LOCAL SUSTAINABLE ENERGY SYSTEM DEVELOPMENT IN AN INSULAR AREA : MUNICIPALITY OF FAVIGNANA, ITALY

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Promoting RES Integration for Smart Mediterranean Islands

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Abstract:	Energy scenarios will be defined, modelled and simulated emphasizing the different adopted

	solutions and providing potential energy strategies. Moreover, environmental and techno-economic feasibility analysis will be outlined

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Executive Summary

The PRISMI PLUS toolkit implementation for Favignana Municipality Flagship Case (FC) is integrated with the current feasibility study and comparative analysis. The specific analysis renders available both the documents to guide the strategic energy planning actions of Favignana as well as the modeling and the pre-and post-processing tools. Current and foreseeable energy scenarios have been developed and compared on the basis of the local RES potential data, also presented in detail, by means of the Programme's simulation tool (EnergyPLAN model), innovative energy production technologies have been considered.

The general definition of approach is shortly described in Section 2. Nevertheless, a detailed definition of the approach, as well as a definition and description of the tools which includes pre-processing tools, such as the wind speed and output power calculator and solar energy tools, simulation tool, that, is EnergyPLAN model, and the post-processing tool can all be found on the PRISMI PLUS website (link).

The current feasibility study is presented in Section 3, in which the modeling and simulation results for the energy scenarios devised are presented. The presentation includes the different adopted technology solutions and provides potential energy planning strategies and techno-economic feasibility analysis. The elaborate includes the description of the case study and the input data, the results of modeling with discussion, the socio-economic feasibility of adopted solutions, the environmental considerations, and the feasible strategy for the case study's area development.

At the end of the document, conclusions are drawn and suggestions for the future energy strategy of the Municipality of Favignana are made.

1. General definition of approach

The PRISMI approach is comprehensively outlined in Figure 1 that describes the flowchart of using the PRISMI toolkit and the overall approach that should be adopted.

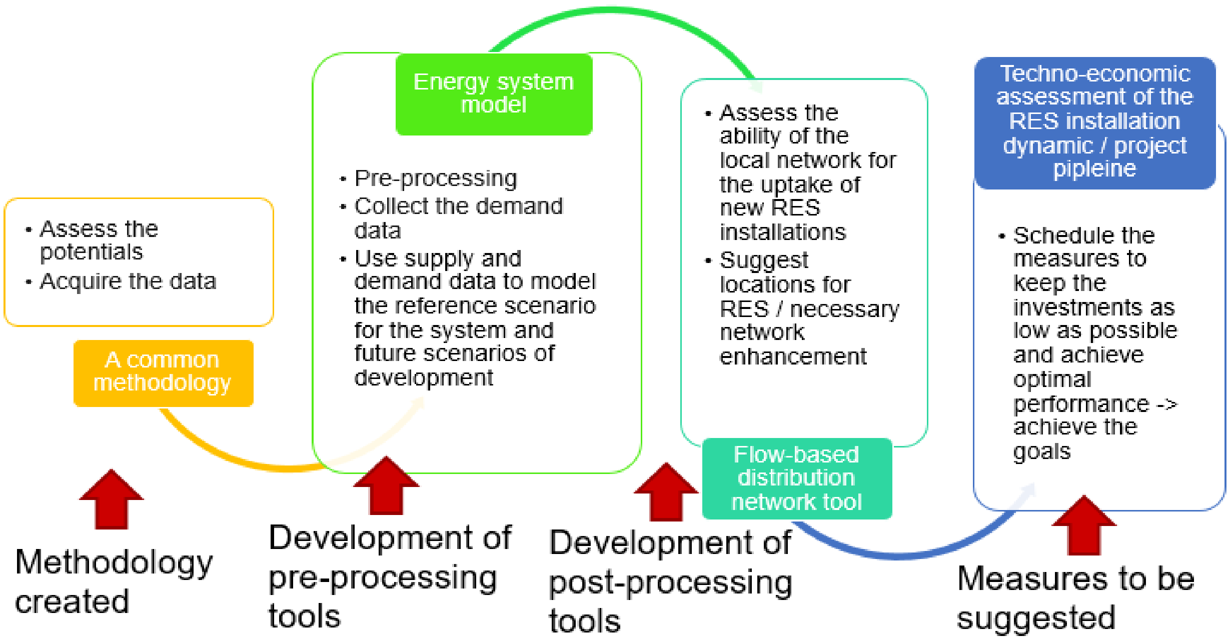

Figure 1 The PRISMI approach step by step

1.1. General framework method for devising the future development energy scenarios for the PRISMI case study considered

As the first step to devise the scenarios, the methodology (described in D3.1.1 of the PRISMI project) should be followed, dedicatedly adapted to Favignana. Hence, the adapted methodology consists of the following actions:

Mapping the energy needs of the island community

Favignana provided the available data about energy consumption for electricity, heating, and transport with as much detail as possible about the subdivision in used energy vectors.

Mapping the locally available renewable energy resources

The data for the potential of locally available Renewable Energy Sources (RES) are collected in the form appropriate for analysis, in the context of providing a systematic overview for further research and deployment. This part of the process is also aided with the dedicated web tool "*Renewables.ninja*[1]" since the major renewable source that can be exploited is solar power. Other identified resources include biomass and geothermal energy but are not yet sufficiently mapped and investigated.

Technologies overview for bridging the gap between energy needs and energy resources

Appropriate technologies, which can exploit the locally available RES and are feasible for use on the location of the local municipality, are considered for the scenarios' analysis. Favignana Municipality indicated the following technologies: PhotoVoltaic (PV), Solar Thermal collectors (ST), Wind Turbines (WT), Electric Vehicles (EVs), Heat Pumps (HPs) and Vehicle-to-grid approach (V2G).

Division of scenarios

The energy system development is examined through three scenarios (LowRES, RES and HighRES). In such a way, the case study examined will have a short overview of available energy resources, present energy needs, and available technologies as the basis for devising the corresponding scenarios.

[1] Stefan Pfenninger, Iain Staffell, Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data, Energy, Volume 114, 2016, Pages 1251-1265, https://doi.org/10.1016/j.energy.2016.08.060.

2. Case study examined – Municipality of Favignana Flagship Case (FC)

Favignana island is located on the west coast of Sicily, latitude 37°55'N longitude 12°19'E, 17 km far from the mainland between Trapani and Marsala. Favignana with its surface of 19.8 km^2 is the main island of the Aegadian archipelago that comprehends the islands of Marettimo, Levanzo and other minor islets like Formica and Maraone. The archipelago of the Aegadian islands belongs to the biggest Marine Protected Area of Europe covering a total surface of 539.92 km^2.

The island encountered a strong depopulation process that seems to have stopped today, the current population of Favignana is about 3400 inhabitants for 1810 family units [28].

The energy system is not linked to the mainland and Favignana's stand-alone system strongly depends on fossil fuels. In fact, seven diesel generators with a total power installed of about 12 MW supply the island's load; furthermore, the overall peak power of installed PV systems is about 170 kW_p.

As regard the island needs, the importance of the touristic sector is visible also in the monthly energy consumptions of Favignana, characterized by a strong seasonality.

Marine transport sector assumes the highest importance in the overall energy consumptions; this is due to several reasons: fishing sector, the common practice for inhabitants of studying/working on the mainland (or vice versa) thus having a huge number of daily travellers, tourism and drinkable water delivery. Particularly, the yearly diesel consumption for maritime transport sector (both private and commercial) is equal to 49647.5 MWh/y. Regarding the terrestrial transport sector, Favignana has a rate of private vehicle per person of 34.3% and a high value in the category cycling/walking equal to 61.8%, particularly the number of cars is equal to 1903 and the one of motorbikes is 967. The relative diesel consumption is equal to 3.8 GWh per year and the one for gasoline is equal to 5.5 GWh. The public transport fleet is constituted by 8 buses, divided in 3 routes that cover 23 km with an yearly distance covered of 186298.5 km. The yearly electric consumption is equal to 12563 GWh/y while the one for thermal purposes is equal to 3410.5 MWh/y and is entirely due to Natural gas.

Figure 2 depicts the primary energy consumption distribution by energy sectors, reference year 2011.

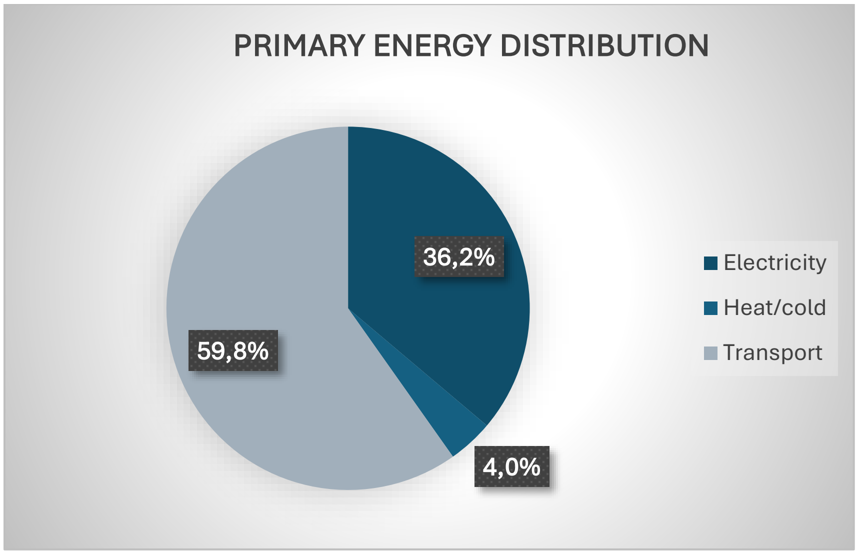

Figure 2 Primary energy distribution

In accordance with the PRISMI method, 4 steps of energy planning are observed:

Table 1 Mapping the needs of the island community- Favignana

Needs	Level	Geographical Distribution	Code
Electricity	High	Concentrated	ElectHC
Heat	Low	dispersed	HeatLD
Fuel for terrestrial transportation	Low	Short dist.	TTranLS
Fuel for maritime transportation	High	Short dist.	MTranHS
Water	Medium	dispersed	WaterMD

Table 2 Mapping the resources available – Favignana

Resources	Level	Code	Resources	Level	Code	Resources	Level	Code
Local primary energy			Infrastructure for energy imports			Water		
Wind	Medium	WindM	Network connection	n/a	GridN	Rainfall	Low	H2OPL
Solar	High	SolarH	pipeline natural gas	n/a	NGplN	Groundwater	Low	H2OGL
Wave potential	Medium	WaveM	Terminal LNG	n/a	LNGtN	Water supply	Low	AquaL
Biomass	Low	BIOML	Oil terminal / refinery	n/a	OilRN	Seawater	Yes	H2OSY
Geothermal potential	Low	GeothL	Terminal petrol. production	n/a	OildDN			

Resources, in particular renewable energy sources, are already described in detail in deliverables of the PRISMI project.

Technologies overview

From the step two of the method, one of the resources is rated as high potential: solar.

Initial step is to calculate the available area for solar PV installation. To do that the software ArcGIS was used, the incoming yearly solar radiation was derived from a Digital Surface Model (DSM) raster surface using the tool “Solar Area Radiation”. The 2x2 m global radiation output raster map was used as value layer dataset for the tool “Zonal statistics as table”. As output of the Zonal statistics as table tool the relevant information used are the total buildings’ roofs surface and the buildings’ roofs surface with a yearly solar irradiation higher than 1000 kWh/m^2y.
Furthermore, a coefficient equal to 0.85 was considered so to evaluate the presence of antennas, chimneys or other obstacles that could impede the installation of PV systems and reduce the available area. The area occupied by PV systems already installed on the island and the area of the solar collector was considered. Particularly, the surface needed for 1 kW_p PV was considered to be 6.5 m^2 for both new installation and already installed PV systems. The available area for the installation of new PV systems resulted to be 185906 m^2 for a maximum installable peak power of 26558 kW_p.

Other relevant resource is wind power, which is restricted in the terms of legislative framework and made difficult for the implementation due to the island being mostly covered by the NATURA 2000 network and the marine protected area.

Favignana island is one of the best site for wave energy conversion in the Italian coasts, in particular the west shoreline records an energy flux of 6.88 kW/m and a yearly energy for unit crest length of 60.27 MWh/m (Iuppa 2015). Although the good potential, such technology has not been considered, since wave energy converter technologies are still prototype and not market ready.
Biomass is not used, and it does not present a good potential, thus it should be imported.

Division of scenarios

Description of installed capacities, demand response technologies and other considerations relevant for scenarios, according to chapter 1.1.
Final, fourth step of the method is the divison of scenarios. Energy system development of the Favignana Municipality has been examined in three scenarios:

1) LowRES – following the same dynamics of RES use, as already proposed in actual SEAP-s
2) RES – Increase of RES use, taking into consideration environmental constraints and legislative framework
3) HighRES – Modelling for a 100% RES energy system of the island

Currently, Sustainable Energy and Climate Action Plan has been developed for the whole Aegadian Islands, this action plan was used to acquire the basic data and then extrapolate the measures towards the year 2025, 2030 and 2035. Considering possible PV installations, calculations based on this method are presented in the table.

Having in mind the method for solar power, described in the description of the study area and input data, the possible installed capacities of PV are calculated.

Table 3 Input data for modelling of Favignana energy system development

2030	LowRES	RES	HighRES
PV [MW]	1.07	2	4
Wind [MW]	0	0	2.8
Solar collector [m^2]	1100	1100	1100
Solar collector [MWh]	850	850	850
HPs [no.]	0	900	1810
HPs [MWh]	0	1700	3400
EV not V2G mode [no. of vehicles]	0	967	967
EV not V2G mode [MWh]	0	33	33
EV in V2G mode [no. of vehicles]	0	0	1903
EV connection [MW]	0	0	8.445
EV demand [MWh]	0	0	921
EV battery [MWh]	0	0	49.014

Further considerations will be elaborated having in mind the year 2030. For the three scenarios the demand is different, and this difference is exactly the amount of demand for HPs and EVs.

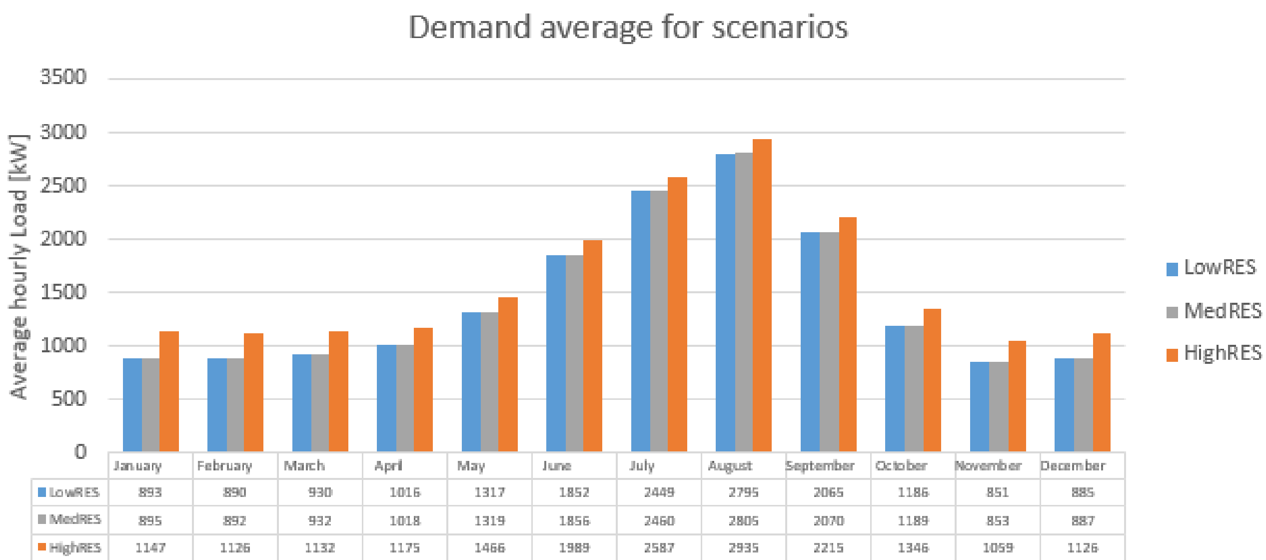

Figure 3 Monthly averaged electricity load of Favignana for the three scenarios

2.1. Results of modelling and discussion

Results of modelling are presented in single figures for all three scenarios, to be easily comparable.

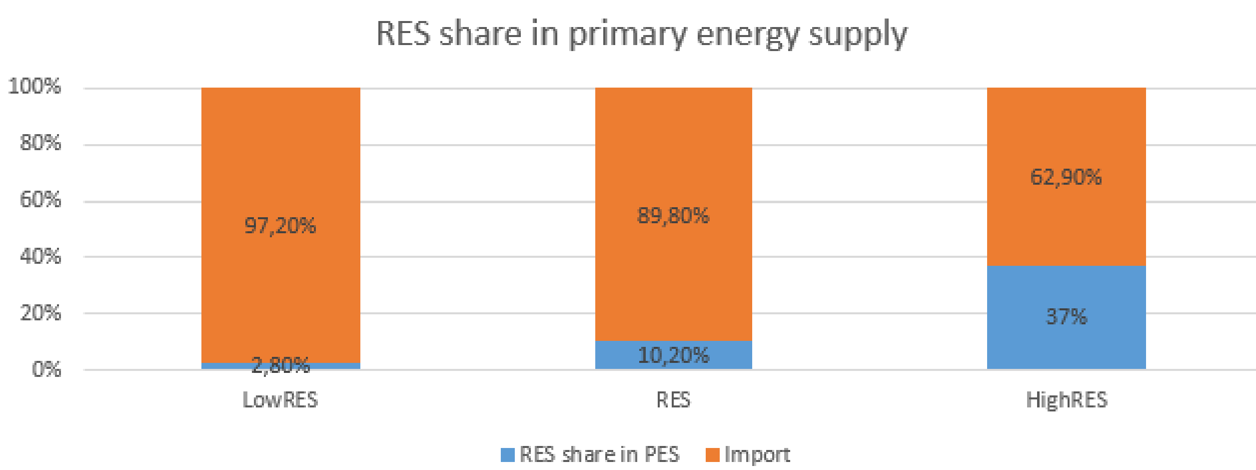

Figure 4 RES share in primary energy supply

For each scenario, the combination of RES sources is used, as presented in table. The high share of imported energy in HighRES is due mainly to marine transport and for a smaller portion to biomass.

Table 4 Results of modelling - RES production on Favignana

LowRES			RES			HighRES		
Solar	1.78	GWh/year	Solar	3.34	GWh/year	Solar	6.67	GWh/year
Wind	0	GWh/year	Wind	0	GWh/year	Wind	4.17	GWh/year
Heating solar	0.85	GWh/year	Heating solar	0.85	GWh/year	Heating solar	0.85	GWh/year

Moreover, based on the previous amounts of energy generation, Figure 5 represents the RES share in electricity production.

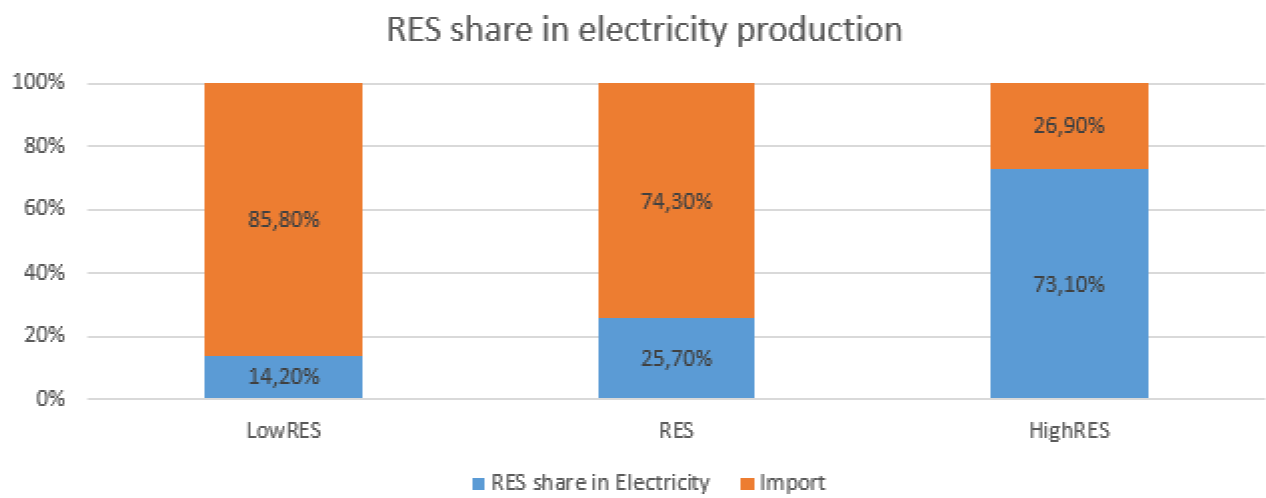

Figure 5 RES share in electricity production

In HighRES scenario, the 73.1% of RES share is achieved. It is noteworthy that the other 26.9% is accounted as import since it derives from biomass that is used as fuel for maritime transport (i.e. 20% of the total fuel) and for power plants.

In Figure 6, the share of particular technologies in electricity supply is illustrated for HighRES scenario.

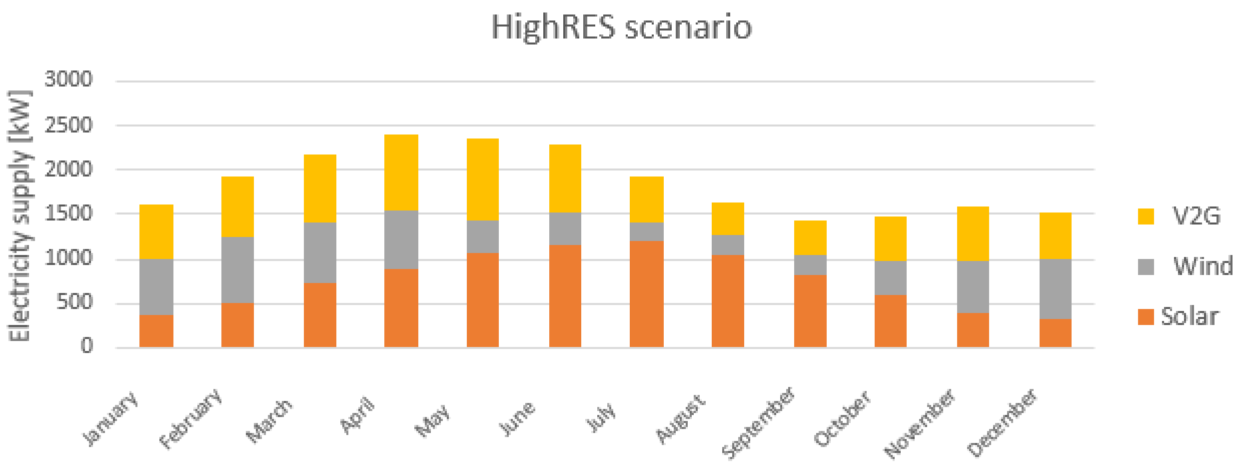

Figure 6 Share of RES in monthly average hourly production for HighRES scenario

2.2. Socio-economic feasibility of adopted solutions

Input data for all scenarios, regarding the prices of technologies implemented, are given in the table.

Table 5 Input data for techno-economic analysis on Favignana

2030	Investment	O&M	Lifetime
PV [kEUR/kW]	1	2%	15
Wind [kEUR/kW]	1,5	3%	15
EV [kEUR/unit]	30	6,50%	10
HPs[kEUR/unit]	5	2%	20
Solar collectors [kEUR/m^2]	800	5%	20

Results of modelling for all scenarios, in terms of investment costs, are given in the following figures. In Figure 7, the share in costs for production technologies is given, with “other” referring to the solar collectors cost.

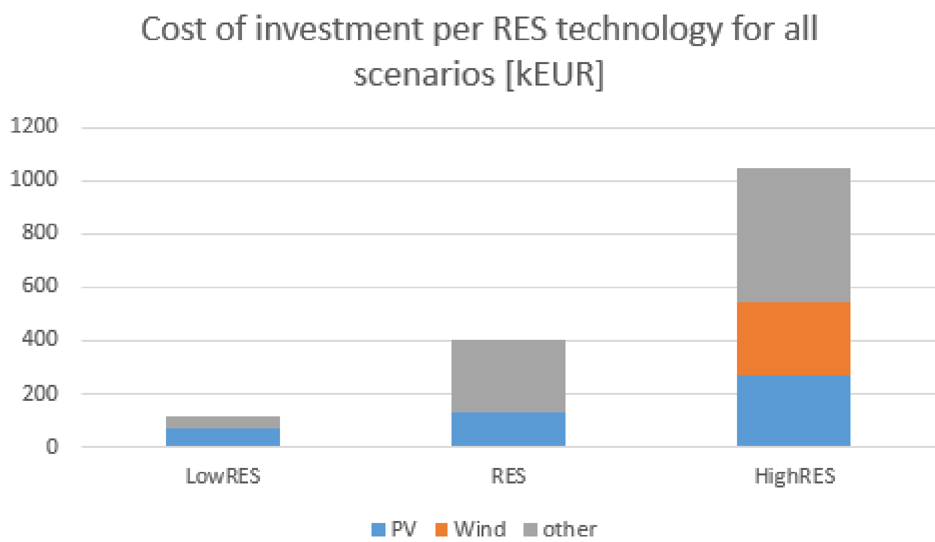

Figure 7 Share in costs for production technologies

In Figure 8, the cost of technologies for storage and balancing is given.

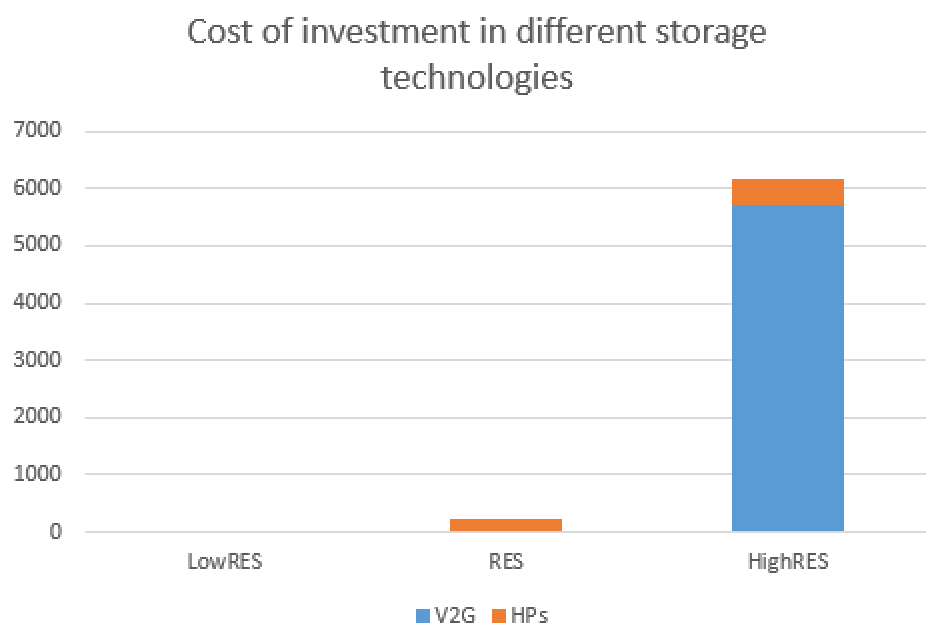

Figure 8 Cost of technologies for storage and balancing

The same scenarios have been modelled and simulated by means of the HOMER software. Exclusively the electric generators have been modelled and thus economic outcomes from HOMER are related to such generators and not to the entire system. The values of major interest are: LCOE (Levelized cost of electricity), Annual Worth (AW), Internal Rate of Return (IRR), Return Of Investment (ROI) and discounted Payback Period (PbP). Such values for the three scenarios are depicted in the table below.

Table 6 Economic analysis in HOMER

LowRES			RES			HighRES		
LCOE	0.2566	€/kWh	LCOE	0.2423	€/kWh	LCOE	0.2334	€/kWh
AW	357275	€/y	AW	569882	€/y	AW	2428445	€/y
IRR	27.9	%	IRR	24.7	%	IRR	24.2	%
PbP	3.63	y	PbP	4.07	y	PbP	4.55	y

As the RES share increase the LCOE decrease, thus the potential electricity price for inhabitants can be lower. The other economic factors reinforce such consideration. Of course, the PbP increase with the increase of the investment cost.
Table 7 and Figure 9 show the need for new jobs of each scenario in the number of full-time equivalents (FTEs). This is calculated based on solar PV, onshore wind power, solar collectors and, additionally, HPs.

Table 7 Number of full time equivalent jobs per scenarios of development of the energy system on the island of Favignana

2030	PV	Wind	Solar Collectors
LowRES	1	0	1
RES	1	0	1
HighRES	2	1	1

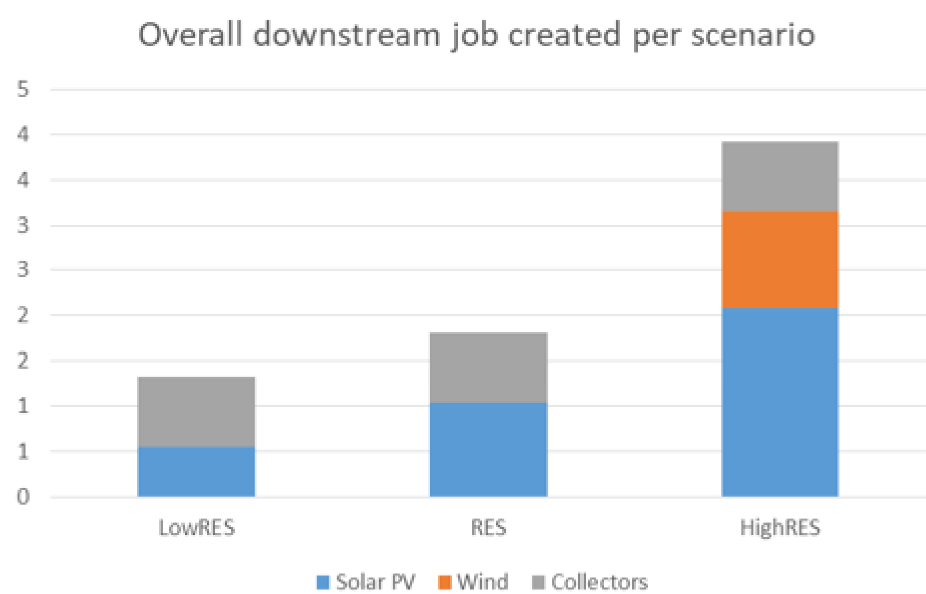

Figure 9 Overall local jobs creation per scenario

Furthermore, it has also been estimated the socio-economic benefits related to HPs that, assuming a 6kW nominal power per HP installed, would have a greater impact on the number of jobs created. In fact, supposing that all the installed HPs would be air-to-air and that their O&M would create the same number of Full Time Equivalent Jobs (FTEJs) per installed MW as solar collectors, they would create 5 new positions in the RES scenario and even 9 in the HighRES one.

2.3. Environmental considerations

Basic outline of influence of scenarios on environment, on two levels:

1) Reduction of GHG emissions

In the Figure 10, GHG emissions are presented, for each scenario. Also, for comparison, emissions in the base year are given.

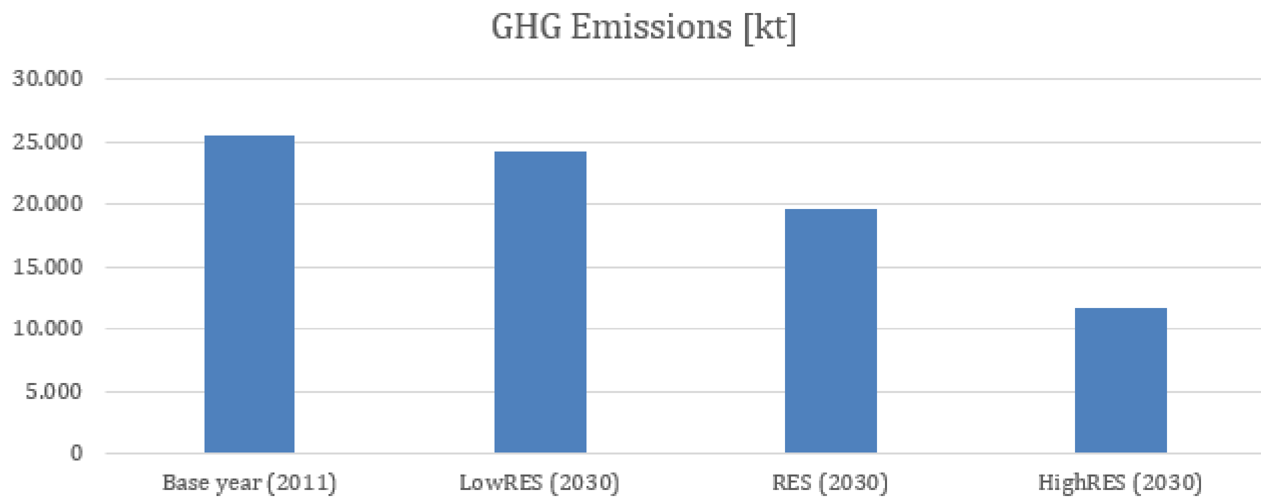

Figure 10 Comparison of emissions for all scenarios and compared to the base year

Since all fuel use in terrestrial transport is replaced with electricity use for EVs and solar thermal collectors and HPs replaced the use of Ngas in households and services, the emissions in HighRES scenario significantly reduced in comparison to other scenarios. The remaining emissions are all due to maritime transport.

2) Environmental constraints in the case study area, which influence the feasibility of scenarios

In Figures from 11 to 13, Favignana environmental constraints are depicted.

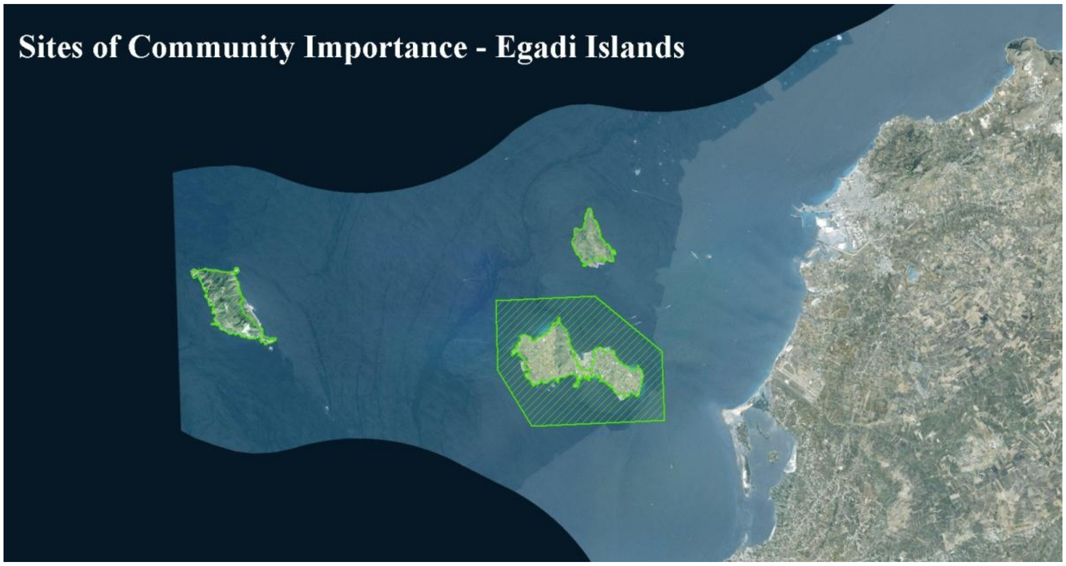

Figure 11 Egadi Islands, sites of community importance

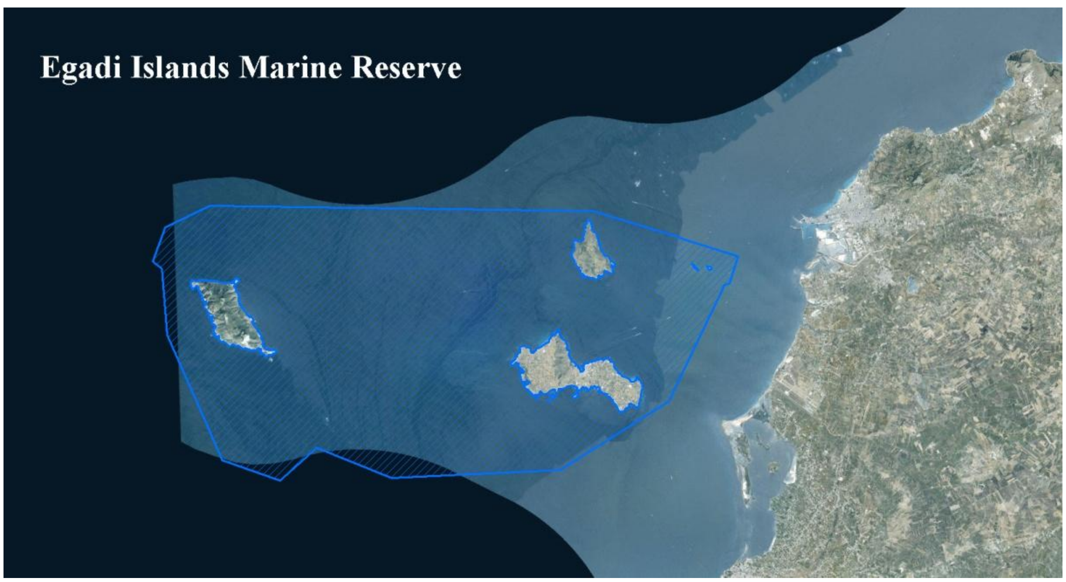

Figure 12 Egadi Islands, marine reserves

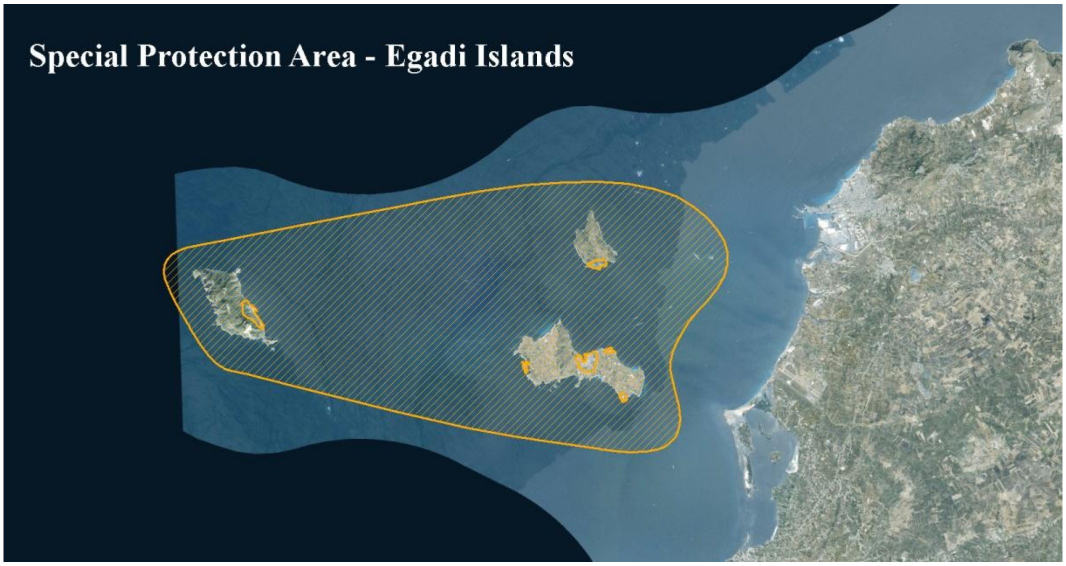

Figure 13 Egadi Islands, special protection areas

As clearly visible, the whole archipelago is almost 100% under environmental constraints, for this reason wind exploitation is forbidden both on and offshore despite its good potential.

2.4. Suggestions for strategy of development

The preliminary results obtained in this study confirms that Favignana has an interesting potential for solar resource that is not exploited, and an interesting wind potential. Although the good potential, wind energy is not exploitable because of environmental constraints. HighRES scenario outcomes shows that wind energy exploitation has a positive impact on the system when HighRES share is achieved since it tends to naturally balance the solar production. The preliminary economic analysis showed that high Investment costs are needed to renew completely the energy system, but such expenses would reduce the Levelized cost of electricity (LCOE) thus reducing the price for consumers and an interesting Return Of Investment (ROI). Furthermore, it could lead to a RES share in the electricity sector that is close to 100% (i.e. the only export needed is for biomass that cannot be produced on the island). Scenarios outcomes show that the heating sector can be easily renewed by means of solar collectors and HPs; the terrestrial transport sector renewal has a great potential in terms of carbon avoidance and positive impact to the grid by means of EVs in V2G mode; the last outcomes is that by far the main energy consumption is due to maritime transport a large part of which is linked to tourism and daily travellers (water delivery contributes for less than the 2%) thus a fleet renewal is the only intervention that could reduce GHG emissions linked to the maritime transport sector.

3. Conclusions

In the current study, the scenario approach in energy systems modelling has been used to model the future scenarios for Favignana Municipality. Moreover, the EnergyPLAN model has been identified as the main simulation tool for energy scenarios, owning to its user-friendliness and performance, proved through past research works. For the purpose of facilitating the future use of the PRISMI PLUS toolkit, various renewable energy sources were identified and modelled in the most ambitious scenario, as well as several energy system flexibility options (V2G, heat pumps). Thus, the subsequent development of an energy strategy is to great extent facilitated.

The methodology that has been applied includes the description of the case study and input data, the results of modelling accompanied by dedicated discussion, the socio-economic feasibility of adopted solutions as well as potential environmental considerations. All the energy scenarios analysed the diversification of RES production to serve the corresponding energy needs. From this study, interesting measures have been identified and then proposed as suggestions for the development of strategic energy planning documents.

Recapitulating, the present study has demonstrated the possibilities to increase integration of locally available renewable energy sources (more precisely, solar energy) and ways to achieve it.
Favignana's SECAP should undertake solutions able to exploit all the several RES that are present in the territory. Furthermore, it should incentivize the adoption of the opportunities presented in this study, namely the use of HPs in the heating sector and Electric Vehicles (EVs).
Such energy transition can lead the considered Municipality towards the sustainable and energy self-sufficient city concept and create new local job opportunities, putting the end-users in the centre of energy transition.

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