LOCAL SUSTAINABLE ENERGY SYSTEM DEVELOPMENT IN AN INSULAR AREA : MUNICIPALITY OF ČAPLJINA, BOSNIA AND HERZEGOVINA

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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 Čapljina 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 Čapljina 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 on. 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 Čapljina Municipality 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.

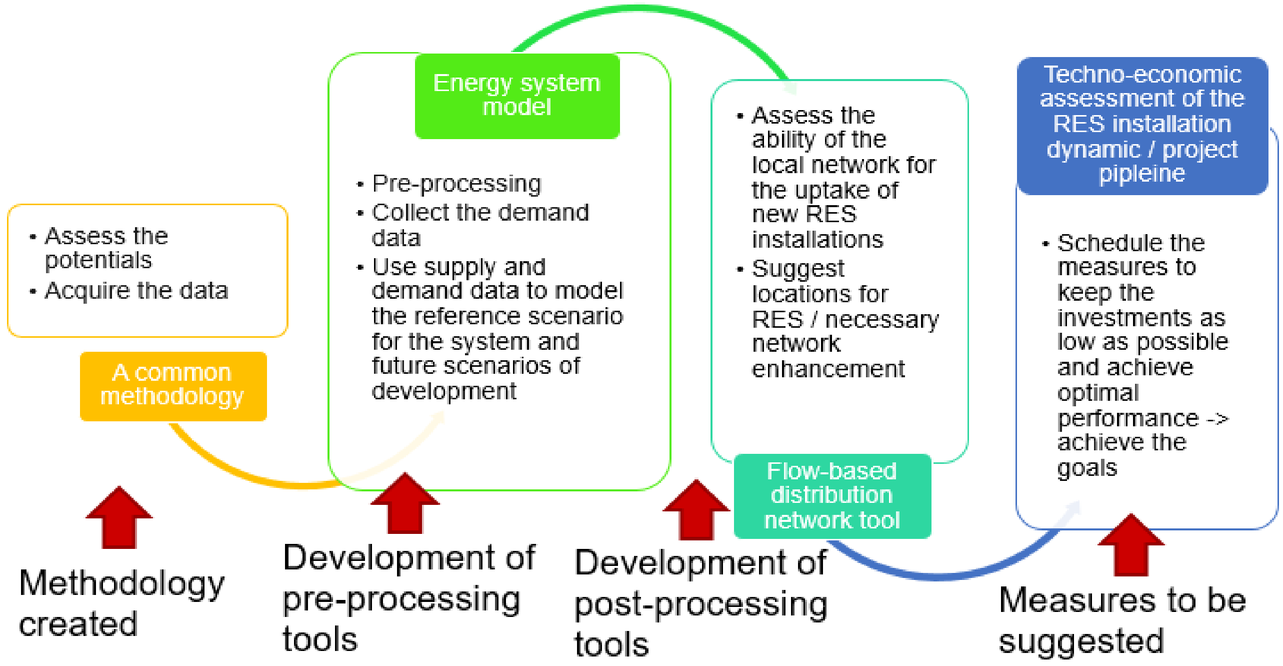

Figure 1 The PRISMI PLUS approach step-by-step

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

Mapping the energy needs of the local municipality

Čapljina 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.[1]

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*" since the major renewable source that can be exploited is solar power.

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'

[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.

analysis. Čapljina Municipality indicated the following technologies: PhotoVoltaic (PV), Wind Turbines (WT), Solar Thermal collectors (ST), Electric Vehicles (EVs), Heat Pumps (HPs), Battery Energy Storage (BES).

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.

2. Case study examined - Municipality of Čapljina Flagship Case (FC)

Municipality and the City of Čapljina is one of 9 municipalities of Herzegovina-Neretva County. It is located in the south of Bosnia and Herzegovina, Region of Herzegovina, stretching alongside river Neretva. Čapljina municipality has a surface of 256 km^2 with altitude of 10 m above sea level and distance of approximately 30 kilometres from the Adriatic Sea. The climate is sub-Mediterranean, as shown in Table 1, characterized by mild winters and hot summers with moderate precipitation during autumn and spring, created by the proximity of the Adriatic Sea and low terrain.

Table 1 Čapljina typical weather conditions

Month	Temperature [°C]	Solar radiation [W/m^2]	Wind speed [m/s]	Precipitation [mm/hour]
January	1.41	70.32	7.21	0.16
February	4.94	129.29	8.18	0.07
March	8.79	187.46	6.88	0.04
April	11.86	211.35	6.13	0.2
May	13.34	233.5	5.71	0.19
June	22.61	314.37	4.98	0.03
July	24.03	304.47	5.09	0.11
August	26.11	269.68	4.76	0.01
September	20.15	198.59	5.32	0.1
October	16.16	161.42	4.84	0.06
November	12.42	73.44	7.66	0.38
December	6.61	64.61	7.4	0.2

The municipality of Čapljina has a population of 26,157 people with population density of 102 inhabitants/km^2. Population density is largest in the urban part of the municipality, the City of Čapljina, while significantly smaller in its rural parts. In the Čapljina municipality, 60% of the population is supplied with drinking water through a water supply system with plans for further development. Number of sewer system users is increasing, but currently only 28% of households are connected to the system. There is no existing gas grid or district heating systems. Table 2 shows estimated energy consumption for households and transport.

Table 2 Estimated enegy consmption for housholds and transport in 2020

Category	Consumption [kWh]		
	Electricity	Heat	Total
Households	28,778,220	3,658,585	32,436,806
Transport	/	/	62,341,636
Total	28,778,220	3,658,585	94,778,442

From a power generation viewpoint, the City of Čapljina is completely connected to the power grid. The main distributor is Elektroprivreda HZHB Mostar d.d with mostly hydroelectric power plants therefore production of electricity largely depends on hydrological conditions.

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

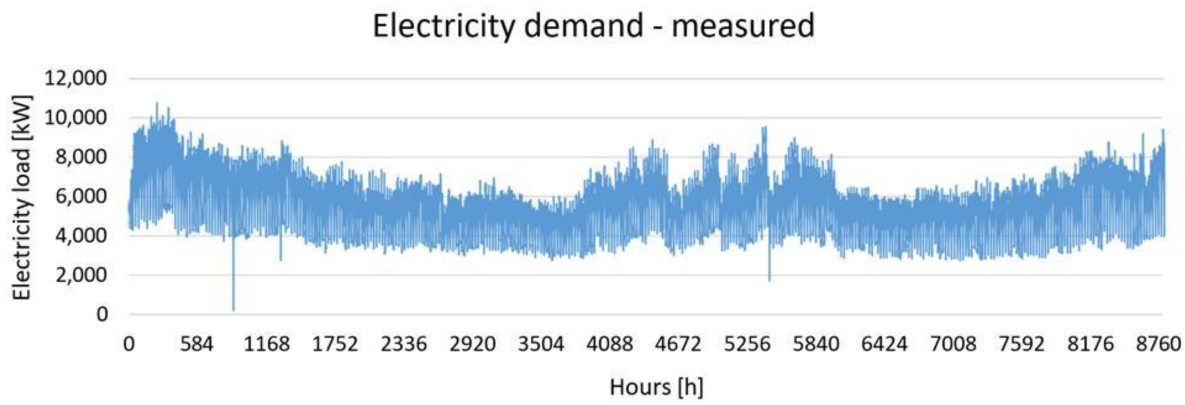

Figure 2 Čapljina power supply for the year 2019

Renewable Energy Potential Data

Weather data needed to assess the potential of renewable energy sources was obtained from Renewable.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 farms 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 3 shows electricity production potential form PV farms in Čapljina. Production is estimated by Renewables.ninja model using solar radiation data.

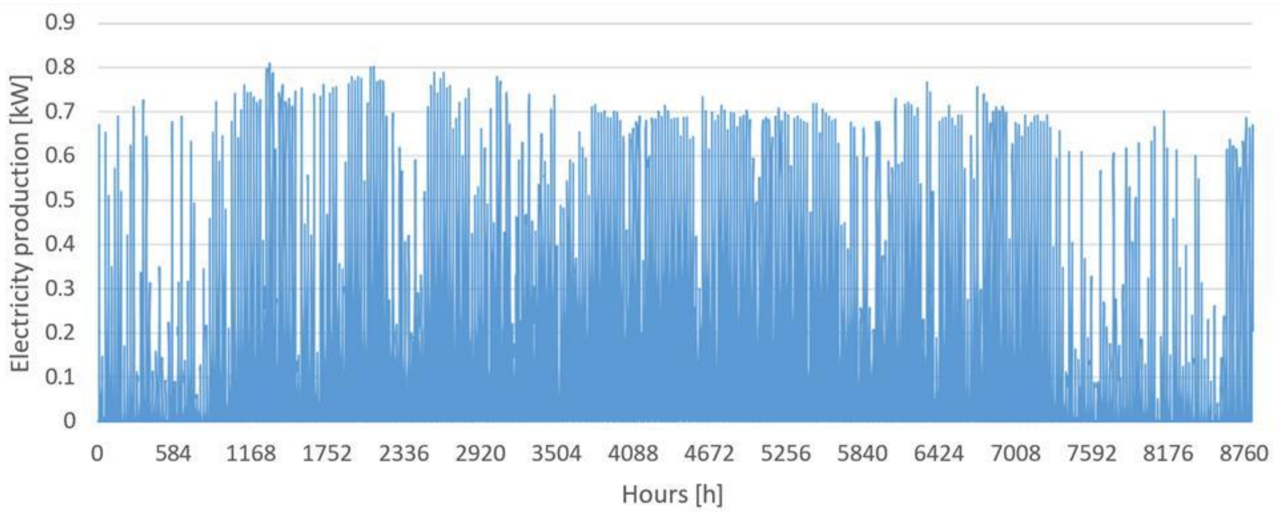

Figure 3 Čapljina electricity production potential from PV farms

Wind energy potential

Wind energy potential is estimated by Renewables.ninja model using wind speed data. Figure 4 shows electricity production potential calculated by Renewables.ninja model.

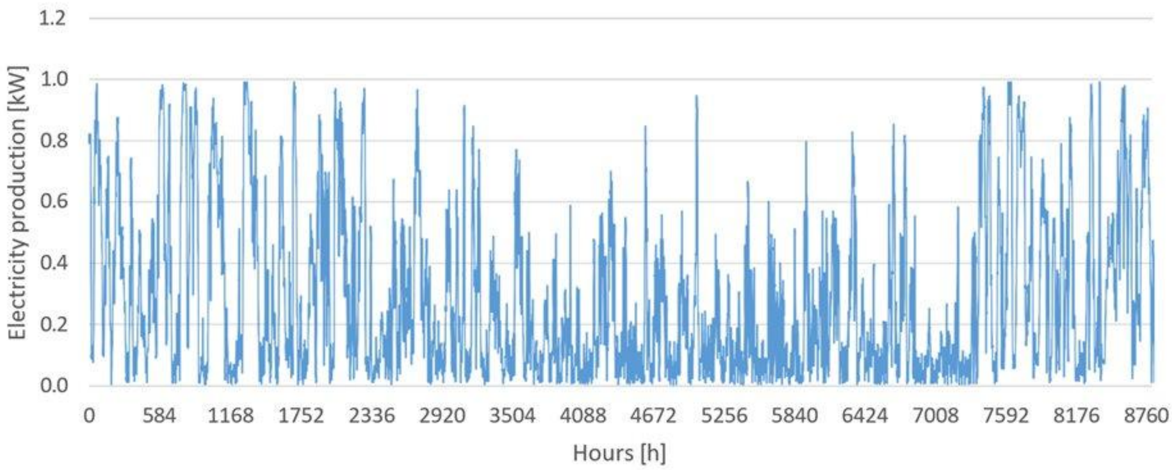

Figure 4 Čapljina electricity production potential from wind farms

Division of scenarios

The division of scenarios for the City of Čapljina followed the typical PRISMI methodology, starting initially with the base case study until 2030 (LowRES), with the implementation of current SEAP and no special additional policies. Secondly, a scenario in 2030 was evaluated with the objective realistic use of RES technologies for higher (RES) penetration (RES Scenario), using 50% of public rooftops and 50% of households for solar PV installations. Finally, the most virtuous case was analysed aiming at 100% RES share(HighRES) and analysing the related issues in terms of grid stability. HighRES scenario used 85% of public rooftops and 75% of households' rooftops, as well as an investment in ground-based PV power plant and a wind power plant. Details of the provided installed capacities are provided in Table 3.

Table 3 Installed capacities of power generators per scenario

2030	LowRES	RES	HighRES
Households PV [kW]	1065	1775	3018
Public buildings PV [kW]	1053	2105	3158
Ground-based PV [kW]	0	0	2000
Wind turbines [kW]	0	0	20750

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 energy systems' configuration is provided in Table 4. The difference between RES and HighRES scenarios is significant, as the RES scenario is planned to correspond to the current possible ambitions of the decision makers, while HighRES scenario represents additional potential for local RES integration and ambitious cross-sector energy transition policies.

Table 4 Division of scenarios

2030	LowRES	RES	HighRES
PV [KW]	2118	3880	8175
Wind [KW]	0	0	20750
Electrical storage [MWh]	0	0	0
EV not V2G mode [no. of vehicles]	707	2120	0
EV in V2G mode [no. of vehicles]	0	0	4241
EV connection [MW]	2.5	7.4	21.2
EV demand [MWh]	160	3060	6210
EV battery [MWh]	35.3	106	212

The increase in the city's 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.

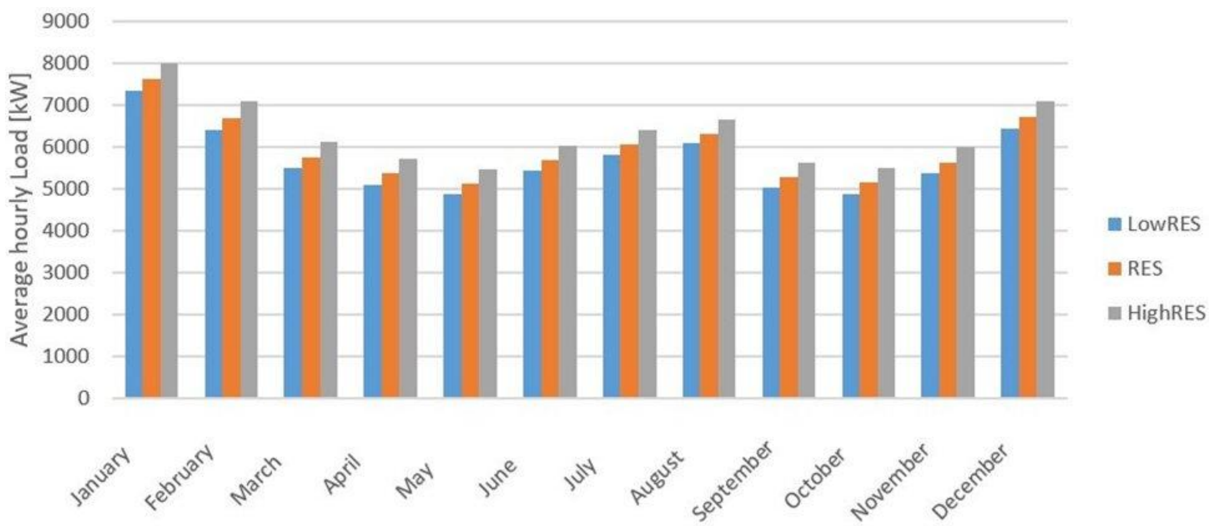

Figure 5 Demand average for each scenario

In order to control grid problems due to the integration of the photovoltaic (PV) sources and wind turbines (which are non-dispatchable), the increase in generation was followed by an increase in the size of EVs, which was necessary in order to maintain CEEP (Critial Excess in Rlectricity Production) at zero.

2.1 Results of modelling and discussion

Results of modelling are presented in Figure 6 and Figure 7 in terms of RES share in PES and in electricity, respectively.

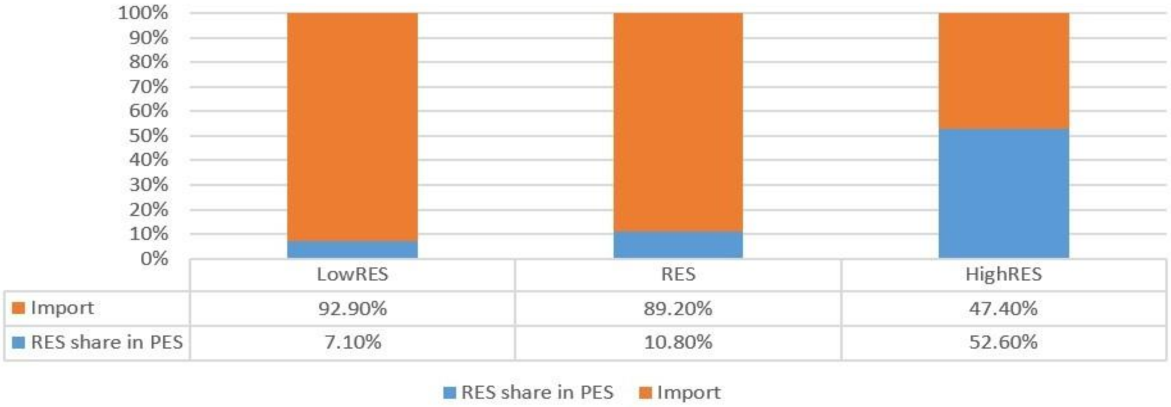

Figure 6 RES share in primary energy supply

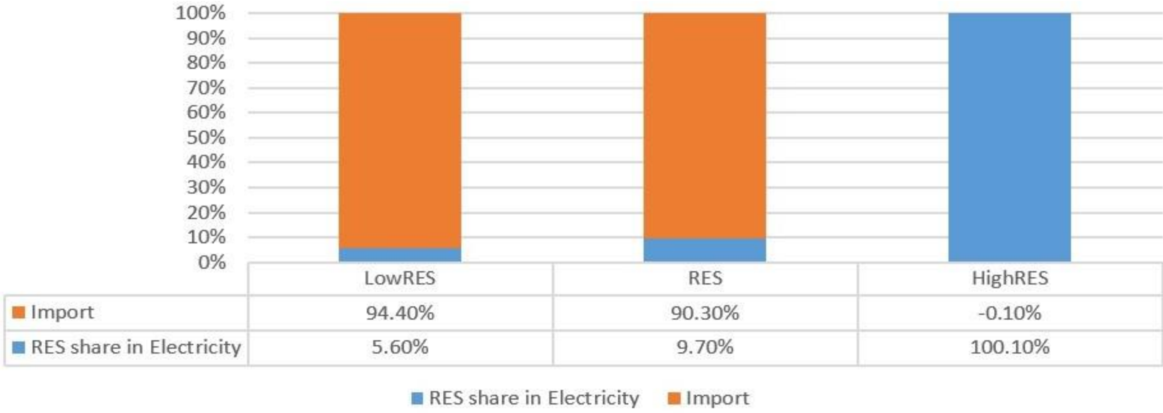

Figure 7 RES share in electricity production

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 3.88 MW.

Table 5 RES percentage of RES penetration

2030	RES share in PES	Import
LowRES	7.10%	92.90%
RES	10.80%	89.20%
HighRES	52.60%	47.40%

2030	RES share in Electricity	Import
LowRES	5.60%	94.40%
RES	9.70%	90.30%
HighRES	100.10%	-0.10%

In the HighRES scenario, 100% independence from fossil fuels is achieved by increasing the PV installations by 4295 kW compared to the RES scenario, for a total PV installed power of 8175 kW and additionally installing wind turbines with capacity of 20.75 MW.

The following two graphs analyse the monthly trends of different energy sources that would make up the city's energy mix in the medium (RES) and long-term (HighRES) scenario, with import referring to the energy that would be imported from the national grid. In particular, Figure 8 considers the HighRES case in which all energy is produced from renewable sources.

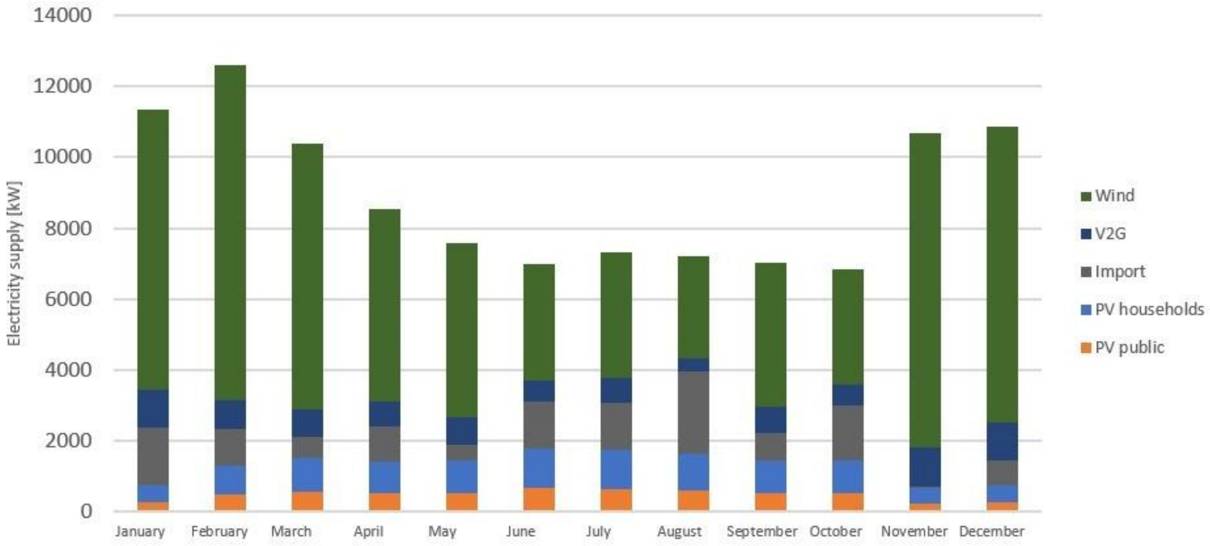

Figure 8 Monthly electricity supply in HighRES scenario

Figure 9 represents the monthly average electricity supply for the moderate scenario (RES), with noticeable implementation of the solar PV plants on rooftops of public and private buildings

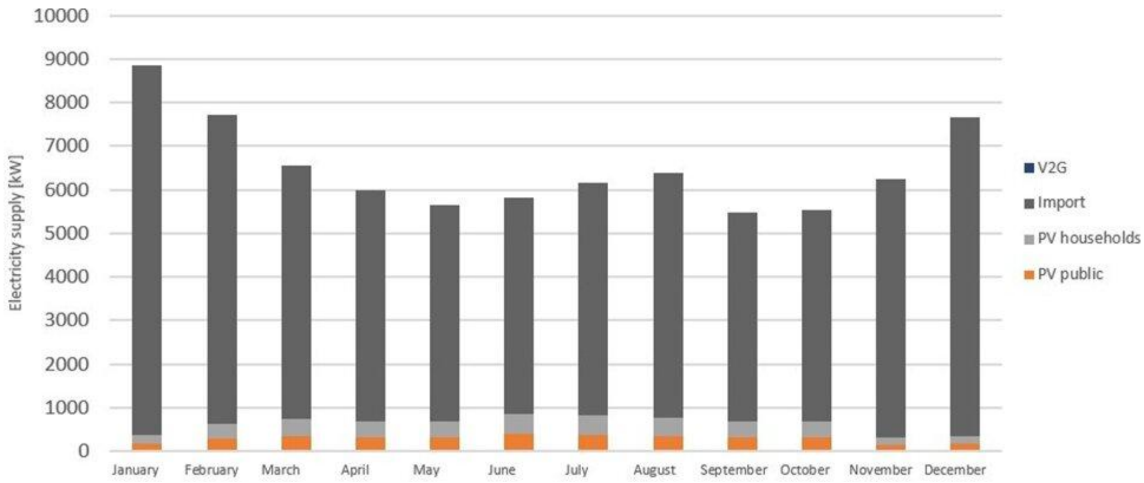

Figure 9 Monthly electricity supply in RES scenario

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 and adding wind turbines. In terms of grid flexibility, 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
Wind turbines [kEUR/kW]	1.2	2%	30

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

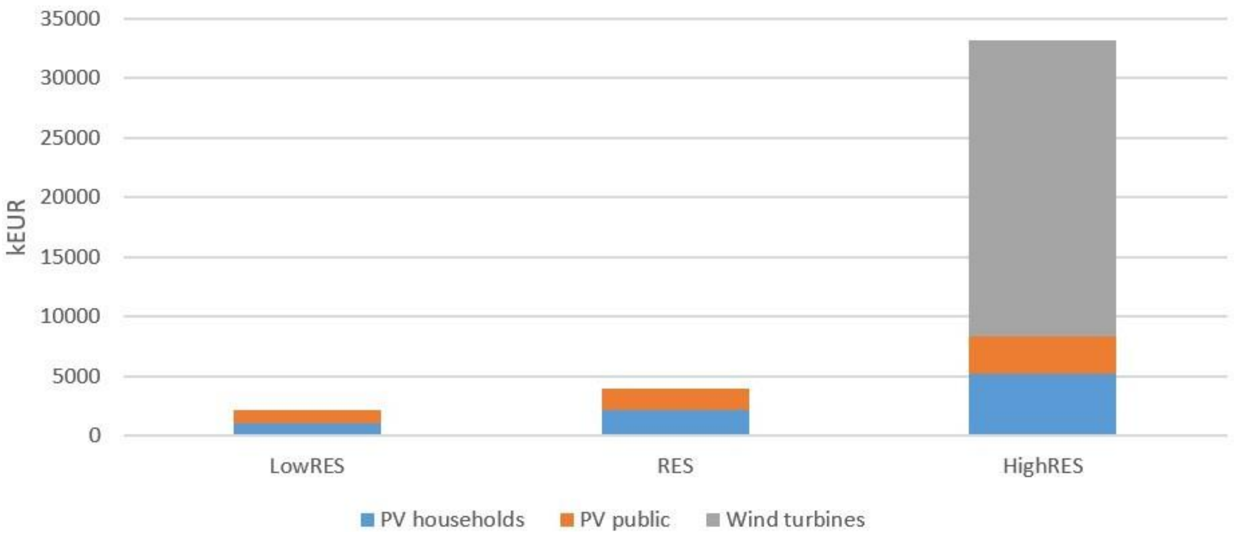

Figure 10 Cost of investment per RES technology for all scenarios

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, with the exception of wind turbines.

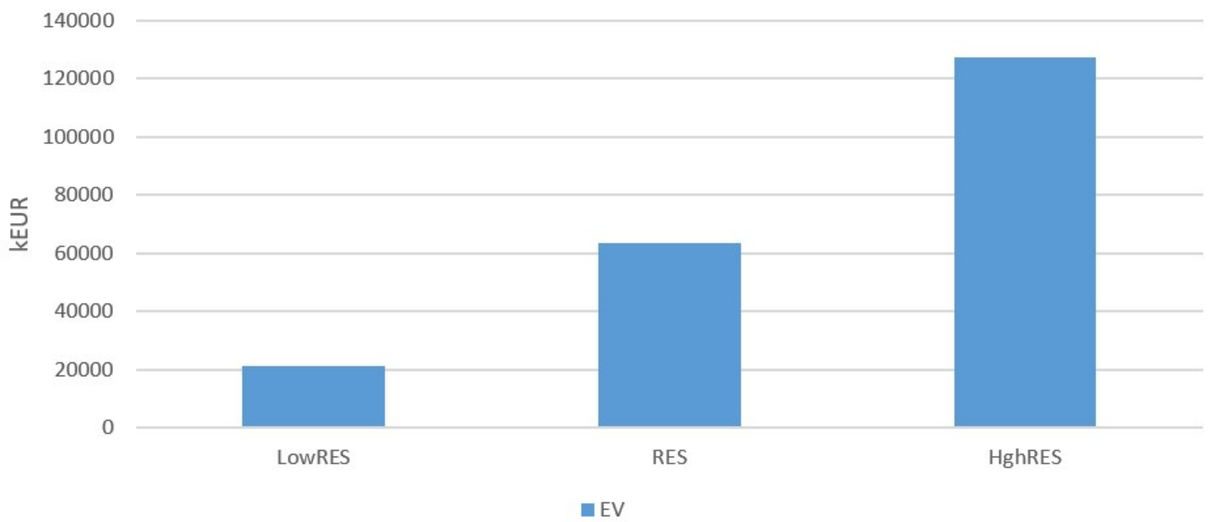

Figure 11 Cost of investment for Electric Vehicles (EVs)

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, it can be envisioned that the installation of 6 MW of photovoltaic power could lead to the creation of a small team of 3-5 people responsible for the routine maintenance of the new (and existing) installations. At the same time, the introduction of a wind farm could, on the other hand, create another 9 additional jobs to maintain and operate wind turbines from HighRES scenario.

2.3 Environmental considerations

In the municipality of Čapljina, water resources are put in the function of supplying the population with sufficient quantities of drinking water for tourism development, electricity production, development of recreational and sports activities and for irrigation in agriculture. Accordingly, it is important to reduce the dependence on electricity production from water resources. One of the key institutions involved in the management of water resources in the municipality of Čapljina is Agency for watershed of the Adriatic Sea.

The reduction of polluting emissions is important as there are over 800 plant species of which more than 36 are on the list of rare, endangered and endemic species. There are also over 80 animal species that are protected on regional, European or global level. The high biodiversity within a relatively small area highlights the unique and diverse environmental factors that have fostered the presence of numerous endemic, relict, and endangered species. Confirmation of the importance of Čapljina municipality on a global scale, is the inclusion of Hutovo Blato on the UNESCO list of natural heritage, and in the NATURA 2000 network, ecological international network of preserved natural heritage and one of the basic mechanisms for the protection of endangered species and habitats in the EU.

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.

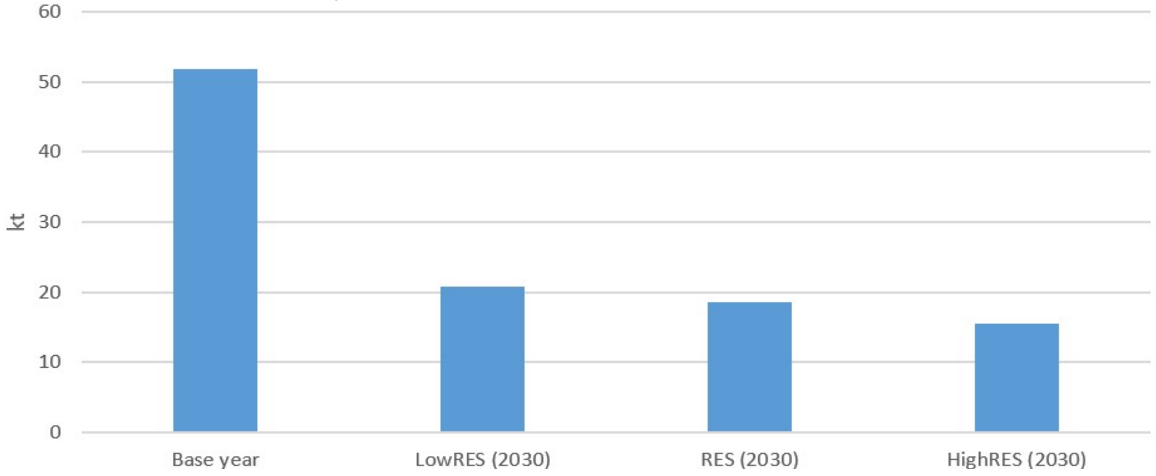

Figure 12 GHG emissions for each scenario

Table 7 GHG Emissions

Scenario	GHG Emissions [kt]
Base year	51.863
LowRES (2030)	20.833
RES (2030)	18.563
HighRES (2030)	15.438

2.4 Suggestions for the development strategy

In the chapter on modeling the future energy system of Čapljina, a significant difference was observed between the RES and HighRES scenarios. The RES scenario reflects the city’s current ambitions, while the HighRES scenario represents a more ambitious policy approach.

Čapljina and its surrounding area have significant untapped potential for renewable energy generation beyond hydropower, which is the dominant source in Herzegovina. One way to encourage the adoption of distributed renewable energy sources, such as solar PV, could be through the creation of an Energy Community. This initiative would support citizen participation and promote the use of rooftops for energy generation. With strong municipal backing, widespread integration of photovoltaic technology could be achieved on nearly all rooftops within 10 years, reducing the need for large-scale solar installations, which may be more challenging to implement.

Public buildings should lead the energy transition by installing rooftop PV systems and replacing fossil fuel boilers with heat pumps for heating and cooling.

After decarbonizing energy generation and the heating/cooling sector, the next priority is the electrification of transport. Since the local energy system is primarily powered by hydropower, it can already provide 100% renewable electricity without greenhouse gas emissions. Early adoption of electric transport, combined with household PV installations and a public campaign for sufficient charging infrastructure, could enable smart charging and even vehicle-to-grid solutions. These measures would help balance the high share of renewable energy in the most ambitious scenario.

3. Conclusion

In the current study, the scenario approach in energy systems modelling has been used to model the future scenarios for Čapljina 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 and wind energy) and ways to achieve it. The study also analysed the importance of electrifying transport to maintain grid stability, highlighting that EVs, especially with Vehicle-to-Grid (V2G) technology, can support the energy system by enhancing flexibility and avoiding the need for large energy storage systems.
As far as the heating sector is concerned, heat pumps and solar thermal collectors represent viable solutions that should be implemented with strong municipal support. The creation of an Energy Community could further encourage citizen participation, facilitating the widespread adoption of renewable energy.

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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