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The PRISMI Plus Toolkit Application to a Grid-Connected Mediterranean Island

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Abstract: Islands are a constrained environment due to their geographical peculiarities and their land use accounting for, especially in the touristic locations, strong variability during the year. Consequently, the variation of energy demand to be met by variable renewable energy leads to a complex issue. This study aims at investigating the PRISMI Plus approach applied to the Island of Procida to drive the transition towards low-carbon and high-renewable energy system. The toolkit involves the analysis of local renewable energy potential, their potential matching of the energy demand, and the prioritization of the technological solutions to achieve the decarbonization targets set by the energy planning strategies. Three scenarios are designed for 2030 considering low, middle, and high penetration of renewable energy in the systems, results indicate that the amount of power production in low, middle, and high penetration of renewable energy scenarios are 0.18, 14.5, 34.57 GWh/year, respectively. The environmental and landscape constraints lead to a restricted set of available solutions. The decarbonization of the electricity supply is foreseen thanks to the available local solar resources plus the electrification of other sectors, i.e. heating by using Heat Pumps and transport by using Electric Vehicles.

Keywords: EnergyPLAN; PRISMI Plus project; techno-economic analysis; urban energy systems; 50% renewable energy systems

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1. Introduction

Due to the increase in population and the amount of electricity demand, it is important to provide usable energy for consumers; adding scattered renewable resources in the distribution network can be an essential factor in achieving this goal [1]. Environmental awareness plays an important role in promoting sustainable energy consumption in households, strengthening the transition to low-carbon energy, and creating a carbon-free society in the EU by 2050 [2]; one of the most effective initiatives to preserve the environment and increase environmental awareness is the consolidation of primary and secondary environmental education [3]. The use of solar panels and wind turbines along with energy tanks can make hybrid energy systems reliable and affect investment costs [4]. Wind and water turbines are among the oldest technologies of the renewable energy industry, so the evaluation of the use of this equipment requires the examination of the technical and economic potential of each region [5]. The use of storage systems along with renewable energy systems has a very positive effect on energy management. Research has shown that the use of energy storage systems can improve the amount of available power [6] which exists all over the world, the supply of electricity they need, the estimation of the energy demand in the future, various parameters such as the amount of annual electricity consumption, the amount of power demand during peak hours and the amount of fuel consumption to produce electricity must be considered for the energy supply of the region. The use of hybrid renewable energy systems based on the combination of storage systems with existing systems is very suitable for reducing fuel consumption and for energy balance [7]. The use of renewable energy sources can reduce the amount of pollution, however, creating stability and energy balance between energy production and consumption is a challenging issue, which can be significantly improved by using energy storage. One of the energy storage hydrogen tanks has a low environmental impact and high-performance efficiency [8]. The results show that the use of hydrogen technology in constrained environments can reduce pollution and combined with other technologies and their modelling, can increase energy performance [9,10]. Dynamic electric load (DEL) prediction can have a positive effect on the flexibility of the power grid. DEL is obtained by maintaining simplicity and using modeling approaches; using data-driven methods can be useful [11].

In recent years, the use of hybrid systems using renewable systems has attracted the attention of many researchers. Due to the attractiveness of using energy storage systems in recent years, much research was conducted regarding the effectiveness of energy storage systems in renewable energy systems. A fuel cell is considered. The results of research that selected hydrogen storage as an energy storage tank, show that storage systems could have a good effect on energy balance, and the combination of renewable systems and energy storage can reduce the price of each kilowatt hour of energy [12]. A safe and reliable energy production network depends on various factors, including the investment cost of the power plant or network and the return on investment on the one hand, and on the other hand the conditions on the power of the network, including the rate of energy loss, the voltage level, and maintenance costs are adequate [13]. Among the parameters that can affect the use of the renewable system, the correct installation and choosing the right place are very important. Research has shown that various factors, such as the type and temperature of the panel as well as the amount and angle of irradiation, can affect the efficiency of solar panels [14].

Increasing the use of photovoltaic panels in intelligent systems is a significant challenge because the amount of power produced by large golden panels is intermittent; predicting the amount of energy obtained from solar panels is a complicated task, and estimates are problematic [15]. Although the use of wind turbines has reduced greenhouse gases and has positive effects on the environment, it is very difficult to check the operation of wind turbines because their efficiency depends on the behavior of the wind. For balance, energy storage systems, batteries and water pumping storage sources, and hydro turbines can be used [16]. Today, many countries around the world have the desire to make their cities smart and to be able to optimize their energy production systems through smartness. In this regard, smart designs need to be installed with various sensors and actuators. With the microcontroller that has many processing capabilities, it can automatically control the system and decide the amount of production based on energy consumption [17]. There are many challenges in the field of controlling greenhouse gases and preventing climate change. Creating energy commitments can have a significant effect on improving the climate.

Many Mediterranean islands are not connected to the electricity grid and independently produce the amount of power they need. The most critical problem is the use of fossil fuels, which cause environmental pollution, also considering the energy demand per month. Energy supply in these areas is a big challenge; the research conducted on these islands show that by examining and forecasting a 20-year period from 2016 to 2036, if the amount of energy consumption increases, 30% to 40 to 70% of new sources of electricity production should be anticipated to supply the required power; in addition, in case of increasing the use of renewable energy systems and energy storage tanks, the price of each kilowatt hour of energy can be increased to 17–36% [18].

Today, the price of connecting the islands to the electricity grid is very high, and on the other hand, most of the islands in the world supply their energy needs with diesel generators and fossil fuels, which cause environmental problems for the regions. A study in arid land shows that the use of renewable energy sources could be used together with batteries and internal combustion engines with biogas fuel. It will be very fruitful to eliminate excess energy in the proposed plan by turning it into freshwater [19].

The effect of decentralization of ecosystem energy processes is presented by Paolo et al. [20]. This research examines the relationship between energy processes and ecosystem services. This research, which includes 150 heating systems in Italy, showed that there is a gap between the efficiency of heating and traditional energy systems. Many countries have started planning for 10 or 15 years to use renewable energy. Pakistan is the sixth most populous country in the world and ranks thirty-seventh in terms of energy consumption. According to the planning, Pakistan is increasing its 30 GW capacity to 50 GW by using hydro sources, wind turbines, and solar panels [21].

Extensive research was carried out by PRISMI on the analysis of the electricity network of the Mediterranean islands. This research, which includes checking size and voltage limits [22], introducing energy designs with EnergyPLAN software [23], checking the construction of smart buildings with renewable systems in islands [24], analyzing the effect of using electric devices on energy production [25], analyzing the use of batteries and energy storages in increasing the independence of the island's power grid [26], introducing practical strategies to balance energy production and demand [27], analyzing the effect of using wave energy in the islands [28], and analyzing the technical and economic evaluation of the use of solar thermal energy in the Mediterranean islands [29], led to the planning of carbon reduction and the energy production trend of renewable systems were predicted until 2030 [30].

2. Literature Review

Dehghani-Sanij et al. [31] have provided an experimental solution for the use of wind turbines independently and alone or in combination with other energy sources, and a basis for evaluating energy growth while evaluating the use of wind turbines in different regions of Canada from a technical and economic point of view.

Nastasi et al. [32] were able to predict dynamic electric load patterns and improve the algorithmic formula by using data-oriented approaches and using the technique of Time of Week a Temperature (TOWT).

Hoseinzadeh et al. [33,34] have investigated the economic and technical use of renewable systems in meeting the energy needs of the region. They show that correct technical and economic strategies can not only improve the performance of the system but can also be fruitful in reducing investment costs and production costs. Although the use of renewable systems can meet the demand of the region and reduce pollution reliably, due to the speed of change in construction technology, the start-up costs are largely high compared to traditional systems. Therefore, the correct estimation of the energy demand of each region, the selection of the appropriate size of the production equipment according to the climate potential of the region, and the selection of the appropriate location are among the things that should be considered in the construction or optimization of energy systems [24].

Maleki et al. [35] have calculated and introduced the effective cost of their hybrid system by using different algorithms while checking the appropriate size of photovoltaic panels, wind turbines, and energy storage tanks in hybrid systems.

Mancini et al. [36] estimated the amount of power produced by photovoltaic panels by means of their model, which included neural networks and wave conversion relationships. The results of Groppi et al. [37] show that the use of hybrid systems, including photovoltaic panels, wind turbines, and diesel generators, could meet the demand for energy on the island. Those analyses should always combine energy and comfort to provide efficient and effective performance.

Ahmadpour et al. [38] investigated the effect of energy commitment letters on public welfare. They show that public welfare could be increased by applying energy commitment letters. Evidence shows that the calculations made on the design of the buildings are far from the measured value and the validation of the predicted calculations is a difficult task.

Heydari et al. [39] presented a new hybrid strategy based on intelligent approaches to predict energy consumption. They based their strategy on three stages: examining the socio-economic effect and energy consumption, examining the historical and socio-economic classification of energy consumption methods, and developing a new hybrid method by applying the combination of Adaptive Neuro-Fuzzyerence System and Whale Optimization Algorithm methods. The results of their simulation show that using the data from 1992 to 2020 of two samples examined in Iran and Italy, there is good accuracy and stability in predicting electric energy consumption compared to existing hybrid and single models.

Alves et al. [40] investigated the use of renewable energy in independent islands. They examined the two principles that exist in inadmissible systems and simulated their scenario with energy plan software. The usage rate of their reflective energy system was 50% in the year 2030. In their opinion, the research shows that they could be suitable for receiving energy systems, and fossil fuels in the islands.

Assareh et al. [41] provided tools for designing energy production systems using a high percentage of renewable energy sources. In this research, they focused on Photovoltaic/Thermal (PV/T) systems and energy generation through tides. They believe there should be a necessary balance between production power and consumption power according to Climatic Conditions [42].

In this study, the PRISMI PLUS toolkit implementation for Procida 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 Procida as well as the modeling and the pre-and post-processing tools. Current and foreseeable energy scenarios were developed and compared based on the local RES potential data, which is also presented in this document. In detail, by means of the simulation tool (EnergyPLAN model), innovative energy production technologies were considered.

First, the general definition of the approach is briefly described. 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 (EnergyPLAN model), and the post-processing tool can all be found on the PRISMI PLUS website [43].

Then, the current feasibility study is presented, in which the modelling 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 elaboration 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 area development of the case study.

3. Materials and Methods

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

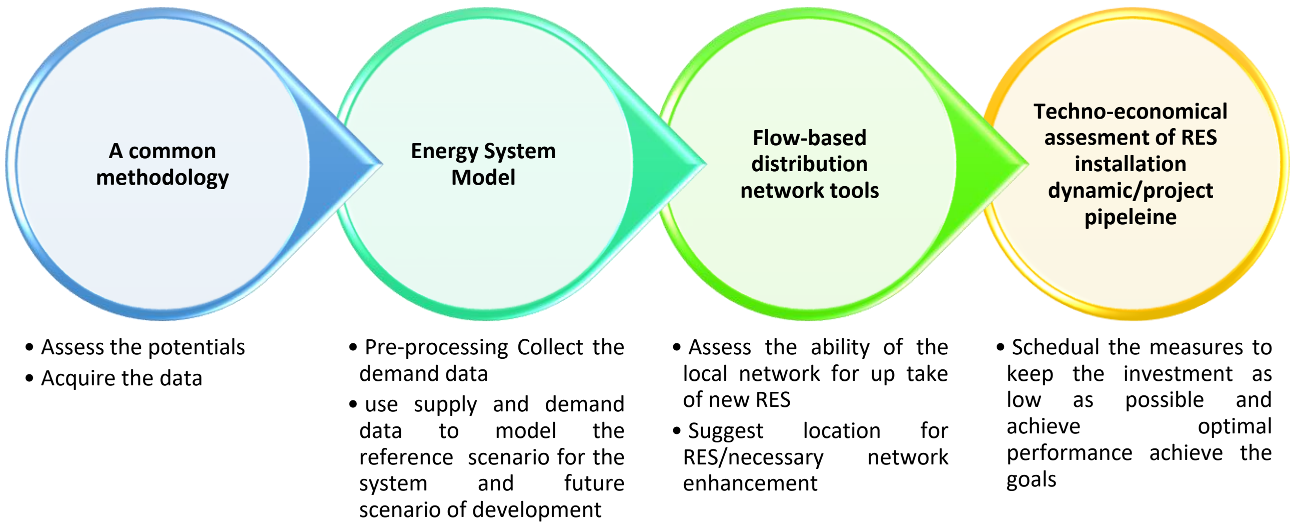

Figure 1. The PRISMI PLUS approach step-by-step.

3.1. General Framework Method for Devising the Future Development Energy Scenarios for the PRISMI Plus Case Study Considered

As a first step to devising the scenarios, the RenewIslands methodology (described in D3.1.1 of the PRISMI project) should be followed, and dedicatedly adapted to Procida FC. Hence, the adapted methodology has consisted of the following actions:

(1) Mapping the energy needs of the local municipality

Procida 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.

(2) 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 by the dedicated web tool "Renewables.ninja" [44] since the only renewable source that can be exploited is the solar resource.

(3) 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 in the location of the local municipality, are considered for the scenarios' analysis. The Procida Municipality indicated the following technologies: Photovoltaic (PV), Solar Thermal collectors (ST), Electric Vehicles (EVs), Heat Pumps (HPs), and Battery Energy Storage (BES).

(4) Division of scenarios

The energy system development is examined through three scenarios. 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.

The fourth step of the PRISMI PLUS method is the division of scenarios. The energy system development for Procida Municipality was examined through the following three scenarios:

Scenario 1	During this scenario, the electricity consumption of the whole island, as provided by Procida Municipality itself, is considered. This scenario is used as a baseline scenario since no other installation/investment are analysed.
Scenario 2	During this scenario, the partial electrification (i.e., 50% of the total consumption) of the heating sector and the transport sector is analysed by means of the installation of HPs and EVs, respectively. In addition, the investment on PV and BES is analysed in order to reach a 50% RES share.
Scenario 3	During this scenario, the full electrification (i.e., 100% of the total consumption) of the heating sector and the transport sector is analysed by means of the installation of HPs and EVs, respectively. In addition, the investment on PV and BES is analysed in order to reach a 100% RES share.

In scenarios 2 and 3, EVs are enabled only for smart charging; no Vehicle-To-Grid (V2G) is allowed. Further considerations will be elaborated based on the year 2030. Table 1 shows the installed PV capacity for the 3 scenarios together with the overall surface occupied by PVs; this information is provided in the form of a range considering that surface area requirement for roof-mounted PV systems can range between 6 and 10 m^2 per installed kWp depending on the technology and the installation site.

Table 1. Input data for the energy system scenarios in Procida Municipality.

2030	Scenario 1	Scenario 2	Scenario 3
PV installed capacity [kW_p]	305	9650	23,200
PV surface range [m^2]	1800–3000	57,000–96,000	139,000–232,000

Figure 2 shows the electricity demand variation between the scenarios due to the increasing electrification of demands.

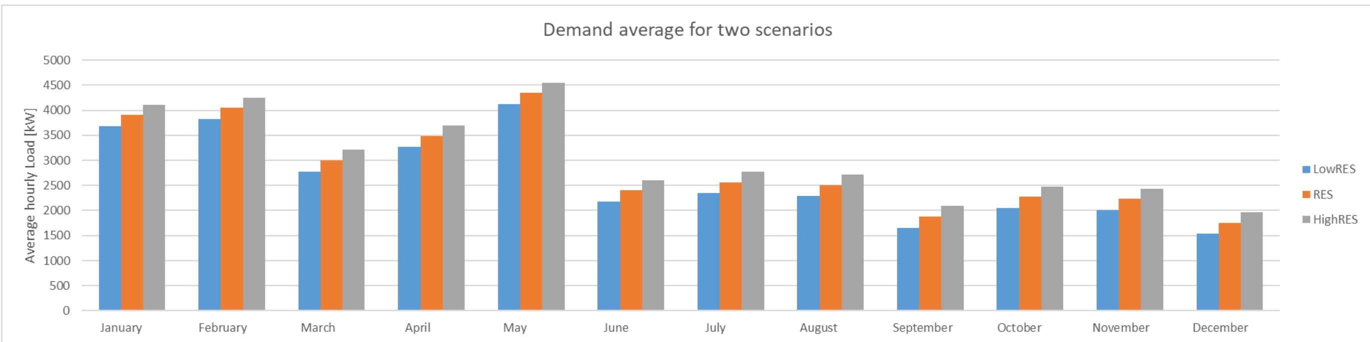

Figure 2. Average monthly load demand for Procida Municipality in 2030 for all scenarios.

Input data for all three scenarios regarding the prices of the PV technology are presented in Table 2.

Table 2. Initial inputs for techno-economic analysis.

2030	Investment	O&M	Lifetime
PV [kEUR/kW]	0.7	1%	25

One of the most important social parameters, which is investigated by recent studies, is the number of newly created jobs related to the PV industry [45–48]. The implementation of PV systems in the Procida Municipality will create the need for new jobs, such as those related to the management, installation, and maintenance of these systems, as well as administrative tasks. It is worth noting that O&M jobs remain stable for the next 25-years, 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).

3.2. Case Study Examined—Procida Municipality Flagship Case (FC)

Procida is the smallest of the three islands comprising the Gulf of Naples, after Capri and Ischia. Procida has an area of 4.26 km^2 and is located 3.4 km from the Phlegraean peninsula and is the closest to the mainland of all the islands in the Gulf of Naples. The municipality of Procida covers the entire island as well as the small neighboring island of Vivara (0.4 km^2), which is a nature reserve. The island's population in October of 2019 was estimated to be 10,428 inhabitants with a density of 2449.1 inhabitants per km^2. Concerning the electricity supply, Procida is connected to the mainland and then to the island of Ischia, another island of the Gulf; the size of the cable was assumed to be 11.67 MW by analysing the peak power of the electricity load profile provided by the Procida Municipality itself that is equal to 9.72 MW that was oversized by a factor 1.2 to obtain the value of 11.67 MW.

The island is strongly dependent on electricity imports, as the possibilities for local energy production are limited. Indeed, only a few distributed PV units are installed on the island with an overall peak power of 305 kWp with a yearly production of 184 MWh/y. The coast is a protected marine area and thus wind turbines are not a viable option. Procida is also a popular tourist location, especially during summer. This results in intensive seasonal loads that sometimes lead to grid congestion issues even though this is not found in the electricity load profile that was provided by Procida Municipality. It can be assumed that the issues are caused by the island of Ischia which is a much more important tourist destination and might cause overloading on the grid that also affects the island of Procida, which is connected to the same cables. The overall electricity demand was not estimated by the Procida Municipality; thus, it was evaluated with the hourly values that were provided. Nevertheless, the overall consumption was equal to 85 GWh in 2018 and 66 GWh in 2019. Comparing such values with those used in the SECAP, related to the year 2010, it should be in the range of 20 GWh (20.99 GWh from the DSO and 20.37 GWh with a bottom-up approach). Such a large difference led us, in agreement with Procida Municipality, to consider the consumption data from the SECAP which was increased by 1% in order to obtain the final consumption that was used for simulation that is equal to 23.19 GWh/y in 2020 and 25.61 GWh/y in 2030.

Table 3 shows the energy consumption subdivided into energy vector and energy consuming sector as provided by the Procida Municipality.

Table 3. Consumption details.

Consumption	Energy Vector	Value	Unit
Heating	Diesel	1281	MWh/y
	Coal	269	
	Biomass	11,434	
	GPL	13,193	
	Oil	1300	
Transport	Gasoline	6279	
	Diesel	6627	
	GPL	893	

Regarding the heating sector, no information on the use of HPs was provided, so the baseline does not consider this technology. Solar thermal collectors are considered for a total installed surface equal to 124.36 square meters. Following a dedicated mapping of the locally available RES, it is derived that the solar energy potential is remarkably high, with the annual solar irradiation at the level of 1900 kWh/m^2 [49]. The hourly solar radiation variation, with the raw data time series is retrieved from the web tool "Renewables.ninja" [43]. Figures 3 and 4 show the hourly Solar Radiation on Horizontal Surface and hourly capacity factor for PV panels in Procida "Renewables.ninja".

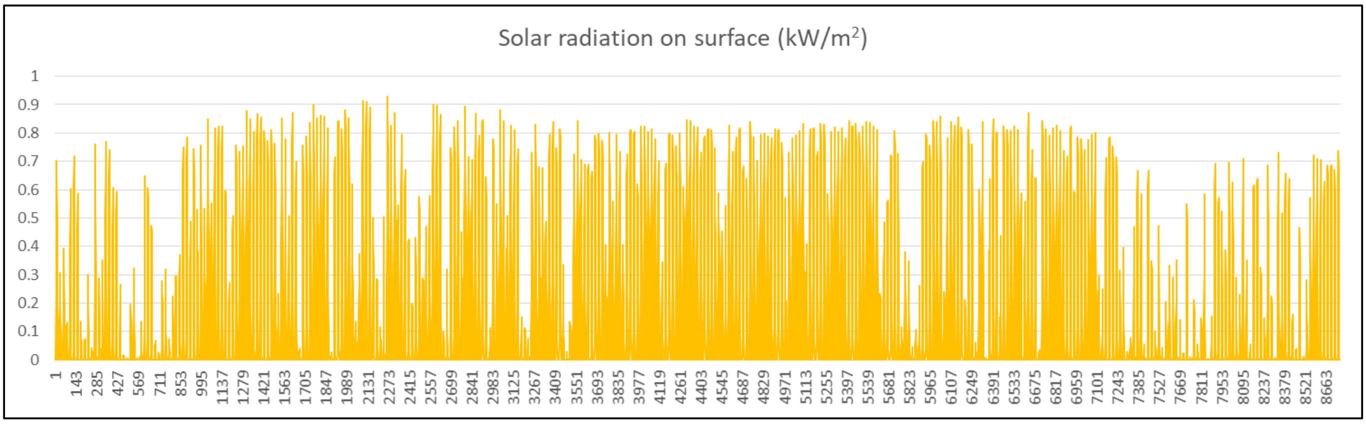

Figure 3. Solar Radiation on Horizontal Surface in Procida in hourly time.

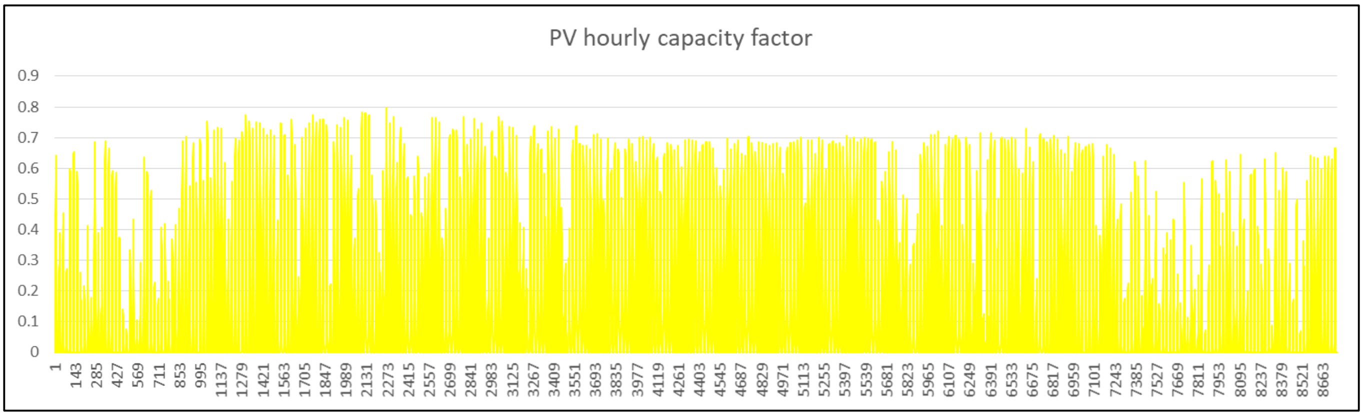

Figure 4. PV hourly Capacity Factor in Procida.

4. Results and Discussion

In the following, the simulation (modelling) results are presented, in order to be easily understood and compared. Figure 5 shows the RES share in primary energy supply (PES). For each scenario investigated, the combination of RES deployed is presented in Table 4.

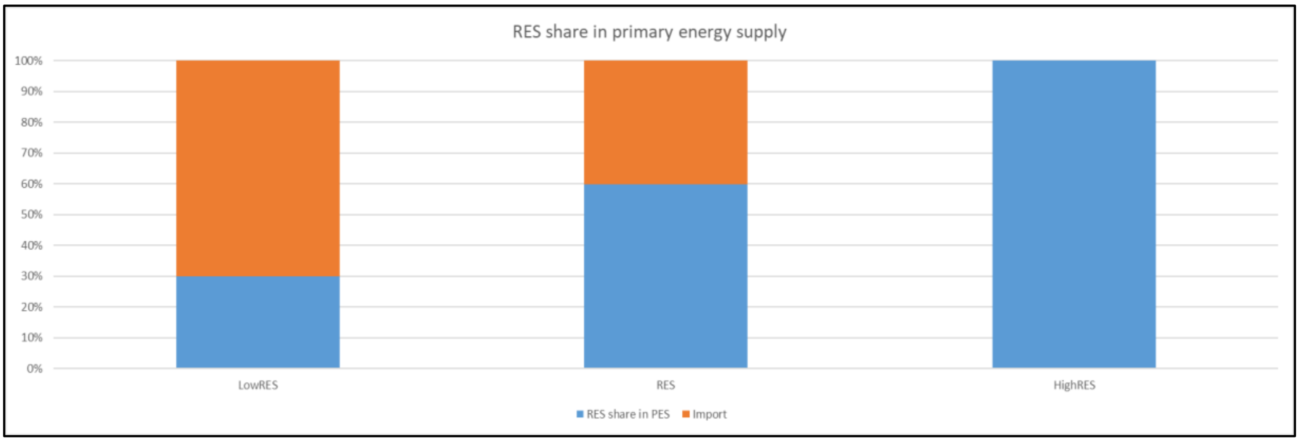

Figure 5. RES share in primary energy supply.

Table 4. Results of modelling—energy generation from RES.

	PV Production	
Scenario 1	0.18	GWh/year
Scenario 2	14.5	GWh/year
Scenario 3	34.57	GWh/year

Moreover, based on the previous amounts of energy generation, Figure 6 represents the RES share of the electricity supply.

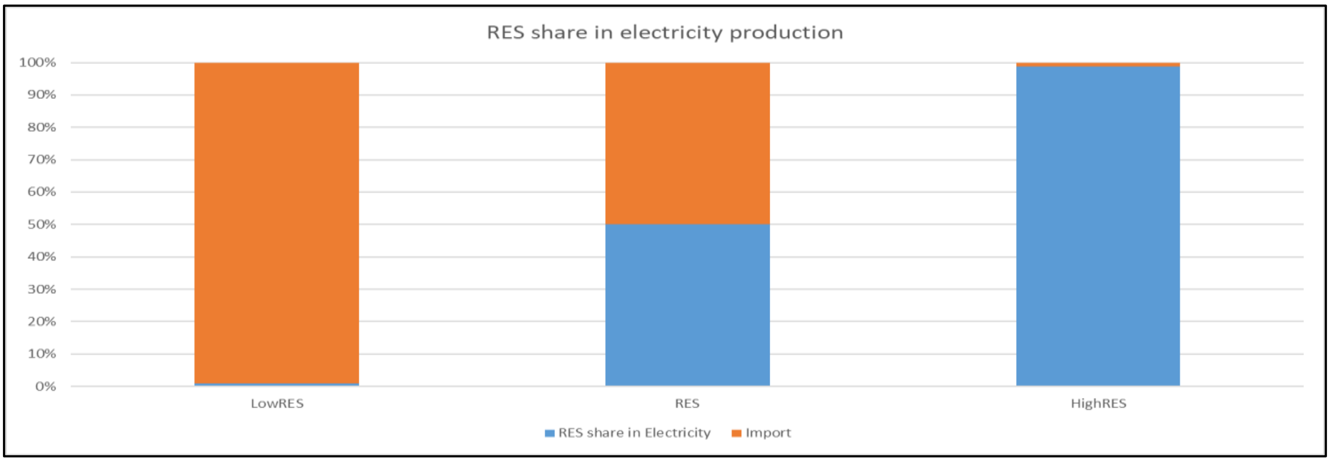

Figure 6. RES shares in the electricity supply.

A great diversification can be noted in the percentages of the RES share in electricity supply. In Figures 7–9, the average monthly values of PV systems' output power are depicted for the three scenarios investigated.

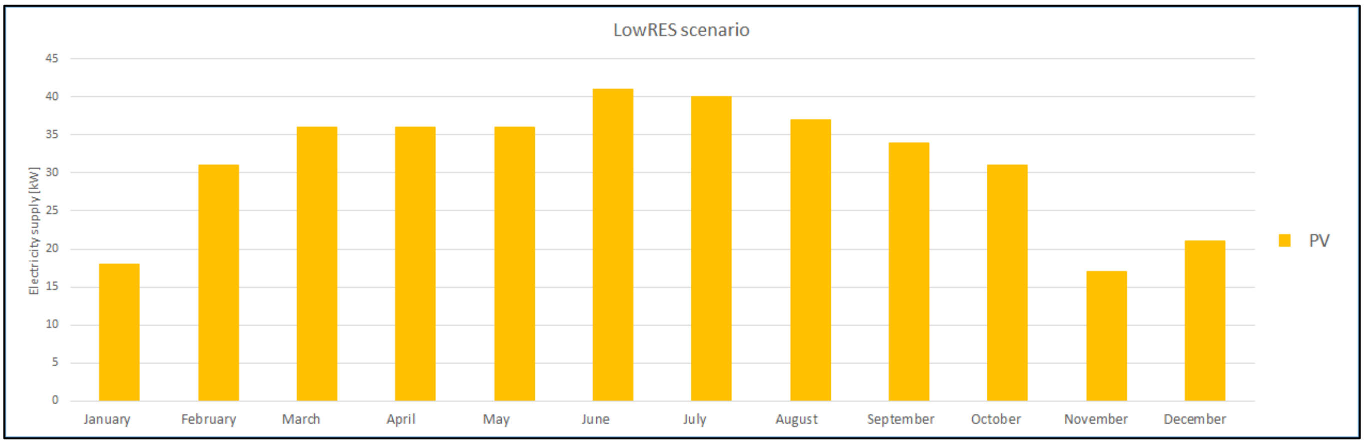

Figure 7. Average PV systems' output power values for Scenario 1.

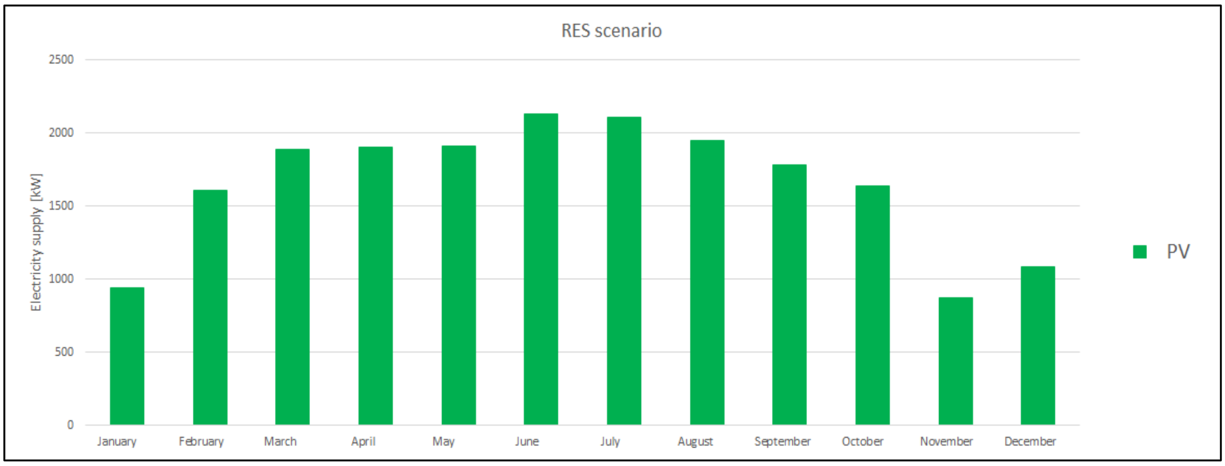

Figure 8. Average PV systems' output power values for Scenario 2.

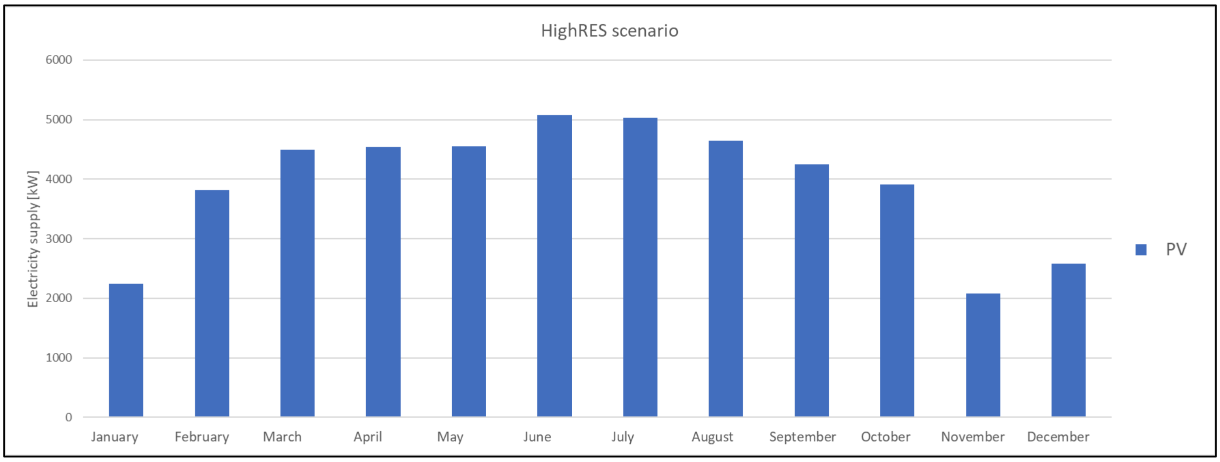

Figure 9. Average PV systems' output power values for Scenario 3.

Figure 10 presents the number of full-time equivalent (FTE) jobs in each scenario investigated for 2030. Calculated for the last year of the analysis (2030), FTEs also need to be considered in the context of dynamics of the energy transition, which includes annual rates of installation for solar power.

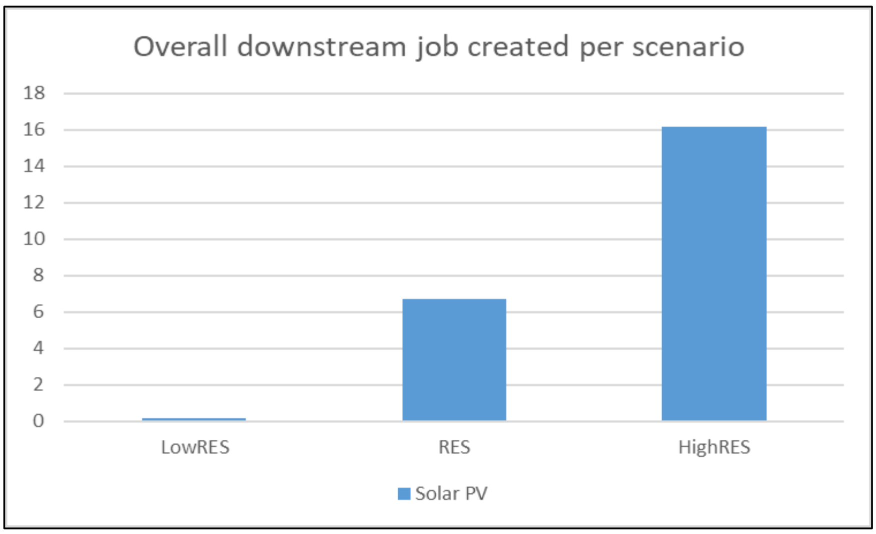

Figure 10. Overall downstream job position creation per scenario for Procida Municipality.

4.1. Environmental Considerations

The reduction of Greenhouse Gases (GHG) emissions is shown in Figure 11 which presents the GHG emissions for each scenario investigated. For comparison purposes, the GHG emissions in the base year are also presented. Since the use of fossil fuels currently employed for electricity generation is partially substituted, the GHG emissions are to a great extent reduced.

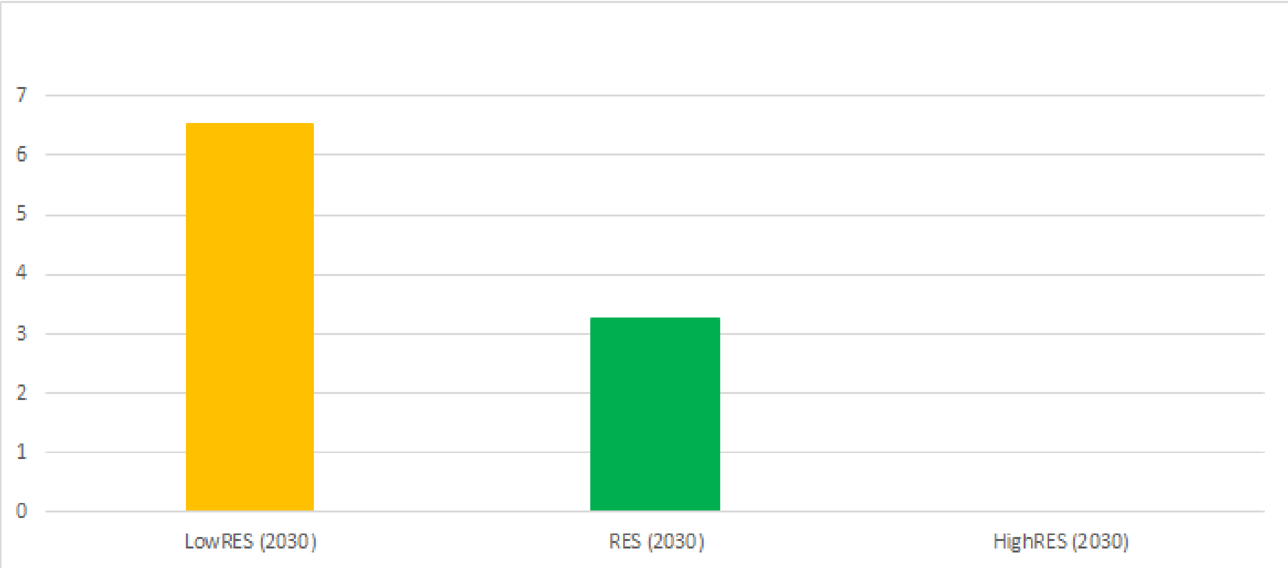

Figure 11. Comparison of GHG emissions for all scenarios as compared to the base year GHG emissions.

4.2. Solar Thermal Collectors' Analysis

In this section, the impact of solar thermal collectors' installation on the island of Procida is analysed. The analysis was carried out in Scenario 1 and Scenario 2 since in Scenario 3 there are no relevant results. The study was carried out as a sensitivity analysis with the ST values ranging from a value of zero, which reflects the results of the scenarios as previously presented, to a value of 100%, which consists of an amount of installed ST able to generate 21.59 GWh/y of heat, thus able to cover the whole heat demand of Procida. In these scenarios, each ST was supposed to have a storage capacity of one day. Figure 12 shows the results in terms of CO_2 emissions and RES share in Primary Energy Sources (PES).

From the graph, it is understood that solar collectors would surely reduce GHG emissions and increase the RES share in Primary Energy Sources. Such an effect would be slightly more impactful in the case of a fossil-fuel-based energy system such as the baseline scenario (in yellow, in Figure 12). Indeed, in the case of a 100% RES share system where the heating system is completely electrified through HPs (Scenario 3), the introduction of solar collectors does not increase the RES share, nor does it reduce the emissions that are already equal to zero. The installation of solar thermal collectors should therefore be considered case-by-case and could reduce the need for HPs and thus the overall electricity demand along with the peak power consumption thus supporting the weak interconnection with the mainland. On the other hand, it would decrease the system flexibility and potentially expose the grid to stability issues. In addition, the occupied surface, which would not be available for PV installation, could be an important factor. Indeed, in the baseline scenario, 124 m^2 of solar thermal collectors are installed in the scenario in which ST should cover 20% of the heating demand and roughly 4000 m^2 should be covered, around 8000 m^2 in the 40% scenario, 12,000 m^2 in the 60% scenario, 16,500 m^2 in the 80% scenario and finally 20,500 m^2 to supply the whole heating demand.

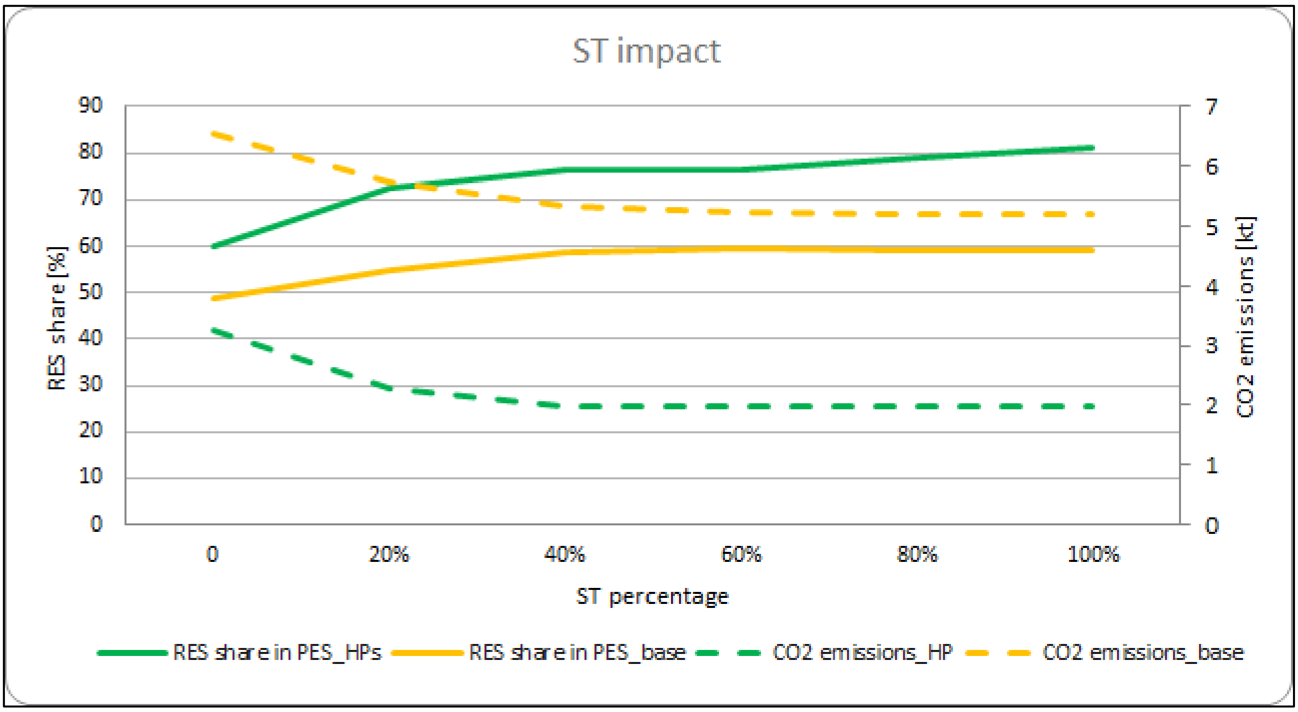

Figure 12. Analysis of the impact of solar thermal collectors on the system emissions (right axis) and RES share in PES (left axis).

Nevertheless, the flexibility that can be offered by HPs in contrast to the potential issue due to higher electricity consumption and the peak demands that could lead to congestion problems does not seem to justify the need to push for a 100% electrified heating system without solar collectors. Thus, the right balance between solar collectors and PV should be found on a case-by-case basis and according to citizens' preferences.

5. Conclusions

In the current study, the scenario approach in energy systems modelling was used to model future scenarios for Procida Municipality. Moreover, the EnergyPLAN model was identified as the main simulation tool for energy scenarios, owning to its user-friendliness and performance, and proven through past research works. For the purpose of facilitating the future use of the PRISMI PLUS toolkit, a pre-processing tool (PRISMI Wind Power calculator) was identified and implemented in the elaboration. Thus, the subsequent development of an energy strategy is to a great extent facilitated. The methodology that was 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 were identified and then proposed as suggestions for the development of strategic energy planning documents. The present study has demonstrated the possibilities to increase the integration of locally available renewable energy sources (more precisely, solar energy) and ways to achieve this. Additionally, the need to shift to sustainable mobility in order to reduce emissions to zero was analysed underlining that EVs represent an interesting opportunity since they could also support the energy system through flexible services that could avoid the need for large energy storage systems. Regarding the heating sector, both HPs and solar thermal collectors represent viable solutions that should be analysed on a case-by-case basis. Such energy transition can lead the considered municipality towards a sustainable and energy-self-sufficient city concept and create new local job opportunities, putting the end-users at the centre of the energy transition.

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