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LOCAL SUSTAINABLE ENERGY SYSTEM DEVELOPMENT IN AN INSULAR AREA : MUNICIPALITY OF TILOS, GREECE

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PRISMI

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 Tilos 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 Tilos 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 Tilos are made.

1. General definition of approach

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

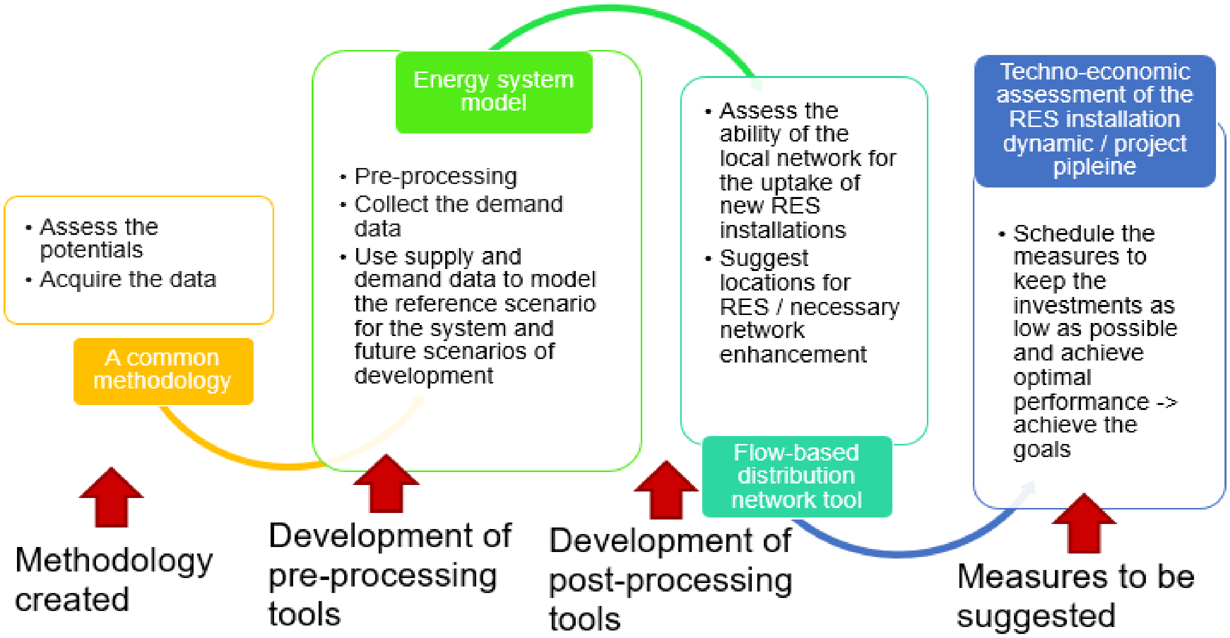

Figure 1 The PRISMI approach step by step

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

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 Tilos. Hence, the adapted methodology consists of the following actions:

Mapping the energy needs of the local municipality

Tilos and REGEA (Horizontal project partner) 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 a 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. Tilos Municipality indicated the following technologies: PhotoVoltaic (PV), Solar Thermal collectors (ST), Electric Vehicles (EVs), Wind Turbines (WT), Battery Energy Storage (BES).

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 Tilos Flagship Case (FC)

Tilos Island, comprising the demo-site of TILOS system, is located at the south-eastern part of the Aegean Sea and belongs to the far-remote complex of Dodecanese (~220 nautical miles from the central Greek mainland port of Piraeus). The island size is approximately 63 km^2 and its coastal perimeter is almost 63 km, with its terrain being basically semi-mountainous and mountainous, except for a long valley extending from the island center to its south. On the island, there are two main communities, Megalo Chorio (north part of the island) and Livadia (south-eastern part of the island), with a total island permanent population reaching approximately 533 habitants (255 and 278 respectively), increasing considerably (even tripling) during the summer period due to tourism. The current electricity needs of Tilos (in the order of 3.2 GWh per year – annual peak demand of approximately 1MW) are covered exclusively by the operation of the oil-fired power station of Kos Island (in the north of Tilos), through an interconnector (undersea cable of 20 kV) that reaches the north side of the island after first crossing through Nisyros island.

Concerning the breakdown of energy needs, out of the total electricity consumption of approximately 3.2 GWh, almost 300 MWh derive from public-use loads such as street lighting, water pumping and bores, with the rest being attributed to the local residential and service sector. This is largely owed to the fact that due to the mild climate conditions, the islanders largely rely on the operation of air conditioning units for both space heating and cooling needs, while it is approximately 1/3 of the local building sector that uses electrical water heaters for satisfying hot water needs.

Table 1 Mapping the needs of the island community - Tilos

Needs	Level	Geographical Distribution	Code
Electricity	Low	Concentrated	ElectLC
Heat	Low	dispersed	HeatLD
Cooling energy	Low	dispersed	ColdLD

Fuel for transportation	Low	Short dist.	TranLS
Water	Low	dispersed	WaterLD
Processing waste	Low	dispersed	WasteLD
Wastewater treatment	Low	dispersed	WWTLD

Table 2 Mapping the resources available - Tilos

Resources	Level	Code	Resources	Level	Code	Resources	Level	Code
Local primary energy			Infrastructure for energy imports			Water		
Wind	Medium	WindM	Network connection	Normal	GridN	Rainfall	Medium	H2OPM
Solar	High	SolarH	pipeline natural gas	n/a	n/a	Groundwater	Medium	H2OGM
Water potential (altitude drop)	n/a	n/a	Terminal LNG	n/a	n/a	Water supply	No	AquaN
Biomass	n/a	n/a	Oil terminal / refinery	n/a	n/a	Seawater	Yes	H2OSY
Geothermal potential	n/a	n/a	Terminal petrol. production	n/a	n/a			

<u>Solar potential</u>

The solar potential for the island of Tilos derives from in situ measurements for the projected implementation of the PV park in the island in the scheme of the Tilos Horizon 2020 project. Solar data are given in an excel file for each hour of the year (time series) both for horizontal and inclined plane. The following graph (represents the hourly solar irradiation distribution in an annual basis.

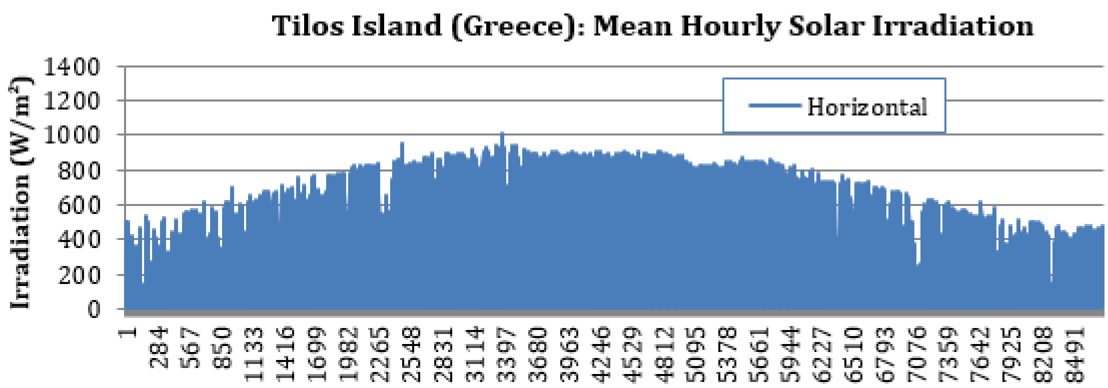

Figure 2 Tilos island, Irradiation at horizontal plane

Wind potential

The quite good wind potential of the island of Tilos is also given by in situ measurements from the wind mast implemented in the area where an 800kW wind turbine is going to be installed. Wind speed is given in hourly time series measured at 30m height.

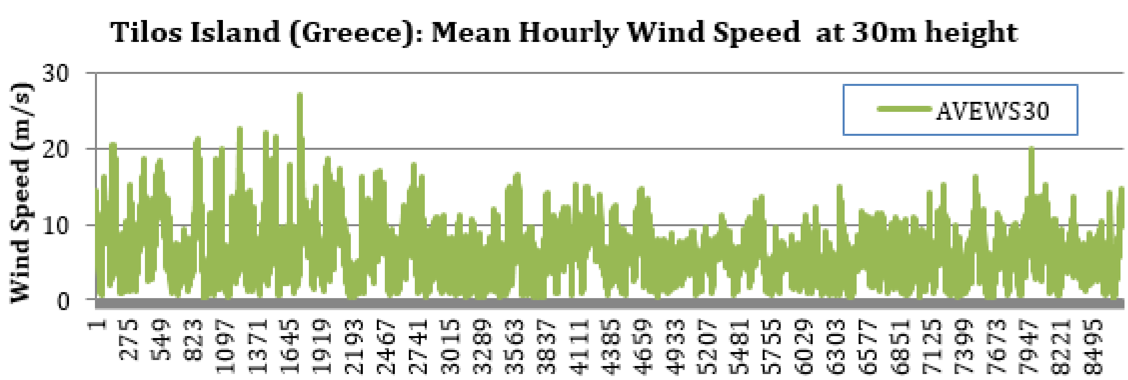

Figure 3 Tilos island, Mean Hourly Wind Speed at 30m height

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. In this phase for th Island of Tilos, the available area for PV installations was not estimated for buildings, but for an open area, as the island has semi-mountainous areas available for solar irradiance exploitation. The nominal power of 1 kW for PVs requires 6.5 to 7.0 square meters obtained surface. These conditions are applicable for Tilos island.

Other relevant resource is wind power, the wind potential may be determined as of medium-high quality (more than 6m/sec for the greatest part of the island territory. Water potential is too low in order to consider for pump hydro plants.

Other technologies, such as biomass exploitation, geothermal, tidal and wave energy have not been sufficiently explored and mapped to be taken into consideration.

Division of scenarios

Final, fourth step of the method is the division of scenarios. Energy system development of the Island of Tilos has been examined in three scenarios:

1) LowRES – following a low-RES exploitation scheme of the solar potential
2) RES – Increase of RES use, taking into consideration environmental constraints and legislative framework, based on the existing configuration of the island which was proposed in Tilos Horizon 2020 project
3) HighRES – Modelling for a ~90% RES energy system of the island

Currently, Tilos Sustainable Energy and Climate Action Plans were developed on the base of Tilos horizon 2020 EU funding innovative project, making Tilos a real case of a Mediterranean clean energy island.

These action plans were used in continuation of the research carried out throughout the last years in the view of increasing RES penetration in the remote islands of the Aegean Archipelagos [Kaldellis 2007], [Kapsali 2016]. Calculations based on this method are presented in the following table (Table 3), considering possible PV and wind installations, along with energy storage.

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 Tilos island, RES scenarios

	LowRES	RES	HighRES
PV [kW]	160	160	1000
Wind [kW]	0	810	810
EV [no. of vehicles]	0	100	0
EV charging rate/car [kW]	0	11	0
Storage Capacity[MWh]	0	2.88	2.88
Autonomy [%]	9%	70%	87%

2.1. Results of modelling and discussion

Results of modelling are presented in single figures for all three scenarios, to be easily comparable. For each scenario, the combination of RES sources is used, as presented in Table 4.

Table 4 RES sources contributions

LowRES		
RES prod.	0.27	GWh/year
Solar	0.27	GWh/year
Wind	0	GWh/year

RES		
RES prod.	2.29	GWh/year
Solar	0.27	GWh/year
Wind	2.02	GWh/year

HighRES		
RES prod.	2.69	GWh/year
Solar	1.31	GWh/year
Wind	1.38	GWh/year

Following these amounts of generated energy, Figure 4 represents the RES share in electricity production.

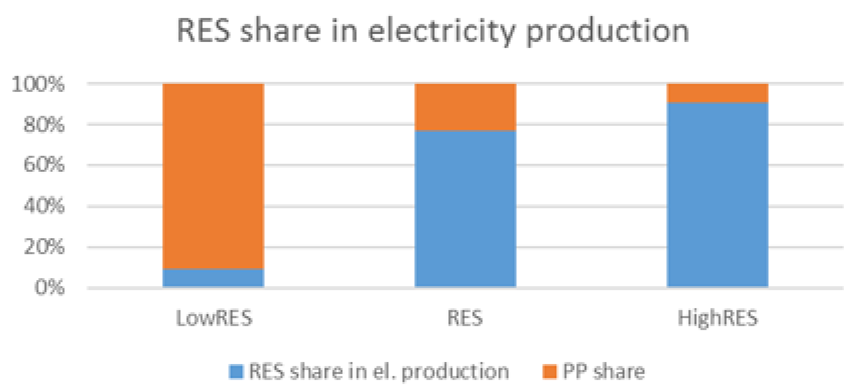

Figure 4 RES share in electricity production

As it can be observed, the Renewables contribution in LowRES scenario is low due to a small Photovoltaic (PV) plant, while the RES scenario already covers a very high percentage of energy production, due to high solar energy potential of Tilos and its corresponding medium-high wind potential. In RES scenario as well, the storage plays a significant role in increasing the renewables penetration, along with some EV. For the HighRES scenario, the wind and storage capacity is the same with the RES scenario, while the Photovoltaic (PV) plant's capacity is significantly increased, as PV technology seem to be the adequate one to cover the increased demand during the tourist period in the summer.

In the following figures, the share of particular technologies in electricity supply is illustrated.

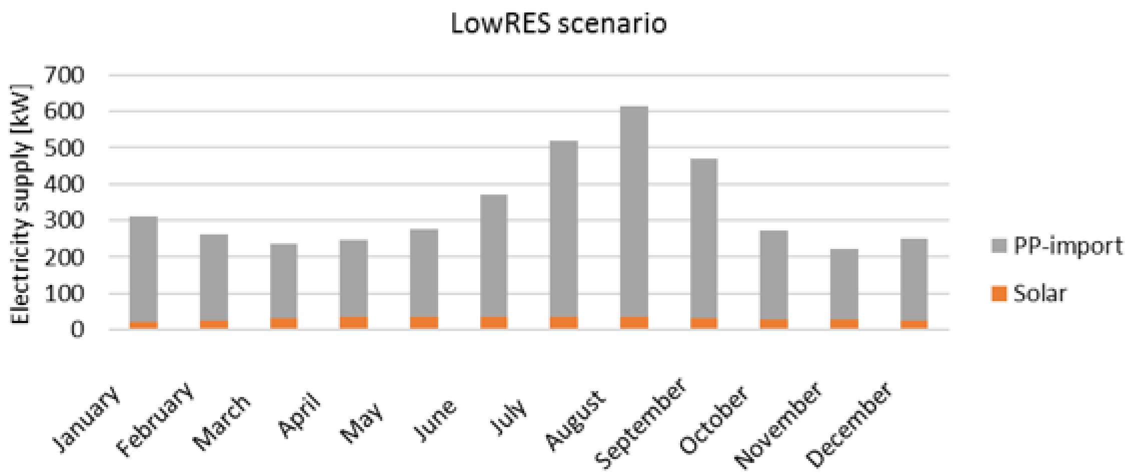

Figure 5 Share of RES in monthly average hourly production for the LowRES scenario

Vehicle-to-grid (V2G) represents the discharge from EV batteries, which is represented as additional supply in RES scenario, along with the storage system. In RES scenario the imports are significantly decreased mainly due to the wind energy exploitation.

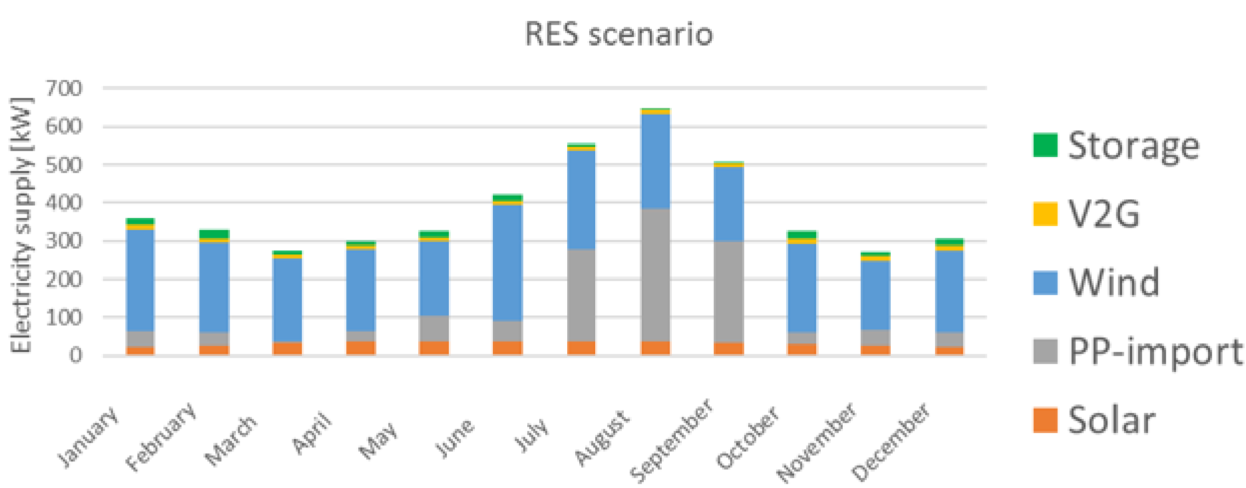

Figure 6 Share of RES in monthly average hourly production for the RES scenario

In HighRES scenario, solar energy is expanded in order to achieve higher RES penetration to the system. EV are not taken into account in this particular scenario, as in the previous RES scenario it seems that the 100 EVs do not contribute sufficiently to the minimization of the imports. Furthermore, it would be irrational to make estimations about a higher amount of cars considering the respective amount of Tilos residents.

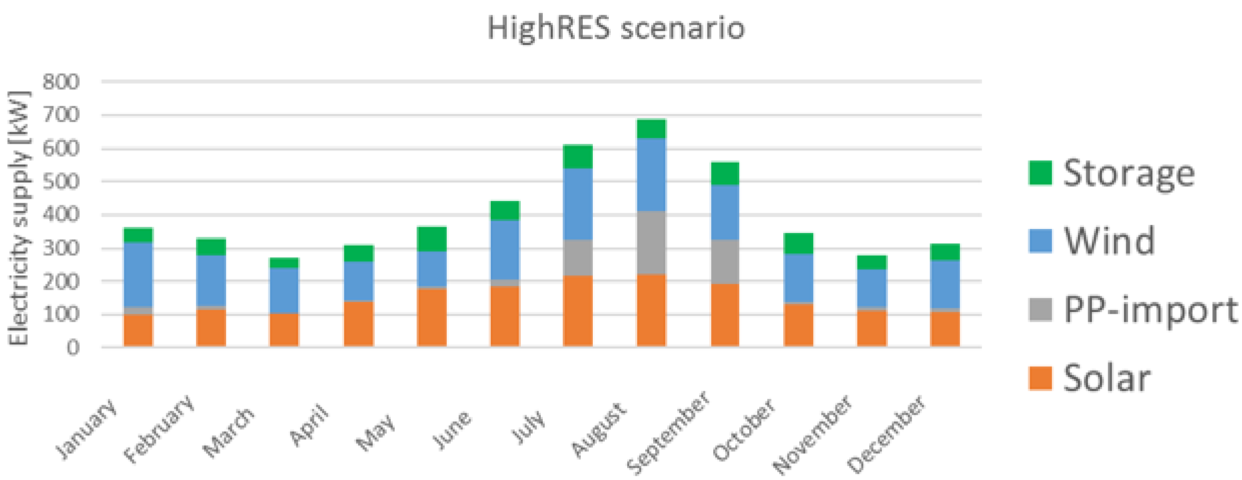

Figure 7 Share of RES in monthly average hourly production for the HighRES scenario

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 Inputs for techno-economic analysis on TIlos

	Investment	O&M	Lifetime
PV [EUR/kW]	813	2%	25
Wind [EUR/kW]	1500	1.7%	25
Batteries [EUR/kWh]	600	1.4%	15
EV[EUR/unit]	30,000	6,50%	10

Results of modelling for all scenarios, in terms of investment costs, are given in the following figures. In Figure 8, the share in costs for production technologies is given.

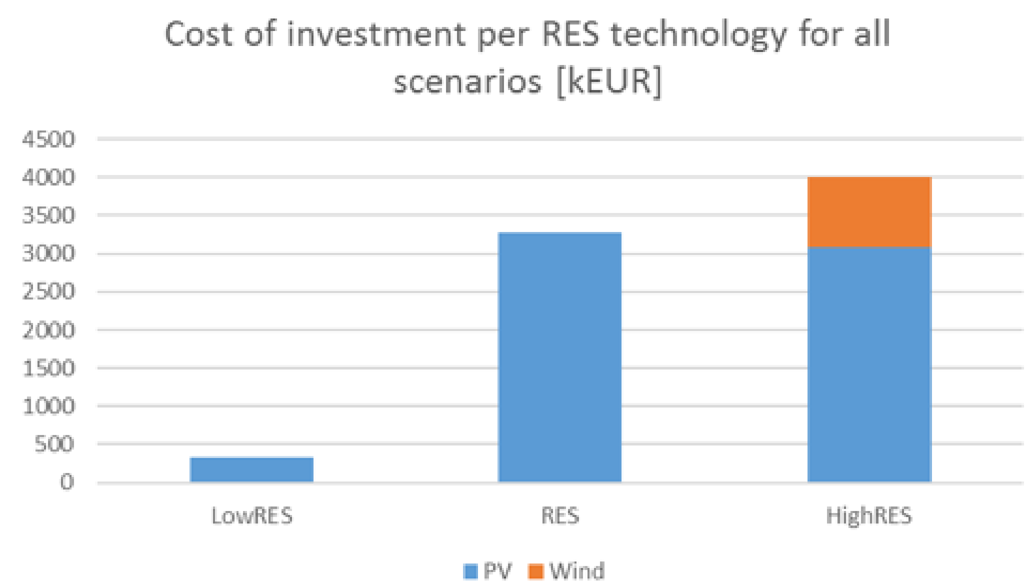

Figure 8 Share in costs for production technologies

In Figure 9, the cost of technologies for storage and balancing is given.

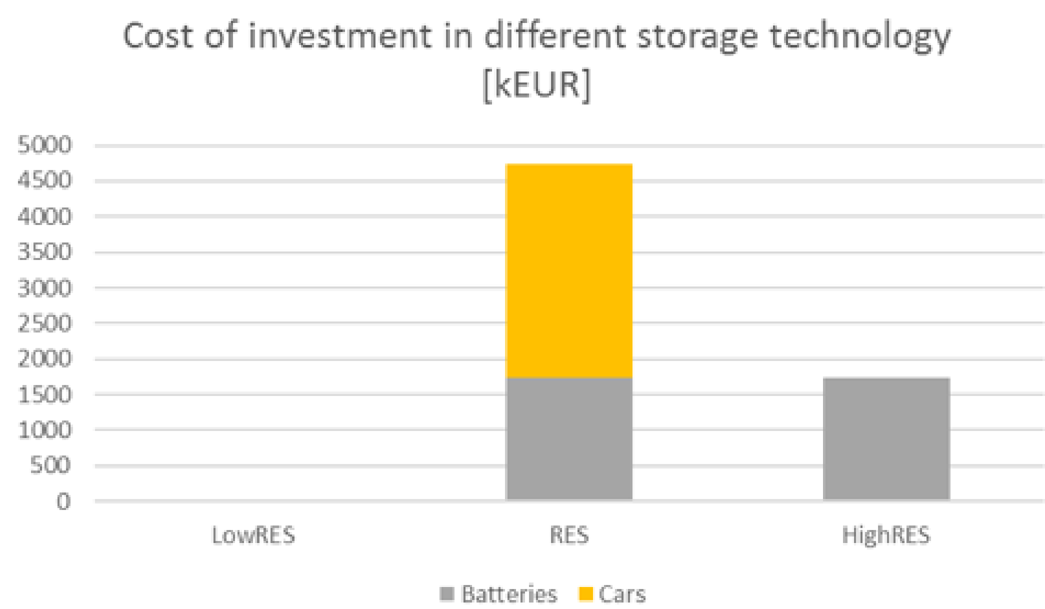

Figure 9 Cost of technologies for storage and balancing

The next table shows the need for new jobs each scenario in the number of full-time equivalents (FTEs).

Table 6 Number of full time equivalent jobs per scenarios of development of the energy system on the island of Tilos

2030	LowRES	RES	HighRES
Engineering	4	7	12
O&M	1	1	3
Instalation	4	7	17

Calculated for the last year of the analysis, 2030, FTEs need to be also taken in the context of dynamics of the transition, which includes yearly rates of installation for solar and wind power. For example, if 1 MW of solar PV are to be installed by 2030, with dynamics of roughly 10% being installed yearly from 2020 to 2030, local community would create roughly 1-2 jobs (FTEs), which would remain stable throughout this period. Further on, O&M jobs remain stable for the next 20 years period, with engineering and installation jobs occurring again during the repowering period (and according to the dynamics set in motion in the period of this analysis).

2.3. Environmental considerations

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.

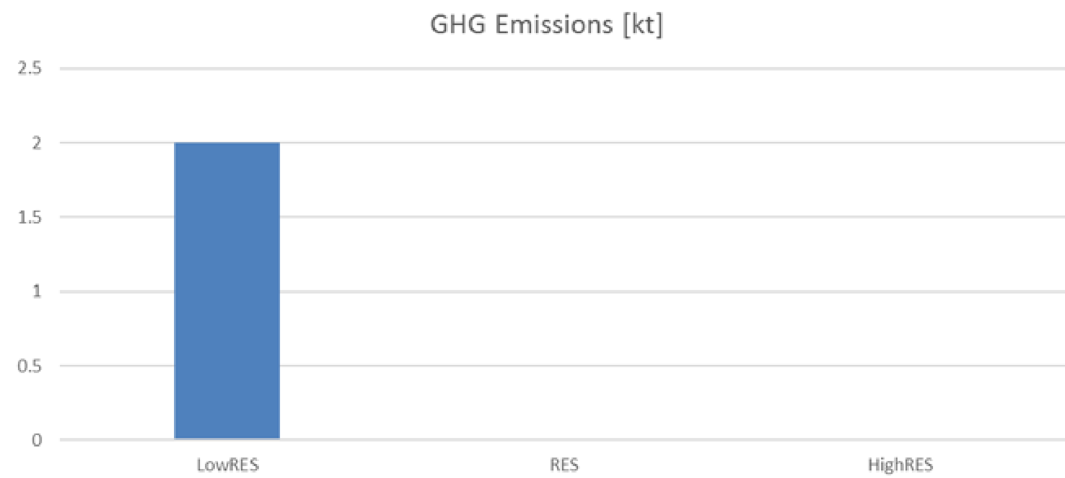

Figure 10 Comparison of emissions for all scenarios and compared to the base year

Since all fuel use in transport is replaced with electricity use for EV's in RES scenario and RES hybrid power station along with energy storage is introduced both in RES and HighRES scenarios, the emissions in HighRES scenario completely reduced.

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

Figure 11 illustrates how much of the area of island of Tilos is included in NATURA 2000 network as well as wildlife sanctuaries, which constraints the installation of any larger production facility.

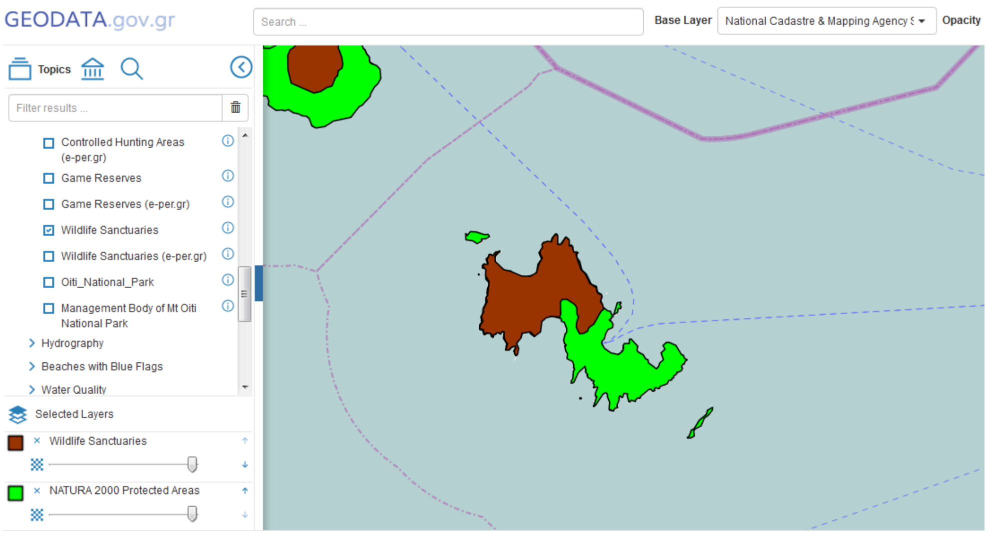

Figure 11 Natura 2000 network on the island of Tilos

From Figure 12, it is visible that there is a number of potential locations, in particular for PV and wind power plant, which could be exploited.

Figure 12 Locations for RES and other energy istallations which are suggested by the Strategic energy study

These locations remain in the plan for RES use as it is already proposed and recently implemented in the TILOS horizon 2020 project.

2.4. Suggestions for strategy of development

For the island of Tilos, some strategic scenarios have been drafted down for futher development. The overall development construction is based on the Tilos Horizon 2020 project that is already being implemented on the Island. In this context, some additional plans could include the following actions:

- Installation of integrated PV on residential buildings as net-metering systems
- Installation of a PV-carport for charging EVs through solar energy
- Extension of the island’s smart grid in more residential buildings
- EVs for the municipality services, such as electric school bus or electric trash trucks
- EVs for renting during summer touristic period

3. Conclusion

In the current study, the scenario approach in energy systems modelling has been used to model the future scenarios for the Island of Tilos. 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. Since the Tilos Horizon 2020 project that is already being implemented on the Island, to further reduce emissions, implementation of EVs and V2G system is advised, as well as further installations of PV. 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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