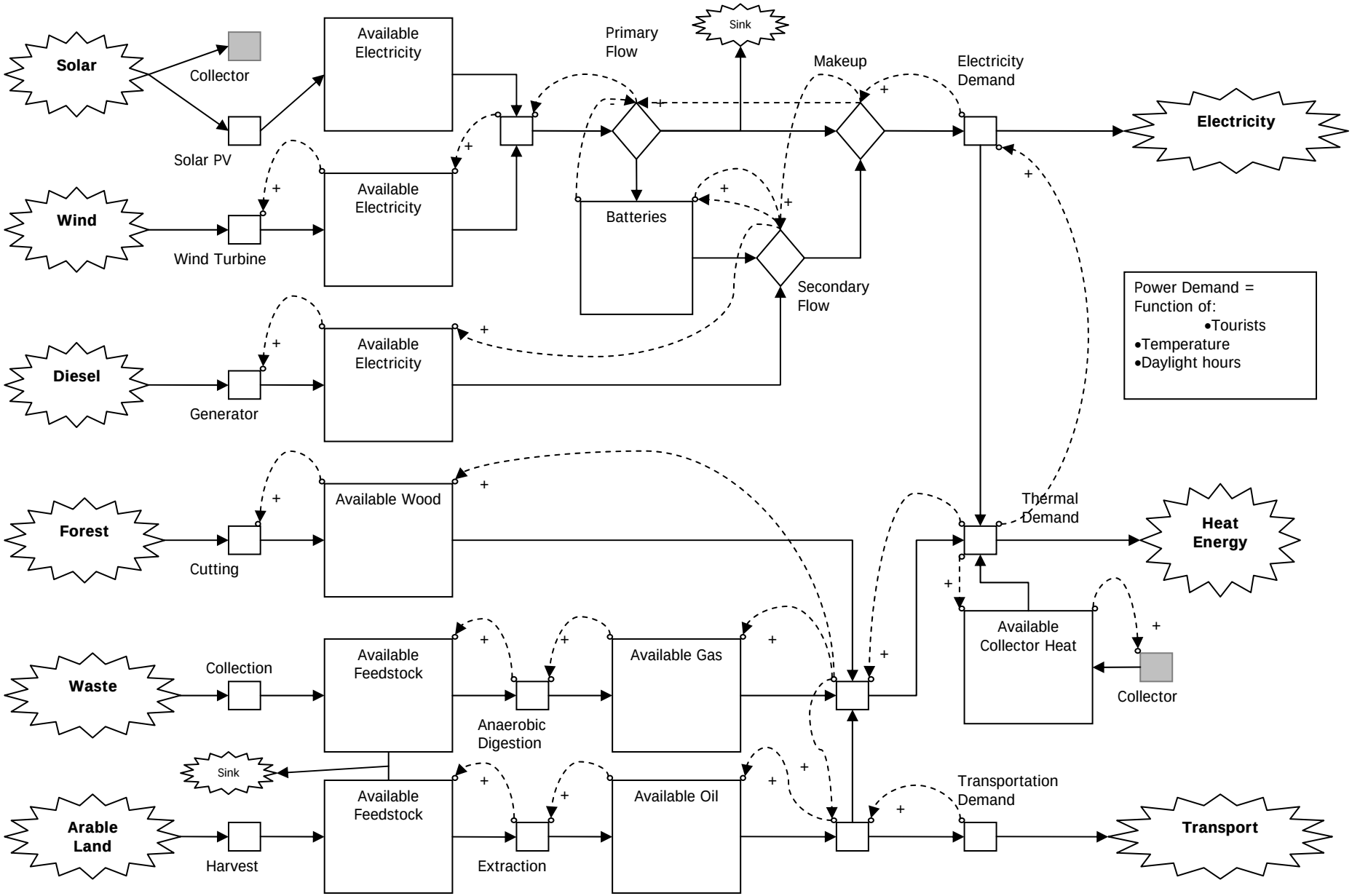



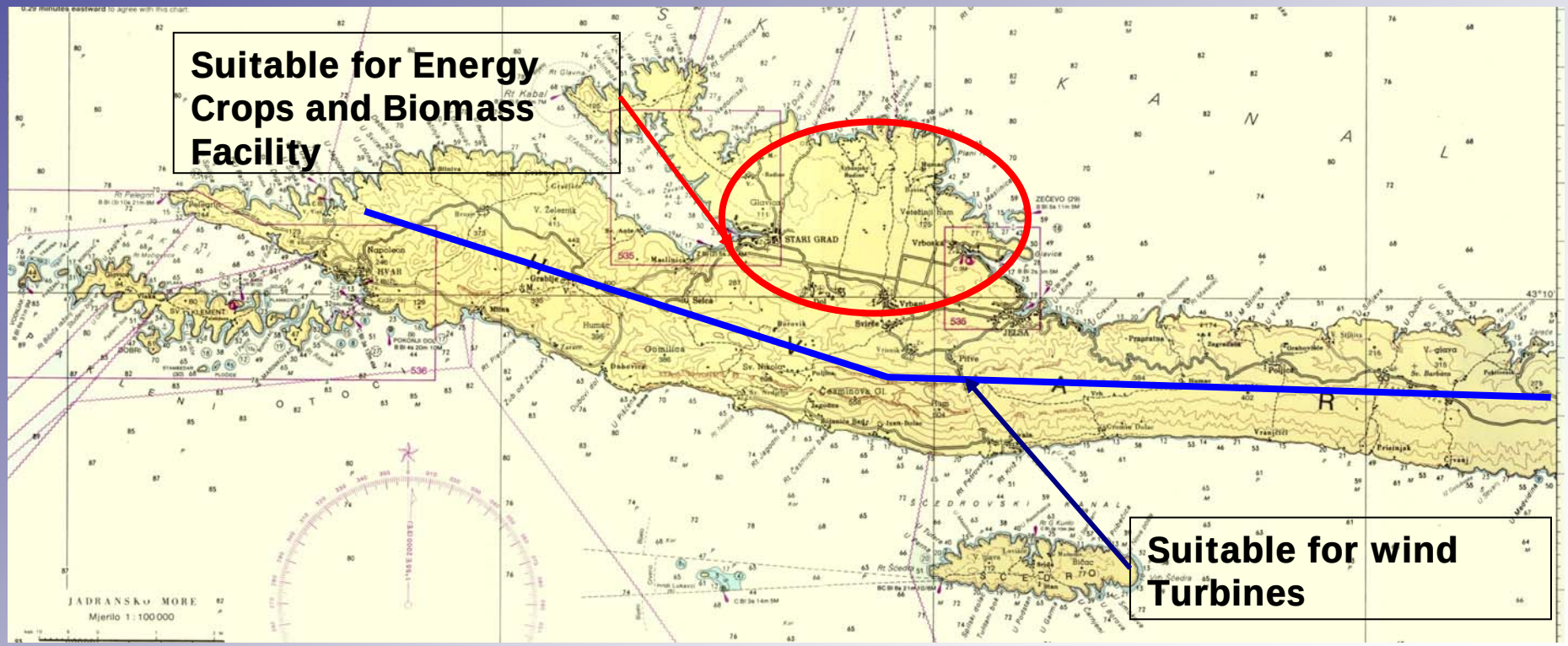
# Energy Planning

- Use Solar collectors for DHW
  - saving electricity: 6,612,579 kWh
  - and oil: 2,473,649 kWh
- Use Biomass for biofuels => save gas and oil
  - Biogas use MSW & Agricultural Waste -> Cooking and heat
    - Potential: 34,412 GJ/y or 978,669 $m^3$/y
  - Biofuel use Energy Crops -> Heating and Transportation
    - Potential:  39,903 GJ/y or 1,154,797 litres/y
  - Wood -> Assumed to be renewable
- Electricity Peak: 18.6 MW

# Energy Model



# Potential Layout



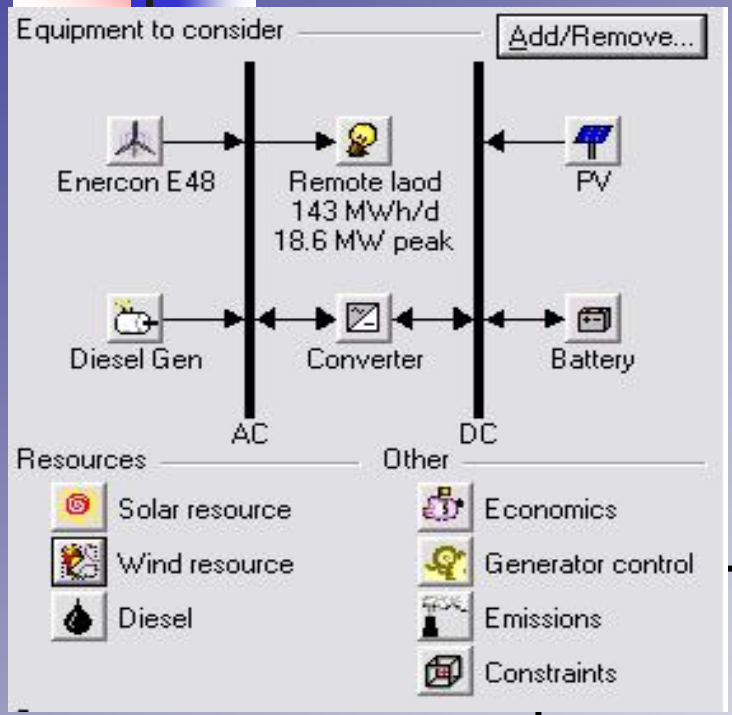
# Energy Mix - Homer

- Modeling done with HOMER.
- To obtain the input data for the HOMER, component information was collected from research literature and manufacturers to obtain estimates of costs, like:
  - the technologies investment cost and technical features
  - their useful life and maintenances requirements
  - the quantities of energy required annually
  - the cost of the energy produced by the various plants

# Energy Mix - Homer

- Matching environmental conditions with electricity demand -> Optimise Renewables
- Different component combinations
- Details
  - Heating load: Excluded b/c high fossil fuel solution -> treated separately
  - Electrical load: Includes non-thermal, electrical heating (minus savings from solar collectors) and cooling.
  - Diesel: Required for peak shaving
  - Storage: Batteries are primary. Hydrogen too pricey for size of the system
  - Grid connection: With and without considered; With offers much simpler, cheaper solutions; Without was favoured since it's an isolated system

# Favoured Concept




| | Installed Power [MW] | Share of Total | Penetration | Hours of Operation per year |
|---|---|---|---|---|
| **Solar** | **20.00** | **30%** | **63.8%** | **4,328** |
| **Wind** | **28.35** | **63%** | **135.4%** | **7,986** |
| **Diesel** | **20.00** | **7%** | | **672** |

# Best solution

Sensitivity Results | Optimization Results

Sensitivity variables

Wind Speed (m/s) 3.47 Diesel Price ($/L) 1

Double click on a system below for simulation results.

Categorized

| PV (kW) | E48 | Gen1 (kW) | Batt. | Conv. (kW) | Initial Capital | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Gen1 (hrs) | Batt. Lf. (yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20000 | 35 | 20000 | 32750 | 20000 | $ 193,787,168 | $ 249,672,592 | 0.449 | 0.93 | 3,013,059 | 672 | 12.0 |
| 20000 | | 13500 | 32765 | 20000 | $ 152,695,840 | $ 317,227,296 | 0.571 | 0.51 | 11,297,766 | 3,044 | 12.0 |

**Simulation Results**

System Architecture: 20,000 kW PV, 35 Enercon E48, 20,000 kW Diesel Gen, 32,750 Surrette 4KS25P, 20,000 kW Inverter, 20,000 kW Rectifier, Cycle Charging

Total NPC: $ 249,672,592
Levelized COE: $ 0.449/kWh

Cost | Electrical | PV | Enercon E48 | Diesel Gen | Battery | Emissions | Hourly Data

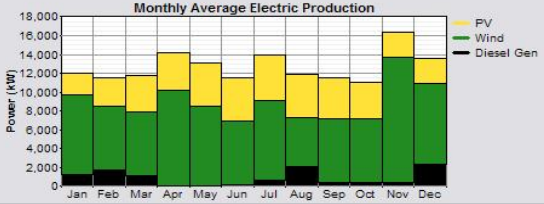
Annual electrical energy production

| | | |
|---|---|---|
| PV array: | 33,216,096 kWh | (30%) |
| Wind turbines: | 70,508,456 kWh | (63%) |
| Diesel Gen: | 7,751,436 kWh | (7%) |
| **Total production:** | **111,475,984 kWh** | |
| Renewable fraction: | 0.930 | |

Annual electric loads served

| | | |
|---|---|---|
| AC primary load served: | 52,054,200 kWh | |
| **Total load served:** | **52,054,200 kWh** | |
| Excess electricity: | 51,558,016 kWh | (46%) |
| Unmet electric load: | 37,073 kWh | (0%) |
| Capacity shortage: | 44,497 kWh | (0%) |

Monthly Average Electric Production

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Cost | Electrical | PV | Enercon E48 | Diesel Gen | Battery | Emissions | Hourly Data

Capital + Repl.: $ 19,472,176/yr  O&M + Fuel: $ 3,916,846/yr  Total Annualized: $ 23,389,024/yr


| Component | Initial Capital ($) | Annualized Capital ($/yr) | Annualized Replacement ($/yr) | Annual O&M ($/yr) | Annual Fuel ($/yr) | Total Annualized ($/yr) |
|---|---|---|---|---|---|---|
| PV Array | 103,755,808 | 9,719,717 | 0 | 796,010 | 0 | 10,515,727 |
| Enercon E48 | 36,631,576 | 3,431,601 | 0 | 1,750 | 0 | 3,433,351 |
| Diesel Gen | 13,756,250 | 1,288,669 | 302,646 | 33,600 | 3,013,059 | 4,637,974 |
| Battery | 19,643,536 | 1,840,183 | 516,348 | 64,337 | 0 | 2,420,867 |
| Converter | 20,000,000 | 1,873,576 | 499,437 | 8,090 | 0 | 2,381,103 |
| Totals | 193,787,168 | 18,153,744 | 1,318,432 | 903,787 | 3,013,059 | 23,389,024 |

# Sensitivity

- Diesel Price vs. Wind Speed

- High wind speeds and high fuel prices
  => wind power
- Very cheap diesel & very light winds
  => generator, battery, PV system

Sensitivity Results | Optimization Results

Sensitivity variables

Wind Speed (m/s) 3.47 | Diesel Price ($/L) 1

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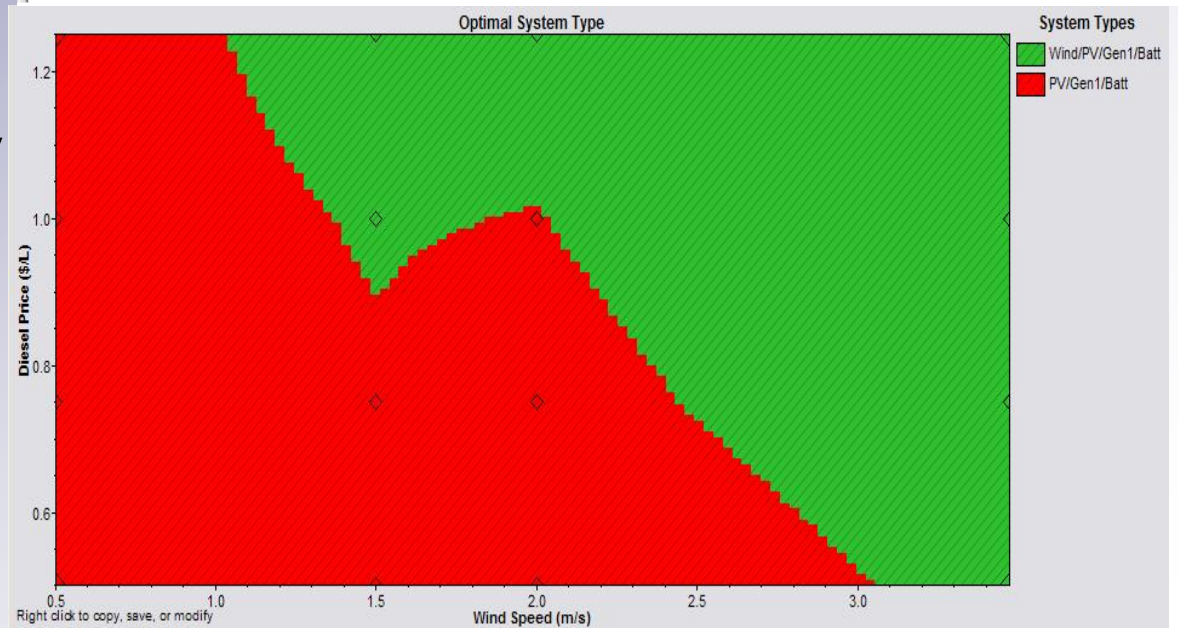

# Business Model

- Name - Magic Enterprise
- Slogan – We convert your poo and give it back to you!! It's like Magic!!

| Cost[+] [€/kWh] | 7pm to 7am | 7am to 7pm | With Solar Panel (24hrs) |
|---|---|---|---|
| Electricity | 0.407 | 0.448 | 0.407 |
| | Variable | Dedicated | Or |
| Oil | 0.067 | 0.074 | 0.71 €/liter |
| Gas | 0.042 | 0.046 | 0.17 €/$m^3$ |

[+]There are no taxes on these rates

# Conclusion

- 93.6% Renewable possible
- Further study required
- Grid Connection should be considered
- Mixing Biodiesel would be required, especially for tourists

| Source | Previous [kWh/year] | Renewable [kWh/year] | Percentage |
|---|---|---|---|
| Electricity – Non-Thermal | 27,708,110 | 25,768,542 | 93.0% |
| Electricity - Thermal | 30,898,724 | 29,198,869 | 94.5% |
| Wood | 18,258,789 | 18,258,789 | 100% |
| Oil | 8,661,451 | 8,661,451 | 100% |
| Gas | 9,071,729 | 9,071,729 | 100% |
| Total - Energy | 94,598,803 | 90,959,380 | 96.2% |
| Transportation [l/y] | 816,953 | 510,122 | 62.5% |
| Total | 102,424,026 | 95,845,607 | 93.6% |