LOCAL SUSTAINABLE ENERGY SYSTEM DEVELOPMENT IN A RURAL AREA : MUNICIPALITY OF MRKOPALJ, CROATIA

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PRISMI PLUS

Transferring a toolkit for RES Integration in Smart Mediterranean Islands and rural areas

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Abstract:	Energy scenarios will be defined, modelled and simulated, emphasizing the different solutions that can be adopted, thus providing potential energy strategies. In the same framework, environmental and techno-economic feasibility analysis will be outlined.

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Executive Summary

The PRISMI PLUS toolkit implementation for Mrkopalj 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 Mrkopalj 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 Mrkopalj 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.

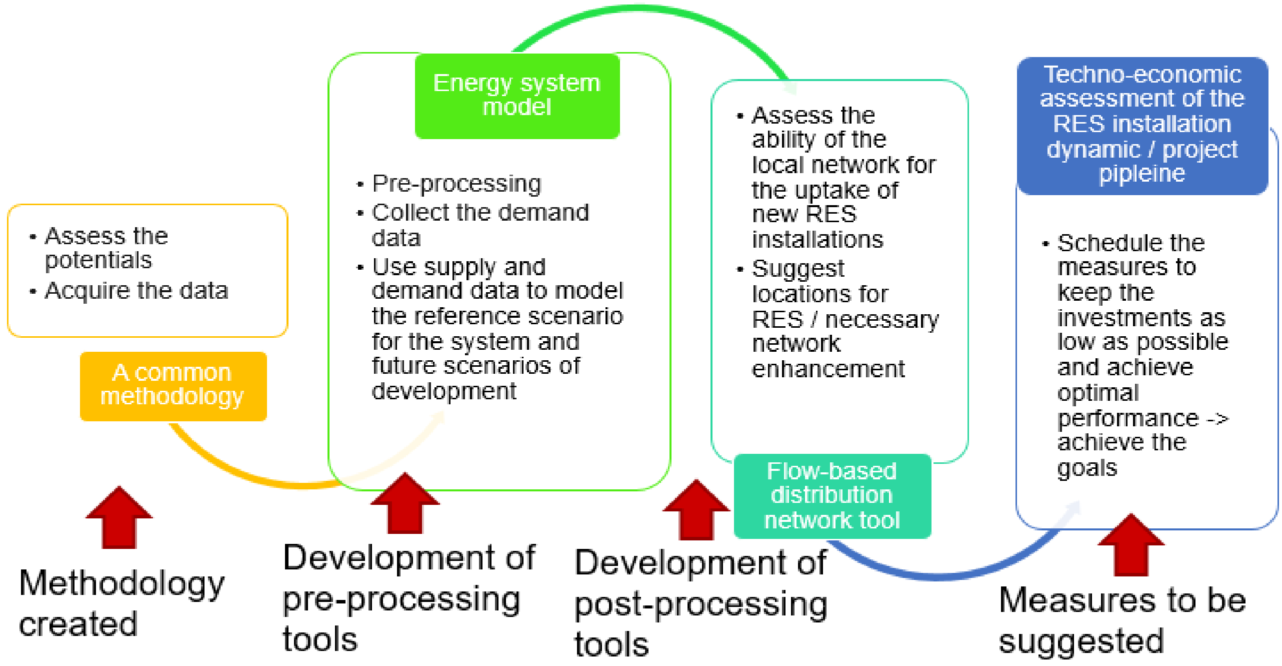

Figure 1 The PRISMI PLUS approach step-by-step

1.1 General framework method for devising the future development energy scenarios for the PRISMI PLUS 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 Mrkopalj. Hence, the adapted methodology consists of the following actions:

Mapping the energy needs of the local municipality

Mrkopalj 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.

[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.

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. Mrkopalj Municipality indicated the following technologies: PhotoVoltaic (PV), Solar Thermal collectors (ST), Electric Vehicles (EVs), Heat Pumps (HPs), Battery Energy Storage (BES), biomass electricity generators (BIO), 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.

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

Mrkopalj is the settlement of the same name municipality which covers south-eastern part of Gorski Kotar or eastern part of Primorsko-goranska County. It has surface of 156.51 km^2 with altitude between 800 and 1400 m above sea level. Most of the area is covered by forest. The main climate characteristic of Gorski Kotar is that the areas above 1200 meters from the sea level belong to the zone of subarctic, snow-forest climate, while the lower mountain areas belong to the zone of warm-moderate rainy climate. Of particular importance is the influence of winds, especially the SE wind (sirocco) and NE wind (bora), which can take on fierce scale in the higher areas. It is important to mention that air temperature generally decreases with increasing altitude, so in the highest, mountainous parts of the municipality that are uninhabited, average temperatures occur for several degrees lower than in the inhabited, lower parts.

Table 1 Mrkopalj typical weather conditions

Month	Temperature [°C]	Solar radiation [W/m2]	Wind speed [m/s]	Precipitation [mm/hour]
January	-0.4	63.06	7.17	0.1
February	3.53	120.17	7.07	0.1
March	6.87	177.95	6.95	0.08
April	9.6	199.22	6.32	0.18
May	11.27	200.54	6.31	0.31
June	20.62	316.49	5.39	0.07
July	20.92	284.8	4.95	0.17
August	21.27	248.47	5.53	0.08
September	16.16	195.05	5.97	0.14
October	12.58	135.64	5.75	0.08
November	8.55	54.79	6.76	0.39
December	4.07	53.69	6.84	0.23

The municipality of Mrkopalj has a population of 934 people with population density of 5.98 inhabitants/km^2. The municipality is extremely rural where inhabited part of the area extends longitudinally through the mountain valley surrounded by hills. In the area of the Mrkopalj municipality there are no water resources in terms of larger surface watercourses nor underground drinking water sources, so water supply is brought through water supply system from the City of Delnice. 80% of water supply is used in households and the only major economic consumer is sawmill in Mrkopalj. There is no existing gas grid, district heating systems and sewer systems are only available in a small area of Mrkopalj itself. The municipality is almost completely connected to the power grid. Table 2 shows the consumption for Mrkopalj municipality in 2020 by category.

Table 2 Energy consumption in 2020 for Mrkopalj municipality

Category	Consumption [kWh]						
	Electricity	Biomass	Fuel oil	Diesel	Petrol	LPG	Total
Buildings	2,149,997	13,045,086	187,091	0	0	0	
Transport	0	0	0.00	1,924,290.9	1,599,972	169,434.24	3,693,697.14
Public lighting	145,767	0	0	0	0	0	145,767
Total	2,295,764	13,045,086	187,091	1,924,290.9	1,599,972	169,434.24	19,221,638.14

The following graph (Figure 2) shows the electricity demand for the year 2019.

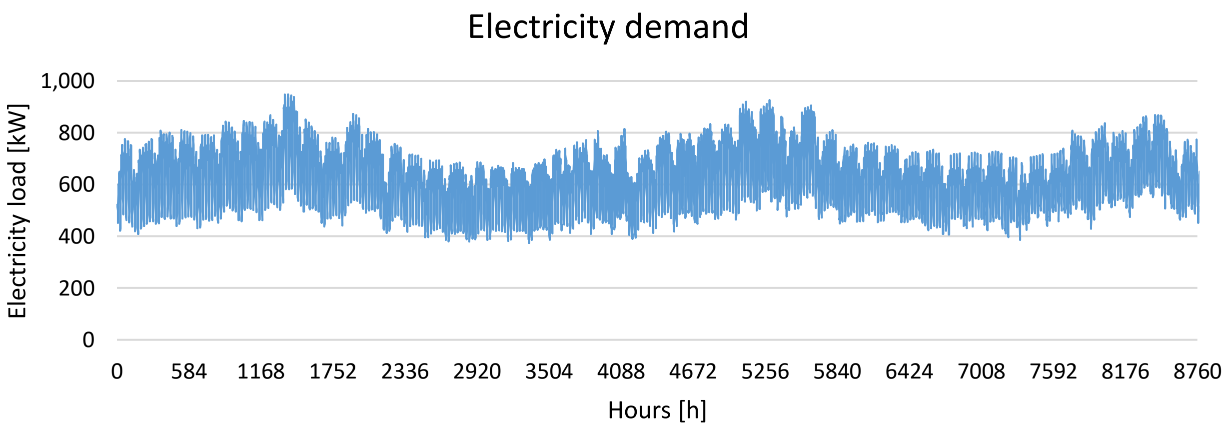

Figure 2 Mrkopalj power supply 2019

Renewable Energy Potential data

Weather data needed to assess the potential of renewable energy sources were obtained from Renewables.ninja, a web tool developed by Imperial College London and ETH Zürich. It shows estimated amount of energy that could be generated by wind or solar plants at any location. Weather data is taken from global reanalysis models and satellite observations. Two data sources are:

- NASA MERRA reanalysis
- CM-SAF's SARAH dataset

Web tool can be accessed on Renewables.ninja website.

Solar energy potential

Figure 2 shows electricity production potential for PV power plants in Mrkopalj. Production is estimated by the Renewables.ninja model using solar radiation data.

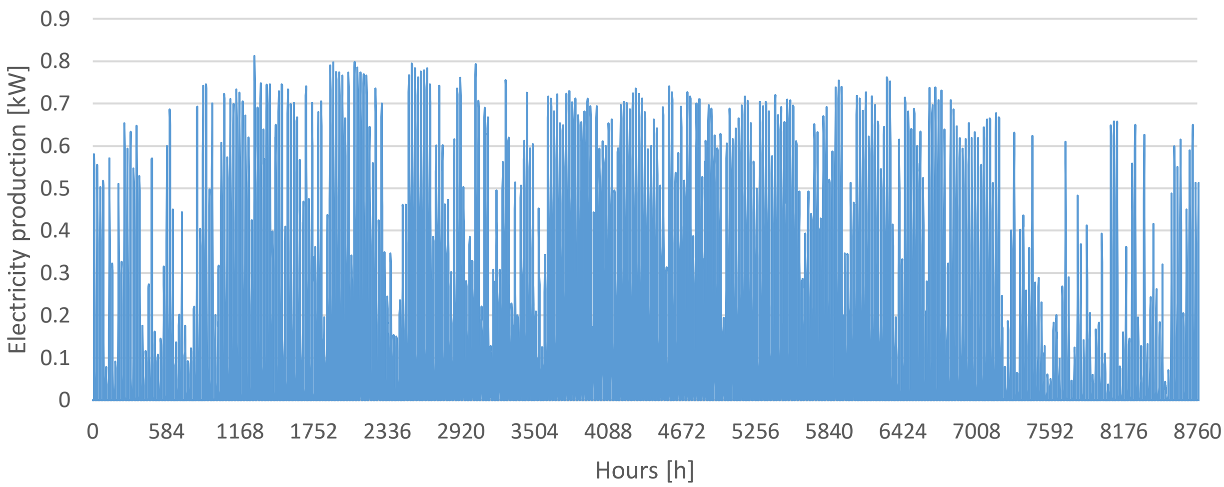

Figure 3 Mrkopalj electricity production potential from PV power plants

Biomass potential

Regarding biomass potential, forests cover 107,236 ha, or 84.2% of the area of Gorski Kotar. Of this, 74,505 ha or 69.48% of forest land belongs to the forest area owned by the Republic of Croatia. Table 3 shows distributions of forests by wood inventory, 10-year increment and cutting volume of Gorski Kotar. Accordingly, Gorski Kotar has a long tradition of wood-processing industry, which to this day remains the largest economic sector in Gorski Kotar.

Table 3 Wood inventory, 10-year increment and cutting volume of Gorski Kotar

	Wood inventory [m^3]			10-year volume increment [m^3]			10-year cutting volume [m^3]		
	Coniferous	Deciduous	Total	Coniferous	Deciduous	Total	Coniferous	Deciduous	Total
State forests	13115	12183	25298	2190	2631	4820	2635	1922	4557
Private forests	1443	4036	5479	409	1049	1458	302	783	1085
Nature park	636	1082	1719	88	216	305	0	0	0
Faculty of Forestry	235	91	326	37	18	55	60	24	84
Total	15429	17392	32822	2724	3914	6638	2997	2729	5726

Mrkopalj municipality surface area is mostly covered by forests (74%), then by arable land, orchards, meadows and pastures (24%), and other agricultural and other forest land (1%). 379.2965 ha of agricultural land is registered in Mrkopalj municipality.

Division of scenarios

The division of scenarios for Mrkopalj followed the typical PRISMI methodology, starting initially with the base case study until 2030 (LowRES), with the implementation of current and no special additional policies (25% of households and public buildings instals 3.5 kW of solar PV on the rooftop). Secondly, a scenario in 2030 was evaluated with the objective realistic use of RES technologies for higher (RES) penetration, using rooftops for solar PV installations, with 50% of households and public buildings installing 3.5 kW of solar PV on the rooftops. Finally, the most ambitious case was analysed aiming at HighRES share (HighRES) and analysing the related issues in terms of grid stability. The different scenarios also had an increasing electrification of the transport sector, in particular the RES scenario considered only the option of smart charging of EVs while the HighRES scenario also included the possibility of Vehicle-To-Grid (V2G). The installed capacities included 75% of households and public buildings installing 5 kW of solar PV, building ground-based PV plant of 1 MW and 1 MW of biomass power plant.

Table 4 Division of scenarios

2030	LowRES	RES	HighRES
PV [kW]	419	838	2796
Biomass [kW]	0	0	1000
Electrical storage [MWh]	0	0	0
EV not V2G mode [no. of vehicles]	48	143	0
EV in V2G mode [no. of vehicles]	0	0	285
EV connection [MW]	0.16	0.42	1.45
EV demand [MWh]	160	270	850
EV battery [MWh]	2.4	5.9	18

The increase in the electricity demand due to the transition to electric mobility is illustrated below. Using the V2G (HighRES) the increase in demand goes hand in hand with the increase in storage capacity.

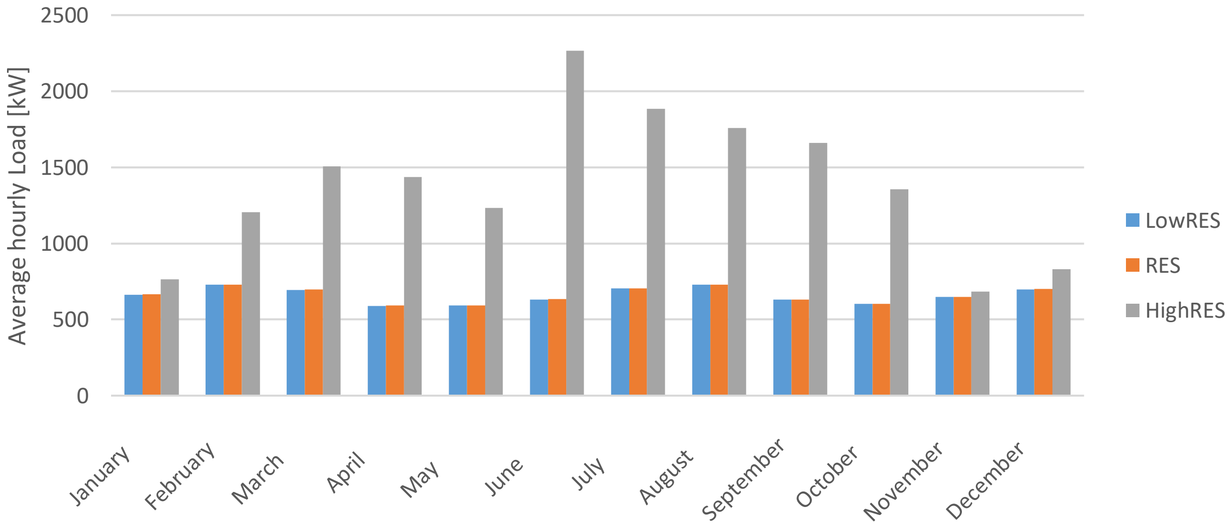

Figure 4 Demand average for each scenarios

In order to control grid problems due to the integration of the photovoltaic sources (which is non-dispatchable), the increase in generation was followed by an increase in the size of the EVs, which was necessary in order to maintain CEEP (Critical Excess in Electricity Production) at zero. Also, dispatchability of biomass power plant secured the supply, while some amount of energy could be exported from Mrkopalj in the HighRES scenario.

2.1 Results of modelling and discussion

Results of modelling are presented in Figure 5 and Figure 6 in terms of RES share in Primary Energy Supply (PES) and in electricity, respectively.

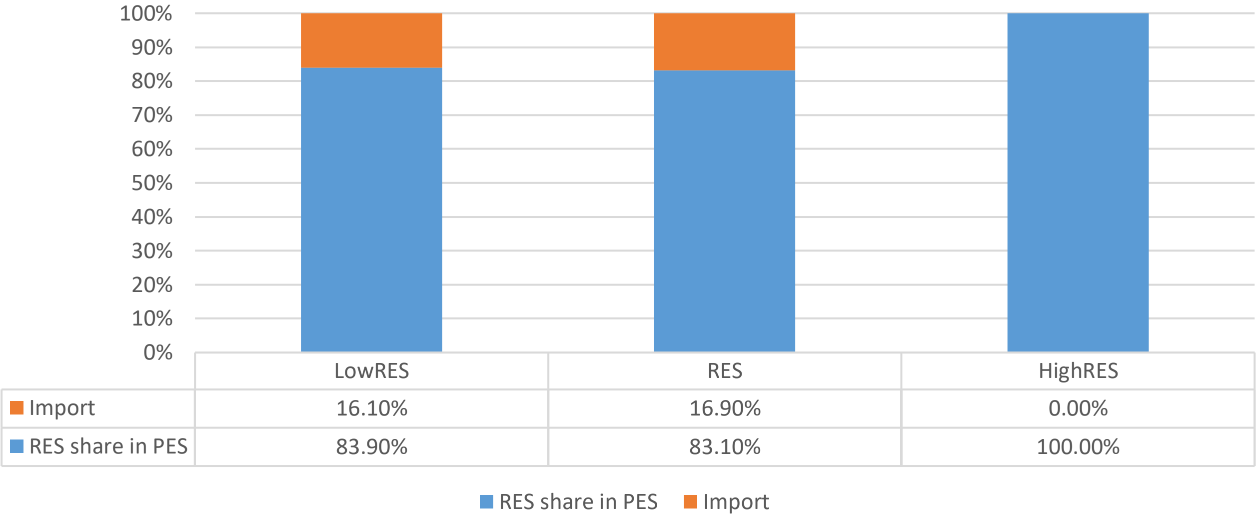

Figure 5 RES share in primary energy supply

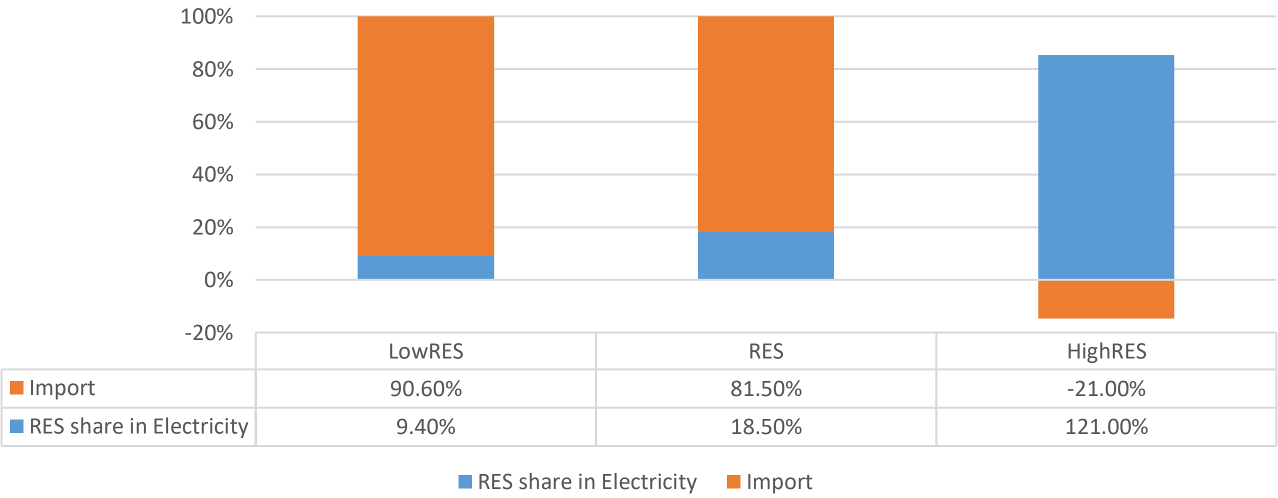

Figure 6 RES share in electricity production

In the table below, the progress of RES integration through scenarios is also numerically expressed. The HighRES scenario enables the Municipality to become the energy exporter, as it provides slightly more energy than it is locally needed, but the technology installed for this purpose is also important for the balancing of the local energy system.

Table 5 RES percentage of RES penetration

2030	RES share in PES	Import
LowRES	83.90%	16.10%
RES	83.10%	16.90%
HighRES	100.00%	0.00%
2030	RES share in Electricity	Import
LowRES	9.40%	90.60%
RES	18.50%	81.50%
HighRES	121.00%	-21.00%

The following two graphs analyse the monthly trends of the different energy sources that would make up energy mix in the medium (RES) and long term (HighRES) scenarios. Figure 7 clearly shows the increase in the RES generated electricity. In the case of RES, the increase is exclusively due to the newly installed PV for a total of 0.84 MW. In the HighRES scenario, independence from fossil fuels is achieved by increasing the PV installations by almost 2 MW compared to the RES scenario, for a total PV installed power of 2.8 MW and installation of 1 MW biomass power plant.

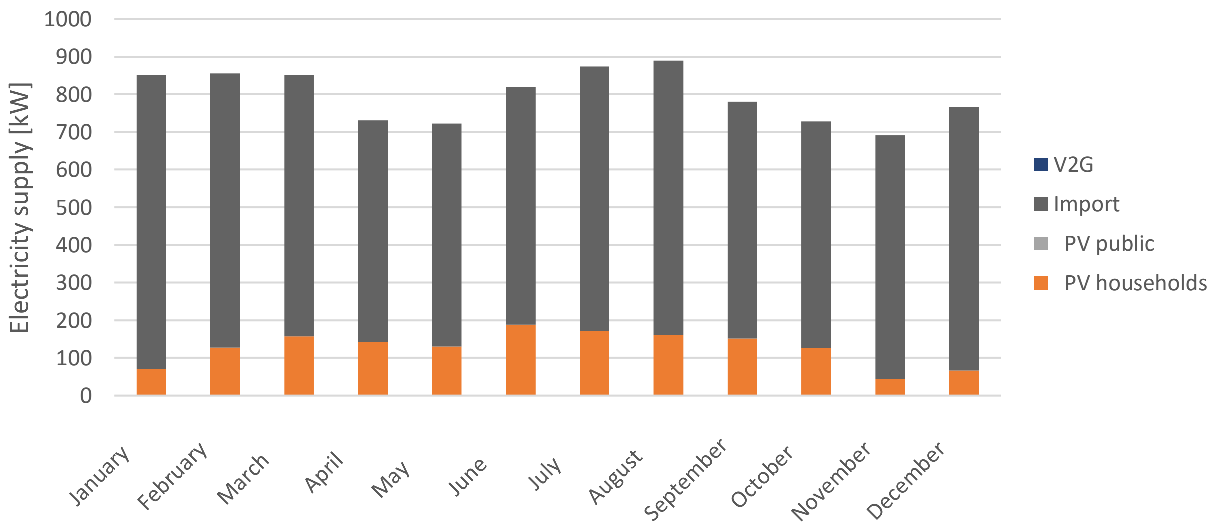

Figure 7 Monthly electricity supply RES scenario

In particular, Figure 8 considers the HighRES case in which all energy is produced from renewable sources or imported.

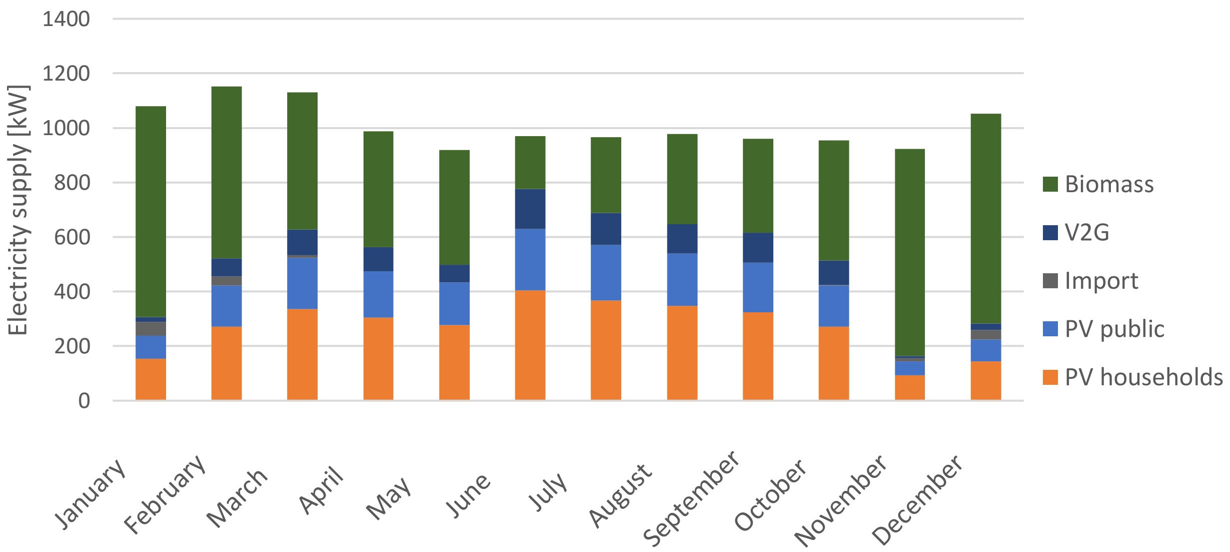

Figure 8 Monthly electricity supply HighRES scenario

2.2 Socio-economic feasibility of adopted solutions

As can be seen from the table below (Table 6), the largest expenditure is on EVs, but thanks to that expenditure there is no need to increase storage. The use of V2G in the HighRES scenario makes it possible to keep the size of electrical storage unchanged compared to the RES case while at the same time increasing the PV park. In terms of grid flexibility, therefore, the use of V2G makes feasible to limit the use of batteries and expand renewable generation while keeping CEEP under control.

Table 6 Technology costs

Technology	Investment	O&M	Lifetime
EV [kEUR/unit]	30	6.50%	10
PV households [kEUR/kW]	1	2%	20
PV public [kEUR/kW]	1.05	2%	20
Biomass [kEUR/kW]	1.5	3%	15

Cost of investment per RES technology for all scenarios [kEUR].

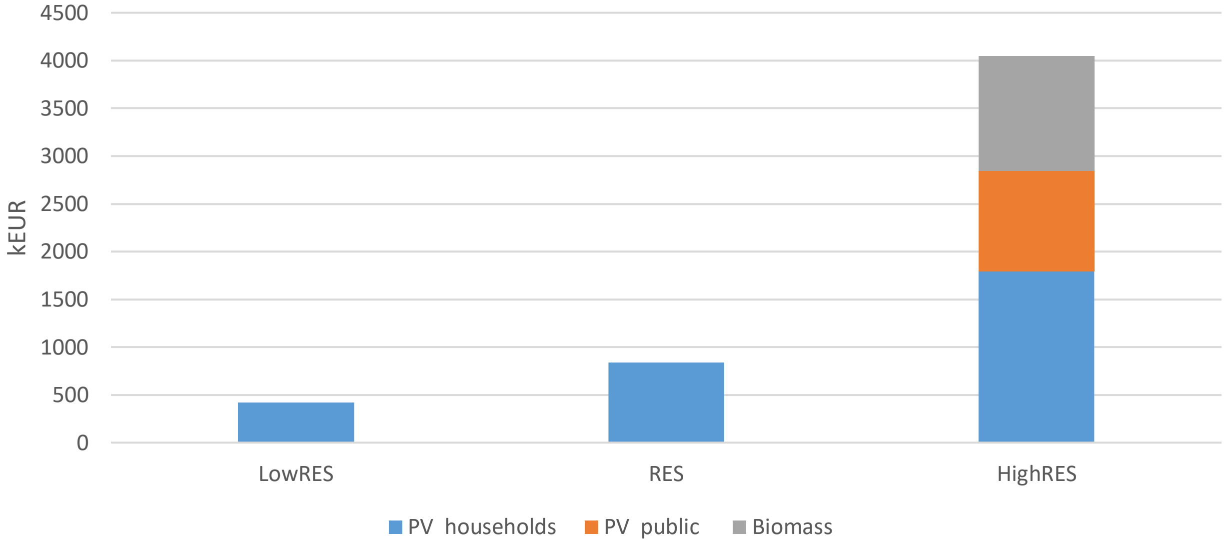

Figure 9 Cost of investment per RES technology for all scenarios

Considering both the cost of electric vehicles (graphed in Figure 10) and the cost of power generation technologies, we can see that the cost of switching from the current to the RES scenario is about the same as the cost of switching from the RES to the HighRES scenario for households PV. Increased costs in HighRES scenario are from additional biomass power plant and public PVs.

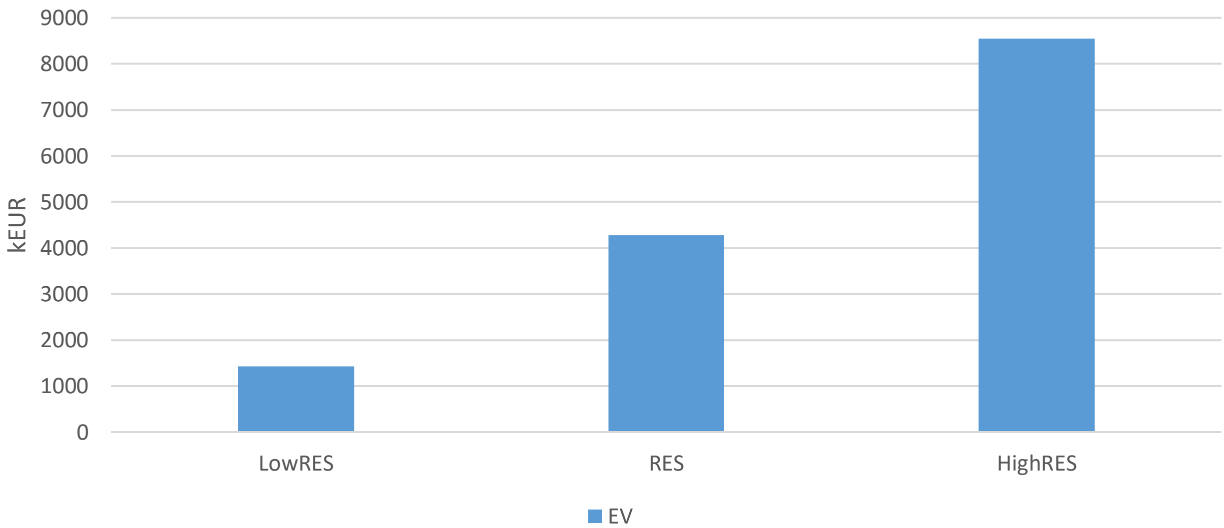

Figure 10 Cost of investment for Electric Vehicles

Although they are among the highest costs, EVs are also the most incentivised and quickest to pay back.

As regards the employment impact of these interventions on the city's fabric, we can say that the installation of 2.8 MW of photovoltaic power could lead to the creation of a small team of 3 people responsible for the routine maintenance of the new (and existing) installations. At present, in fact, maintenance work for private individuals is extremely expensive due to the distance between them and the companies responsible for the maintenance of these installations, which sometimes makes the investment unprofitable.

2.3 Environmental considerations

From an environmental point of view, the reduction of polluting emissions on the area of Mrkopalj municipality is even more important as there are several distinct values, some of national, some county and some of local significance. 33.61% of the municipality's area pertains to protected natural heritage Due to its specifics, the area of Gorski Kotar, and therefore Mrkopalj (marked red on Figure 11) as well, is almost completely included in proposal of NATURA 2000 sites in the Republic of Croatia, as it's one of the few habitats inhabited by all three large carnivores of the Republic of Croatia: bear, wolf and lynx. Ecological network NATURA 2000 is an ecological international network of preserved natural heritage and is one of the basic mechanisms for the protection of endangered species and habitats in the EU. In total, within the NATURA 2000 proposed area on the territory of Gorski Kotar, there are 62 protected species.

Figure 11 Gorski Kotar and north Lika included within NATURA 2000

In Figure 12 and Table 7, we noted the positive impact in terms of Greenhouse Gas (GHG) emissions obtained thanks to the increased energy production from RES and the electrification of the transport sector.

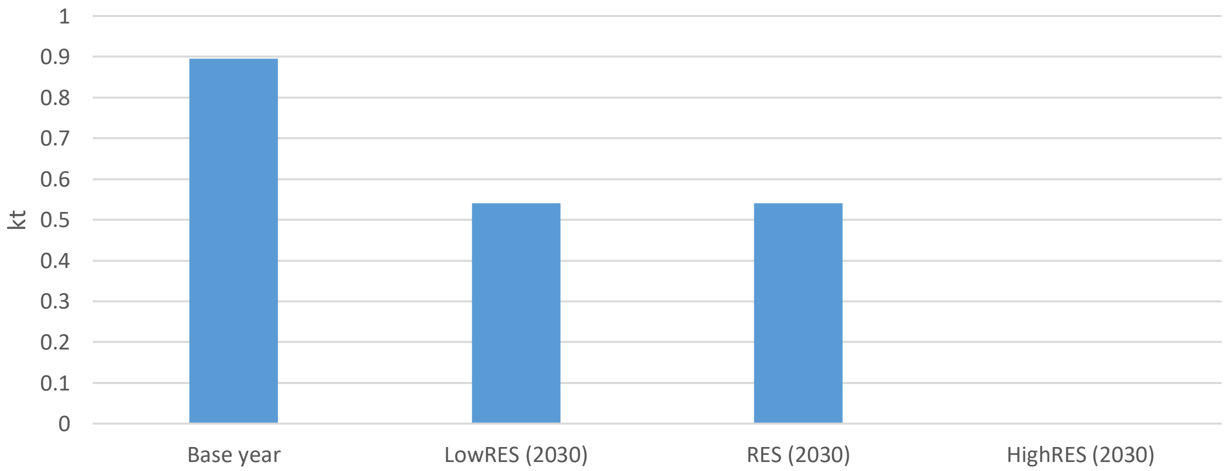

Figure 12 GHG emission for each scenario

Table 7 GHG Emissions

Scenario	GHG Emissions [kt]
Base year	0.895
LowRES (2030)	0.541
RES (2030)	0.541
HighRES (2030)	0

2.4 Suggestion for strategy of development

In the chapter on the modelling of the future energy system of the Municipality of Mrkopalj, it was observed that a large difference exists between the RES and HighRES scenarios. With former representing the current ambition and easily achievable targets for the Municipality and the latter representing the potential with more ambitious policy. The Municipality area has significant potential for electricity generation from renewable energy sources. One way of fostering the adoption of distributed RES, such as solar PV, might be establishment of an Energy Community, which could support the active participation of citizens and increased use of the rooftops for generation of energy. The Municipality should spearhead such policy with the installations of solar PV on the public buildings' rooftops. If the municipality firmly supports such a community, it could ensure the widespread integration of photovoltaic technology on almost all the roofs within 10 years, thus avoiding the installation of large photovoltaic systems, which might be more difficult to implement.

Public buildings should also become the core of the energy transition through investment in their heating and cooling systems being adapted to the use of heat pumps, instead of fossil fuel boilers or biomass. The EV charging stations on public building's parking spaces would also help to adopt this relevant technology.

The combination with PV installations in households and a public campaign for sufficient charger availability can enable smart charging and even vehicle to grid concepts to support the balancing of the high share of RES in most ambition scenario.

3. Conclusion

In the current study, the scenario approach in energy systems modelling has been used to model the future scenarios for Mrkopalj 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 biomass) and ways to achieve it. Considering the protected native fauna, use of roofs for energy generation is advisable. EVs and V2G technology 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.
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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