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On the path to energy independence: hybrid energy systems evaluation towards Favignana smart energy island

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PRISMI project outcomes and RES integration in Med islands

- An **integrated toolkit** for assessing and mapping the local potential of RES and their exploitation in new energy systems
- A **Sustainable Energy Action Plan** drafted for each case study area with recommendations **and strategies for developing integrated RES**
- The establishment of a PRISMI **Network of Stakeholders** to support exchange of knowledge and best practices in RES integration in Mediterranean islands.

Research aims

- **increasing the RES share** in the small Italian island of Favignana
- designing a **hybrid system** that exploits the island RES potential by means of different storages systems:
  - Battery Energy Storage (BES)
  - Hydrogen Energy Storage (HES)
- **Renew and upgrade the public transport** systems introducing:
  - Fuel Cell Electric Vehicles fleet
  - HCNG fuelled bus fleet

Methodology

Common methodology for RES assessment and mapping on the Mediterranean islands (PRISMI).

3 main steps:

- mapping island needs and legislative framework
- assessing RES potential
- design and dynamically model energy scenarios

The energy scenarios were implemented and simulated using the software HOMER (Hybrid Optimizaiton Model for Electric Renewable). All the intervention related to the mobility sector were evaluated outside of the software

Methodology

In order to study the impact of the renovation of the public transport service, the **fuel consumption** per km has been found for the different solutions examined as well as the CO_2 emission per km. The following values from literature* have been used regarding diesel and hydrogen driven buses:

$$V_{diesel} = 0{,}18\ [l/km]$$
$$V_{H_2} = 0{,}089\ \left[kg_{H_2}/km\right]$$

CO_2 emission for diesel buses has been calculated as:

$$CO_2 = V_{diesel} \times CC_d \times \frac{44}{12}\ \left[ton_{CO_2}/km\right]$$

CC_d is the fuel carbon content [%]

* Hatch, C. et al., Economic analysis of hydrogen production from wastewater and wood for municipal bus system, *Int. J. of Hydrogen Energy*, Vol. 38, pp 16002-16010, 2013.

Methodology

Regarding **HCNG fuelled bus**, the hydrogen content in the mixture considered is equal to 20% vol. since it is an optimum value as reported in literature*. Moreover, the Lower Heating Value (LHV) of hydrogen enriched natural gas blend at 20% vol. is 30.713 MJ/Nm3. The value of emission for unit of energy was available and it is equal to $CO_2 = 51{,}13\ [kg_{CO_2}/GJ]$*.

In order to evaluate the **fuel consumption per km** the following equation was used:

$$V_{HCNG} = V_{diesel} \frac{LHV_{diesel} \times \eta_{diesel}}{LHV_{HCNG} \times \eta_{HCNG}}$$

V_x is the average consumption for fuel x $[l/km]$

LHV_x is the Lower Heating Value of fuel x $[MJ/l\ or\ Nm^3]$

η_{diesel} is the compressor ignition engine efficiency

η_{HCNG} is the spark ignition engine efficiency

* De Santoli, L. et al., A small scale H_2NG production plant in Italy: Techno-economic feasibility analysis and costs associated with carbon avoidance, *Int, J. of Hydrogen Energy*, Vol. 39, pp 6497-6517, 2014.

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Methodology

The performance and the carbon dioxide emissions per technology used are summarised in the following table:

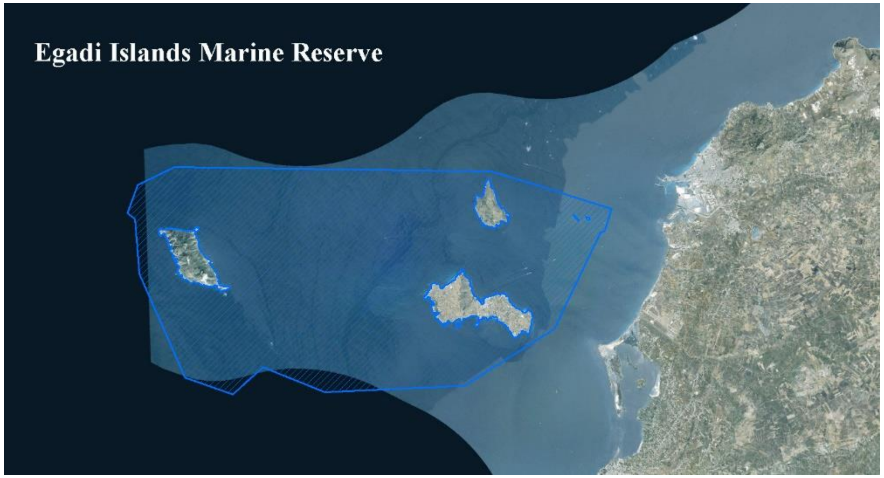
Technology [unit]	V [unit/km]	CO_2 emissions [kg/km]
Diesel [l]	0.18	0.476
FCEV [kg]	0.089	0
HCNG [Nm^3]	0.242	0.38

Case study: Favignana

Favignana island is located on the west coast of Sicily, lat: 37°55'N long: 12°19'E. S= 19.8 km2, 17 km far from the mainland. The archipelago belongs to the biggest Marine Protected Area in Europe (539.92 km^2). The current population in Favignana is equal to 3400 inhabitants. This number increase enormously during summer due to touristic flux, thus strongly influencing the island's needs as electricity and the public transport service.

Favignana's **stand-alone system** strongly depends on fossil fuels:

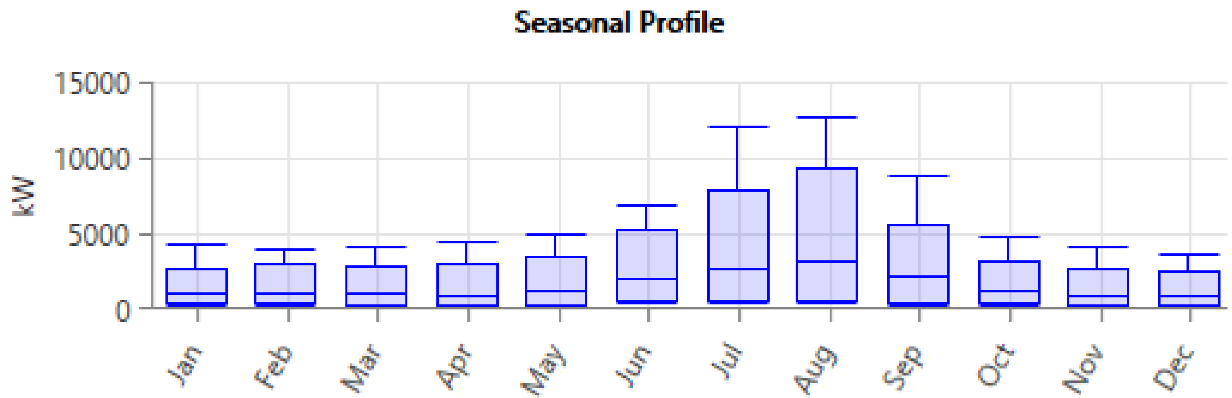
- 7 diesel generators, $P_{diesel} = 12\ MW$
- 25 PV systems, $P_{PV} = 170\ kW_p$



Case study: Favignana

Electric load is the one typical of a Mediterranean island whose main income is tourism. Thus, it has a strong seasonal feature.

Peak power: 11,990 kW
lowest power: 200 kW
annual load: 13,915 MWh/y



Regarding the **transport sector**, Favignana has the lowest rate of private vehicle per person (34.3%) of all Italian small islands and the highest value in the category cycling/walking (61.8%). The public transport is constituted by 8 buses, divided in 3 routes that cover 23 km with an yearly distance covered of more than186,000 km. The public transport service needs has a strong seasonality too, the time schedule changes depending with the season, 6 buses are used just in the months of July and August.

This situation was considered as baseline scenario.

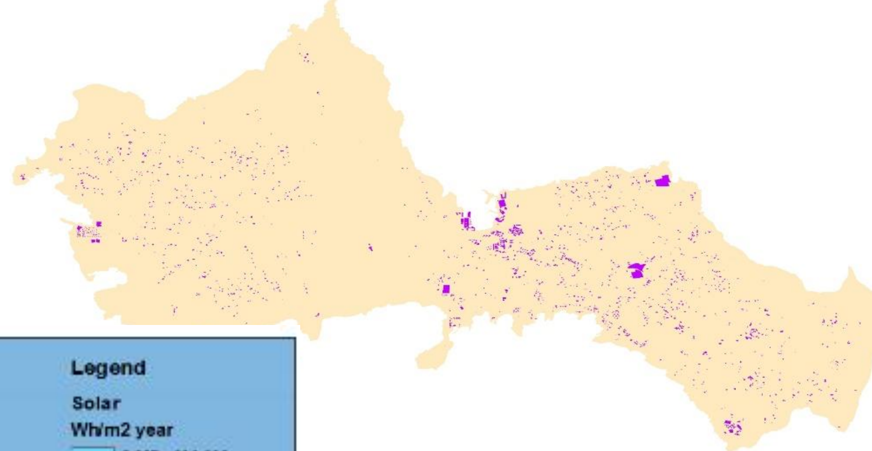
Case study: Favignana

The **baseline scenario** was simulated on HOMER in order to **compare the energy scenario simulated to the current situation on the island**. The 7 diesel generators were implemented singularly in the software, 5 generators with a power of 1890 kW and 2 with a power 1290 kW. Distributed PV systems with an overall peak power of 170 kW_p have been considered.

Quantity	Value	Unit
Excess electricity	1.1	%
RES share	1.9	%
Diesel consumption	3,638,047	l/y
HySys emissions	9,539	$tonCO_2/y$
Transport emissions	87.93	$tonCO_2/y$
Overall emissions	9,627	$tonCO_2/y$

Case study: Favignana

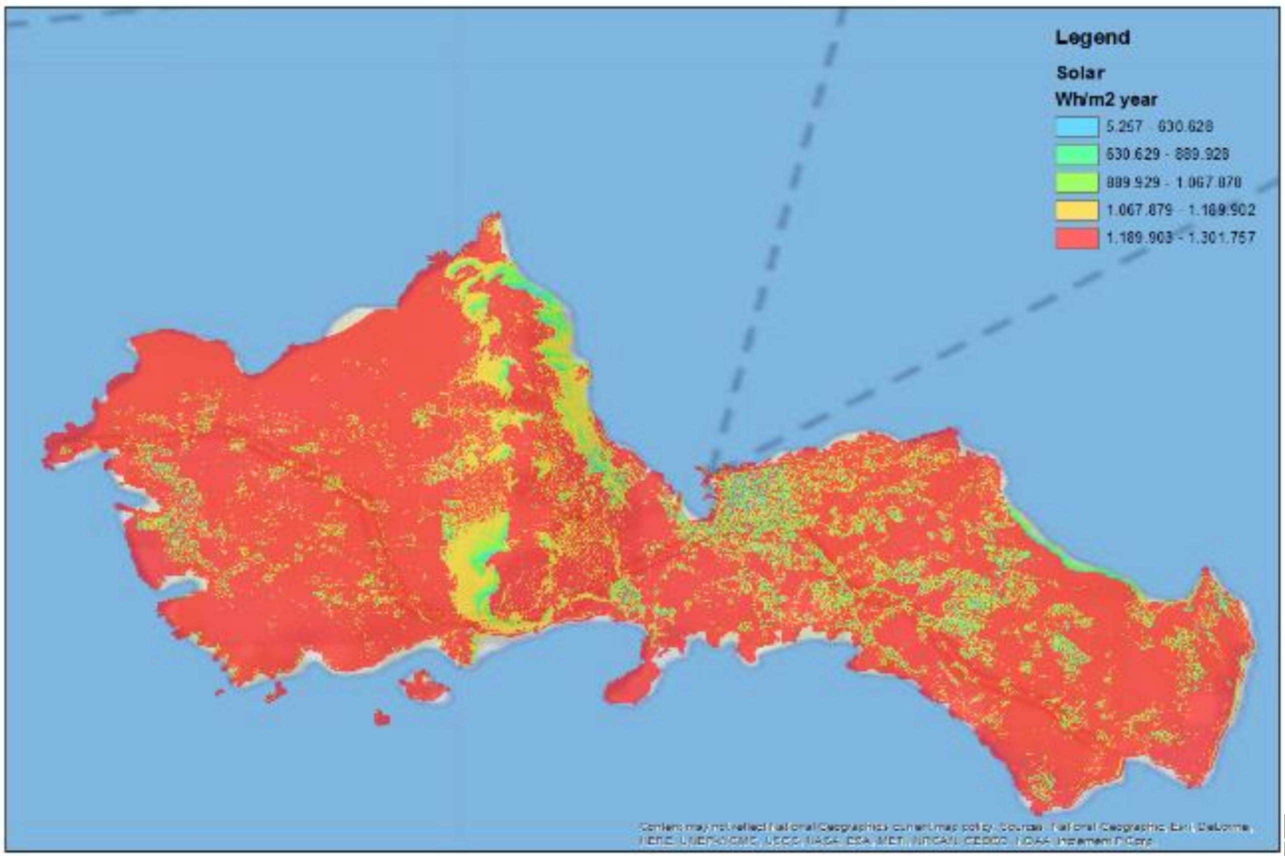
RES potential assessment



Solar yearly irradiation = 1,300 kWh/m^2

derived from a Digital Surface Model (DSM) raster surface using the tool "Solar Area Radiation".

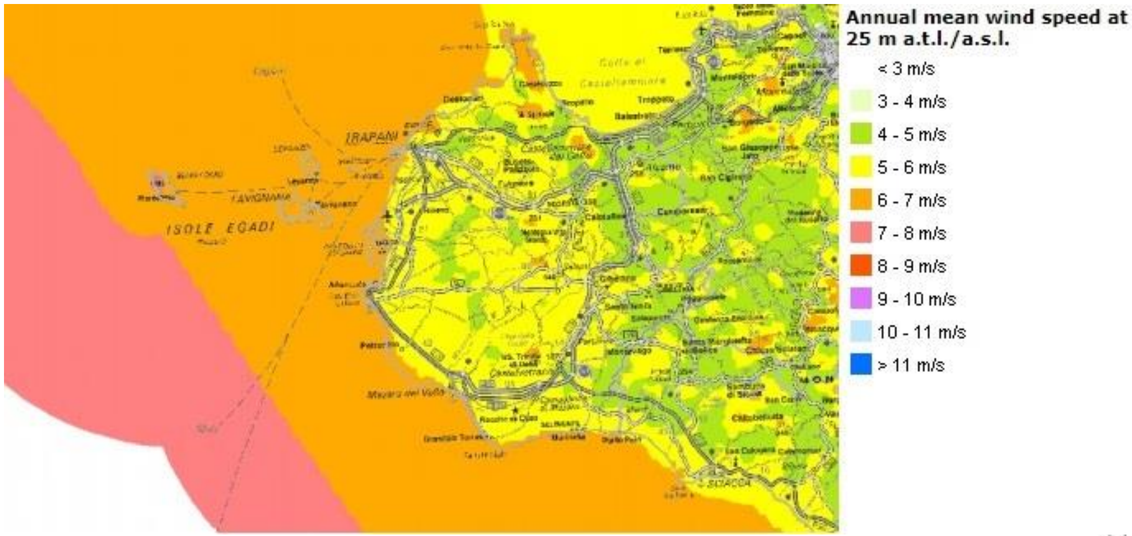
Rooftop available surface = 18.59 hectares



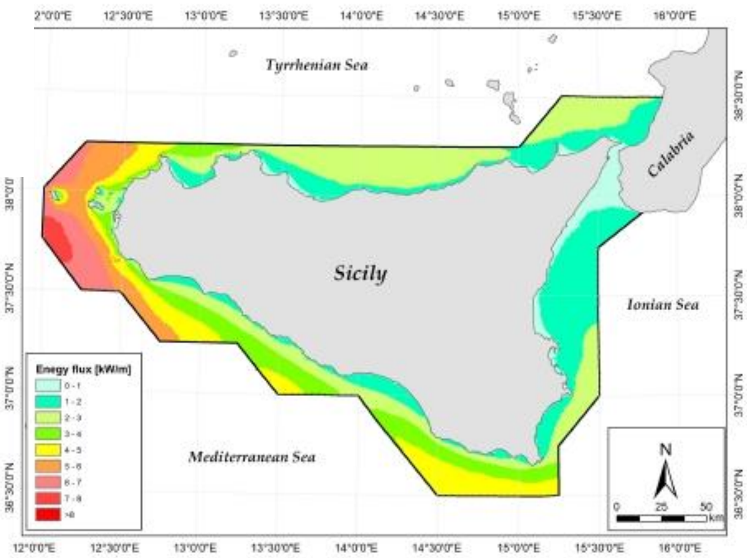
Case study: Favignana

RES potential assessment

Wind speed at 25 m = 6-7 m/s*



Wave energy flux = 6.8 kW/m**
yearly energy for unit crest length = 60.27 MWh/m**



* Interactive eolic atlas, ATLAEOLICO, http://atlanteeolico.rse-web.it/
** Iuppa, C. et al., Investigation of suitables sites for wave energy converters around Sicily (Italy), Ocean Science, Vol. 11, pp 543-557, 2015

Energy scenarios & simulations

The installation of 900 kW_p has been considered that is the goal identified by the Ministerial Decree “Eneergy to small islands”. The systems considered have been separated in two plants:

1. 500 kW_p power plant
2. 400 kW_p distributed systems

The **BES** system consists of a Trojan 31 – AGM battery set with a 8 string size obtaining a bus voltage of 96 V. As **HES**, an alkaline electrolyser with a 0.82 efficiency was considered. **5 case scenarios have been simulated and compared.**

	Case 1	Case 2	Case 3	Case 4	Case 5
RE systems	PV	PV	PV	PV	PV
Storage	BES	HES	HES	BES + HES	BES + HES
Mobility	-	FCEVs	HCNG vehicles	FCEVs	HCNG vehicles

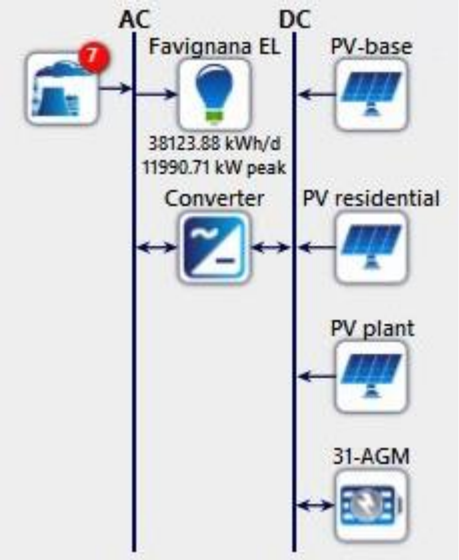
Energy scenarios & simulations

Both the public transport fleet and the hydrogen tank were not considered economically since those can be considered as CAPital EXpenditure of the mobility sector.

Technology	CAPEX [€/kW] or [€/kg]	Replacement [€]	O&M [€/y] or [€/h]	Lifetime [y] or [h]
Diesel generators	0	250	0.01	25000
PV commercial	800	800	8	15
PV residential	1000	1000	10	15
Converter	400	350	-	10
Trojan 31 - AGM	300	300	10	10
Electroliser	1000	500	50	10

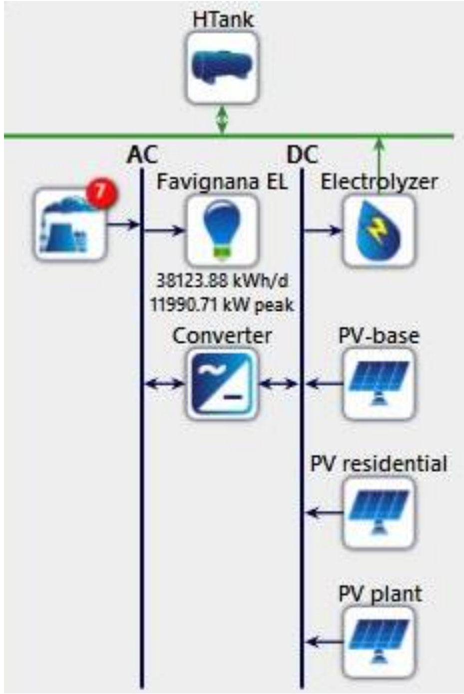
Results

Quantity	Case 1	Unit
Battery size	1941	kWh
LCOE	0.257	€/kWh
Return on investment	32.6	%
Excess electricity	0.0	%
RES share	12.34	%
Diesel consumption	3,244	l/y
HySys emissions	8506.7	tonCO_2/y
Transport emissions	87.93	tonCO_2/y
Overall emissions	8,594	tonCO_2/y
Carbon avoidance	1032	tonCO_2/y



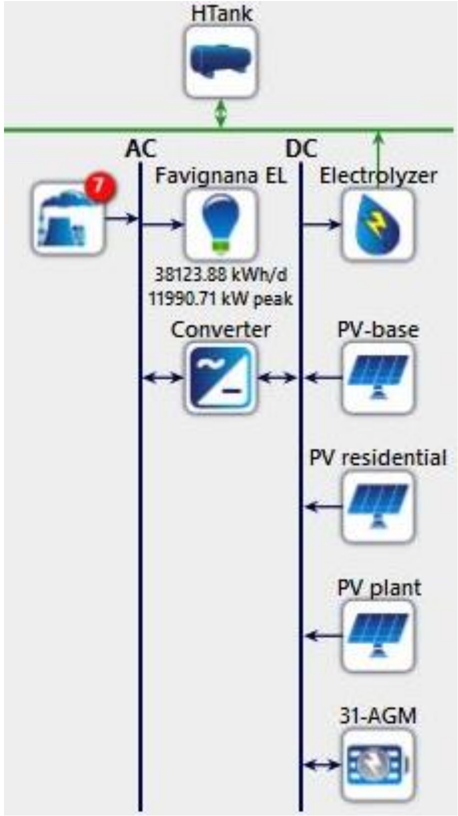
Results

Quantity	Case 2	Case 3	Unit
Electrolyser size	90	90	kW
Hydrogen saved	2304	2304	kg/y
LCOE	0.261	0.261	€/kWh
Return on investment	62.9	62.9	%
Excess electricity	0.7	0.7	%
RES share	12.71	12.71	%
Diesel consumption	3297157	3297157	l/y
HySys emissions	8645.9	8645.9	tonCO_2/y
Transport emissions	75.77	70.86	tonCO_2/y
Overall emissions	8,720	8,716	tonCO_2/y
Carbon avoidance	906.23	910.24	tonCO_2/y



Results

Quantity	Case 5	Unit
Electrolyser size	50	kW
Hydrogen saved	857	kg/y
Battery size	700	kWh
LCOE	0.257	€/kWh
Return on investment	45.3	%
Excess electricity	0.3	%
RES share	12.78	%
Diesel consumption	3245245	l/y
HySys emissions	8509.8	tonCO_2/y
Transport emissions	70.86	tonCO_2/y
Overall emissions	8,580	tonCO_2/y
Carbon avoidance	1046	tonCO_2/y



Conclusions

- The GIS analysis demonstrates that a wider exploitation of solar energy is the most suitable option in the short-medium period. Since the yearly solar irradiation is 1300 kWh/m^2, the whole island's areas can be used for large PV plants installation. Indeed, even though the average wind speed is equal to 6-7 m/s and it is compatible to the installation of small wind farms, that solution is not allowed owing to environmental and landscape constrains called for current Italian regulations.
- Using a BES system to manage the electricity excess deriving from the installation of 900 kW_p PV arrays, a carbon dioxide reduction of 10.72% and a LCOE of 0.257 €/kWh can be accomplished. In that case, the terrestrial public transportation is not renovated.
- Using a HES system, 2304 kg/y of renewable hydrogen it is produced. FCEVs and HCNG-fuelled vehicles have been considered as potential options for greening the local public mobility. HCNG-fuelled vehicles' solution attains the best environmental performance.
- The hybrid energy system comprising both batteries and electrolyser results the best way to manage the electricity excess leading to a carbon avoidance value of 10.87% and to a LCOE of 0.257 €/kWh.

Next steps

- Study how to increase the RES sharing and how the mobility sector could be renovated
- Develop a sensitivity analysis of the best scenario analysed.
- Consider the investment and the profits related to the transport sector.
- Consider to intervene in other crucial sector of the island (i.e water needs and marine transport)

Thanks for your attention!!

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