Decarbonising electricity and water access

Žirje

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The Clean Energy for EU Islands Secretariat

Who we are

The launch of the Clean Energy for EU Islands Initiative in May 2017 underlines the European Union's intent to accelerate the clean energy transition on Europe's more than 1,400 inhabited islands. The initiative aims to reduce the dependency of European islands on energy imports by making better use of their own renewable energy sources and embracing modern and innovative energy systems. As a support to the launch of the initiative, the Clean Energy for EU Islands Secretariat was set up to act as a platform of exchange for island stakeholders and to provide dedicated capacity building and technical advisory services.

The Clean Energy for EU Islands Secretariat supports islands in their clean energy transition in the following ways:

- It provides technical and methodological support to islands to develop clean energy strategies and individual clean energy projects.
- It co-organises workshops and webinars to build capacity in island communities on financing, renewable technologies, community engagement, etc. to empower them in their transition process.
- It creates a network at a European level in which islands can share their stories, learn from each other, and build a European island movement.

The Clean Energy for EU Islands Secretariat provides a link between the clean energy transition stories of EU islands and the wider European community, in particular the European Commission.

1. Introduction

Objectives

As part of a Call for Proposals launched in 2019 for project support to islands, the Clean Energy for EU Islands Secretariat is providing Technical Advisory services to the island Žirje, a Croatian island in the Adriatic Sea. They face the challenge that the existing electricity grid covers only a part of the island's settlements, while it is inaccessible to most of the inhabitants. Expanding electricity access to the entire island will improve the conditions and quality of life of all its inhabitants and enable equal opportunities. This is exemplified by the ambition to develop a water desalination plant to ease access to drinking water since they now fully depend on freshwater imports from the mainland. Furthermore, increased electricity access could reduce emigration, which is one of the fundamental priorities identified in the regional and local strategic documents. In order not to jeopardize the future of its inhabitants, protect nature and preserve the environment, it is necessary to invest in renewable energy sources.

The aim of Žirje is thus threefold. First, it wishes to expand electricity access to all inhabitants of the island. Second, it wishes to install a water desalination plant that uses excess energy to become more independent of freshwater imports from the mainland. Third, it wishes to do both these things in a way that protects nature and preserves the environment.

Guide to the reader

The island's renewable resources are investigated with modelling software to identify the optimal mix of renewable technologies for the island's electricity consumption when all inhabitants are connected to the grid and a water desalination plant, using excess renewable energy, is integrated. This report thus presents a techno-economic optimization of combining electricity and water production on Žirje to find the lowest-cost renewable energy supply system among different possible grid configurations.

Section 2 discusses the island background, its current electricity and water consumption, as well as the renewable resources. Section 3 shows the methodology, the input components and the general assumptions in the model. Section 4 presents and discusses the result of the simulation model, while Section 5 offers a final conclusion on how to electrify Žirje in low-cost and low-carbon way.

2. The local context

Island background

The Croatian island Žirje has a surface area of 15 km^2 and is home to 103 permanent residents under the administrative direction of the City of Šibenik, see Figure 1. The island is mostly rural with as main industries agriculture and fishery. However, tourism also plays a big role during Summer in July and August. The island has a latitude at around 43°, which puts it in the 'temperature zone' climate zone. This means that solar radiation arrives with a smaller angle compared to the equator. The mean temperature is around 16°C, with a relatively constant precipitation throughout the year.

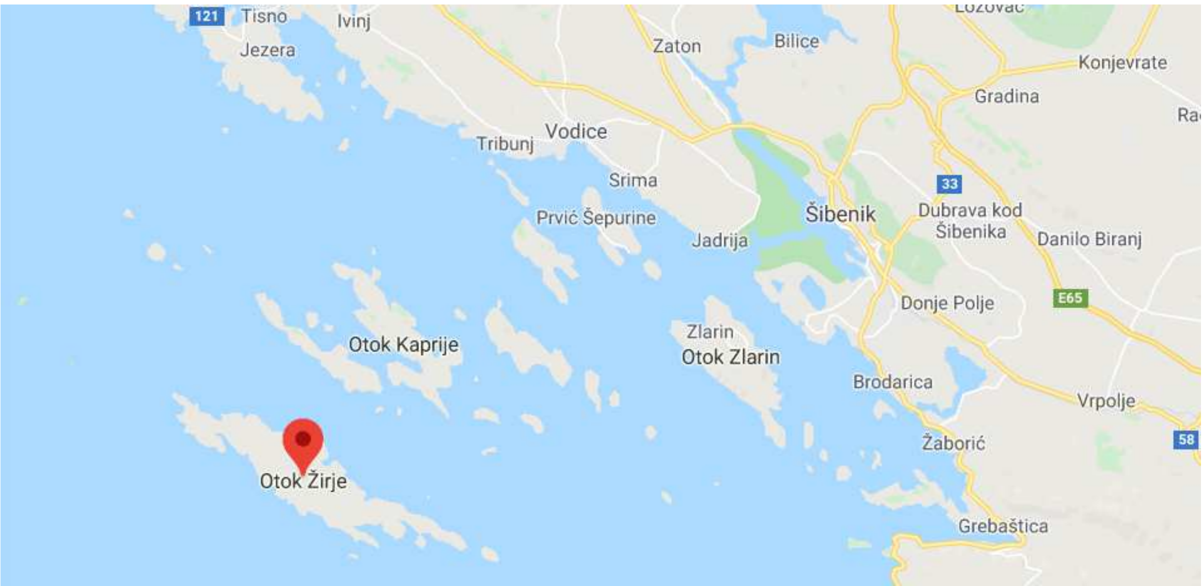

Figure 1: The Island of Žirje's location from Sibenik (Source: GoogleMaps)

Electricity demand

The total electricity consumption for the year 2018, as given by HEP (the Croatian distribution network operator) is shown in Table 1, classified per type of load. No significant decentral production is yet present on the island, so all electricity comes from the grid connection with the mainland. The load profile, which displays the electrical consumption for each hour of the day for the entire year, was unavailable. Therefore, a synthetic load profile is created. This is firstly based on the electrical consumption for the year 2018. However, this electricity consumption is insufficient since a portion of the island's inhabitants does not yet have electricity access. Based on population numbers, an increase of 32% in electricity consumption has been assumed.

	Total Consumption [kWh]	**Residential [kWh]**	**Commercial [kWh]**	**Municipality [kWh]**
2018	612,349	319 541	247 877	44 931
Future scenario 32% increase	808,300	421,794	327,197	59,309

Table 1 Yearly electricity consumption in 2018 and expected future growth

Secondly, these yearly figures can be converted into an hourly load profile through load distributions. Load distributions were obtained from HOMER Pro, a software developed by HOMER Energy that aids in finding grid configurations according to user requirements. These load distributions differ per (i) load type, (ii) between week and weekend days, (iii) and per month of the year. Residential loads consume most of the electricity (see Table 1). This load distribution has a peak in the evening and is close to zero during the night. Another significant portion of the electrical consumption comes for commercial loads. This load distribution has a uniform consumption from 9am to 5pm, after which it steadily drops close to zero by 8pm and stays near zero until the next morning. A smaller portion of the consumption comes from municipal loads, which mostly corresponds to street lighting. This load distribution steadily increases from 6am to 9am, then remains constant until 4pm, after which it increases with a peak at 8pm and then drops down until the next morning. Additionally, consumption also differs between weekdays and weekends. For residential profiles, more electricity is used in the weekend when people are home during the day. The opposite is true for commercial and community load profiles, which are slightly higher during the week. Moreover, the load distribution is also influenced by the time of year, or the seasonality, which traditionally results in a peak during the colder months in Winter due to heating.

In the case of Žirje, tourism in July and August plays a major factor as electricity consumption increases by a factor of twelve during these months, as indicated by the representative of Žirje. The month before and after the high season are estimated by the author to have an increase of a factor of four as they ramp up and ramp down to the high season, respectively. The yearly load distribution can be seen in Figure 2.

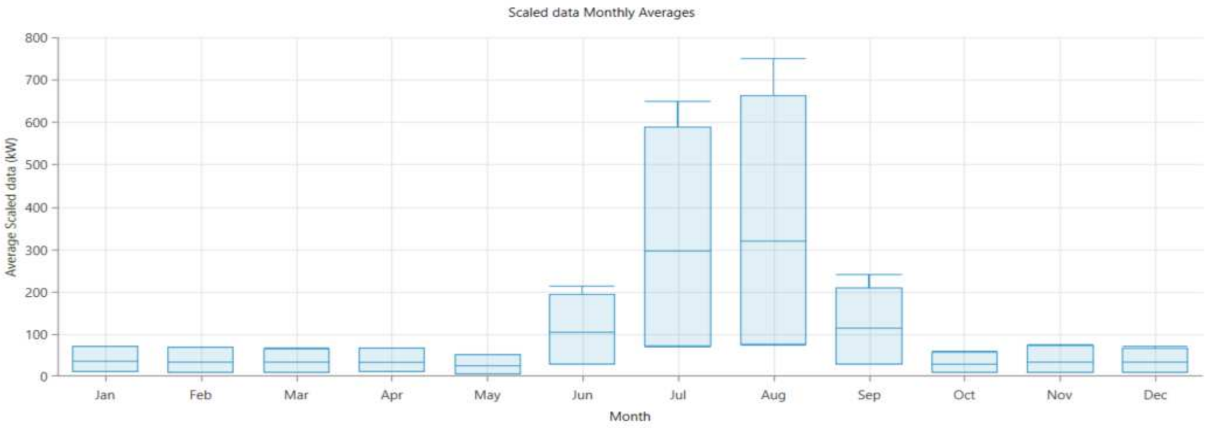

Figure 2 Seasonal electricity load profile

Lastly, these load profiles per load type were summed to form one synthetic load profile of the total electrical consumption, which is incorporated into the model for the system sizing simulation. Figure 3 illustrates a typical weekday and weekend day of this synthetic load profile for Žirje. The expected average electricity demand for Žirje is then projected to be 2,215 kWh/day. However, the actual daily demand differs significantly between high season and the rest of the year. Where the peak load in the off-season is only about 70 kW in the off-season, this can reach up to 750 kW in the high season.

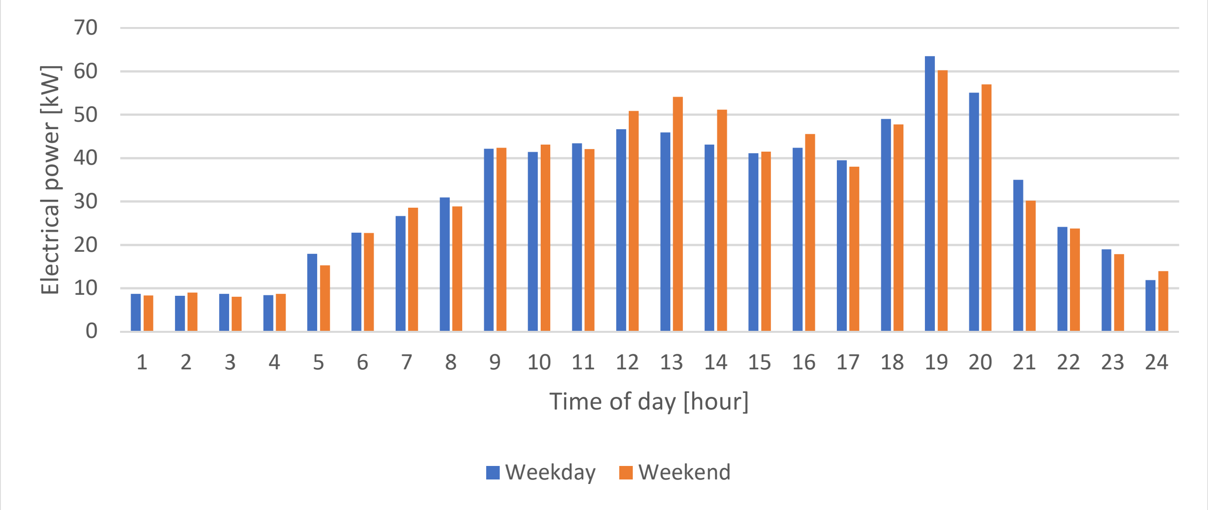

Figure 3 Typical hourly demand profiles for a Weekday and a Weekend in January

Renewable resources

Wind speed are taken from the NASA Surface meteorology and Solar Energy database. The measurements are at 50 m above the surface of the earth and are averaged over a 10-year period (July 1983 - June 1993). The monthly average wind speeds remain quite stable in the region, with an average of 4m/s throughout the year. The highest average wind speed occurs in February with 4.6 m/s and the lowest in July with 3.6 m/s (see Figure 4)

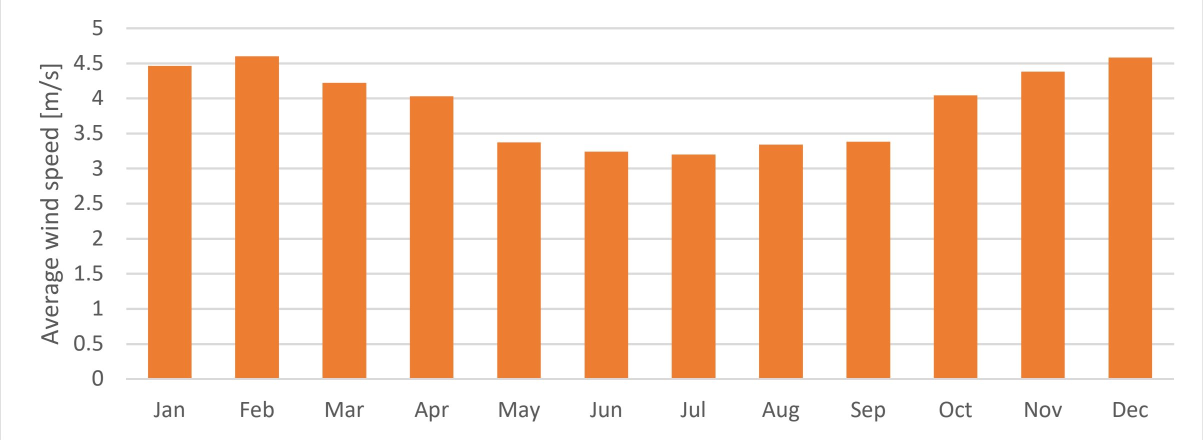

Figure 4 Monthly average wind speeds on Žirje

Solar irradiation data are taken from the NASA Surface meteorology and Solar Energy database. The measurements are monthly averaged values over a 22-year period (July 1983 - June 2005). The annual average of solar irradiation on Žirje is 4.39 kWh/m^2/day. The lowest radiation is 1.38 kWh/m^2/day in December and the highest is 7.51 kWh/m^2/day in July (see Figure 5).

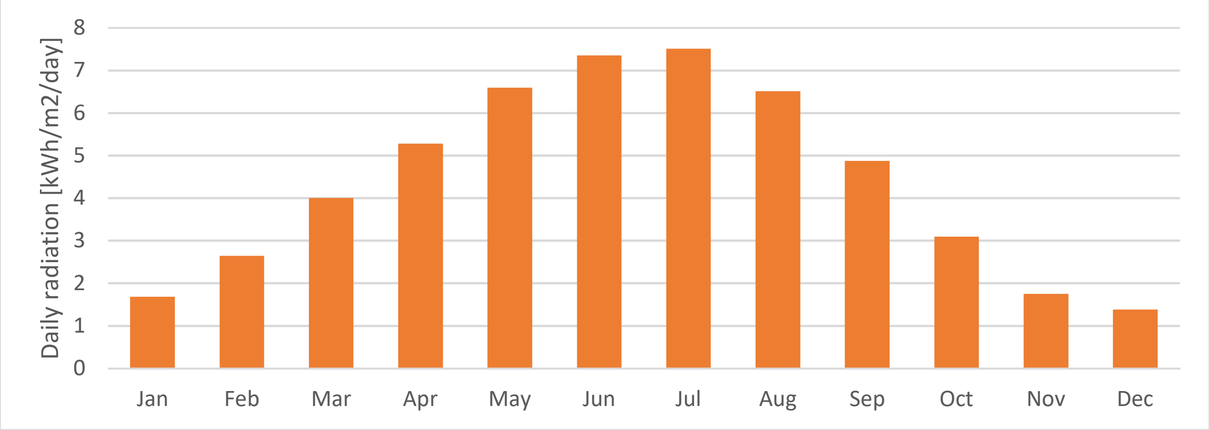

Figure 5 Monthly average solar global horizontal irradiation on Žirje

High levels of solar irradiation characterize the south of Croatia. The photovoltaic power potential map in Figure 6 clearly indicates that Žirje has one of the highest solar irradiance measurements in Croatia. Furthermore, the irradiance in Žirje is higher than in many countries that are already implementing solar PV technology as a feasible alternative.

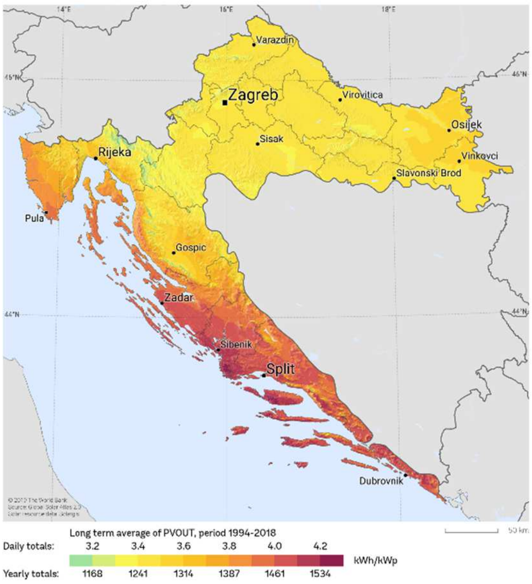

Figure 6 Photovoltaic power potential map (Source: World bank group and Solargis)

Current water supply

The current water supply system is based on water imports from the mainland by tankers. Results from the wells researched on the island for irrigation purposes show that the local water is not suitable for consumption, either in quantity or microbiologicaly. No public water supply network is installed on the island. Water from the mainland is supplied when needed. This means that there are no deliveries between November and May. In the high season, during July and August, water is delivered 2 to 4 times per month. During the other months, water is delivered approximately once per month.

The volume of each shipment is 480 m^3 of water. In order to provide enough freshwater for the households and agricultural purposes without the dependency on water imports, 16 m^3/day would need to be produced in the off-season and about 48 m^3/day in high season during July and August. This demand could be met by seawater desalination. Residents pay 1.38 \$/m^3 for imported water, which is the same price as on the mainland. However, this low price is only state subsidized up to 45 m^3 per year per natural person. Once consumption is higher, the price becomes 11,61 \$/m^3. Non-residents pay this higher price from start with no subsidies.

3. Methodology

The goal of this report is to provide Žirje with information on renewable technology grid configurations and their related costs. This will allow them to make an educated choice on how to expand their electricity production in a way that preserves the environment and prevents carbon emissions. This is done using HOMER Pro, a software developed by HOMER Energy that aids in finding grid configurations according to user requirements. This section first identifies the various renewable technology components included in the model. Secondly, it examines the general assumptions of the model.

Components

The electrical components that are included in the model are:

***Wind turbines**:* Due to legal regulations, it is not allowed to build wind turbines on the island. Still, this report will include wind turbines to determine how they stack up against other renewable alternatives as a reference. If wind turbines are not in the optimal solution, no harm done. If they are, an additional scenario is modeled without any wind turbines. Only small-scale wind energy converters could be set up on the island. One reason for this is the relatively low peak demand and load profile in the off-season. Another reason has to do with difficulties in shipping due to the small harbour as well as to installation restrictions for heavy and large-sized equipment. Based on these requirements, a 100-kW XANT wind turbine with a hub height of 31.8 m has been chosen from the HOMER database. These turbines can be installed without a crane and are hence ideal for more remote locations. The capital cost was given by a XANT sales representative and equals $325,000 for the turbine itself, the installation, and the additional civil and electrical works, while the O&M cost are about $3,500 per year. The expected lifetime of the wind turbine is 20 years.

Solar PV: There are various sub-categories for solar PV technologies that are available, the most common type, polycrystalline, is incorporated into the HOMER model. According to the author's experience in similar projects globally, the capital cost for the engineering, procurement and construction of PV panels is estimated at $950/kWp, which includes the cost of the inverters. The O&M cost is defined at $13.6/kW per year. The expected lifetime of the PV panels is 20 years and the performance rating g factor is 80%, including, e.g. aging, wiring, connection losses, dust, and shading. A module orientation towards the south is assumed with the azimuth being zero. The slope of the modules is set at 43.65 degrees.

The grid: The grid transports electricity from the mainland to the island and is maintained by the national Distribution Network Operator HEP. The inhabitants of Žirje pay the same rate as people living on the mainland. In the first half of 2019, the price of electricity was 0.147 $/kWh for a single meter and has remained quite consistent throughout the years (1). Excess electricity from local production cannot be sold back to the grid, but instead is used to power the desalination unit.

Desalination unit: There are two main approaches used to desalinate sea water: thermal distillation or filtration. Since no additional heat source (e.g. from producing industry) is available on the island, thermal desalination processes are not considered as they would require importing fossil fuels to create heat (which is the opposite of what Žirje is trying to achieve). The filtration process is electrically driven and can use excess electricity from renewables on the island. In this sense, desalination units can be considered as flexible energy sinks whenever excess energy generated by renewable energy sources is available. Not all desalination processes can handle the discontinuous power flow of excess electricity, but reverse osmosis (RO) has been shown to adapt to a variable power source (2). Furthermore, RO is also most widely used with 62% of renewable desalination using RO and 42% being powered by PV systems (3). It is appropriate for capacities up to 100 m^3/day, requires 5 kWh/m^3 and has an assumed hourly nominal capacity of 8.25 m^3. Typical figures for the investment cost of new installed desalination capacity range between $800 and $1500 per unit of capacity (m^3/day), with large variations depending on local conditions (labour cost, interest rate, etc.) (3). Typical operation and maintenance costs are estimated at about 2-2.5% of the investment cost per year. This would at worst make $75,000 in investment costs and $1,875 O&M costs for a desalination unit with a production capacity of 50 m3/day.

General assumptions

Several assumptions were made in order to run the simulations. These assumptions are drawn from experience in similar projects as well as international best practices. The input parameters for the HOMER model include the following general assumptions:

- Project lifespan: The systems are assumed to have a 20-year lifespan since most global RE independent programmes use a lifespan of 20 years.
- Exchange rate: For the purpose of this analysis an exchange rate of 6.96 Croatian Kuna/USD is assumed.
- Discount rate: The nominal discount rate is 3%, based on the estimated interest rate for lending money indicate by Žirje
- Inflation: The average expected Croatian inflation rate is 1.36%, based on the projections of 2021 to 2024 (4).
- Cost reflectivity: There are no recoverable costs at the end of the lifespan of the system.
- Grid expansion: The capital costs for expanding the grid are not considered in this analysis since these would be the same, no matter what combination of electricity technologies is chosen. Still, these costs should be included if one would to know the full cost of expanding electricity access on the island.

4. Results and discussion

Electricity production using renewables

Various configurations of energy systems are modelled by implementing the demand profile into the HOMER simulation software and selecting the energy sources. The energy sources included solar PV, wind, and the electrical grid. The goal of Žirje is threefold. First, it wishes to meet the future energy demand when electricity access is expanded to all inhabitants. Second, it wishes to install a water desalination plant that uses excess energy to become more independent of freshwater imports from the mainland. Third, it wishes to do both these things in a way that includes a significant fraction of renewables in order to preserve the environment.

The result from the model with the lowest net present cost are presented in Table 2. The HOMER model revealed that the lowest cost energy solution for Žirje is a solar PV system that is connected to the mainland grid. The undersea cable capacity is not known but assumed to be sufficient as there were no power delivery issues in the base case. This solution has a renewable fraction of 43.1%. Compared to the current grid connected system, by implementing PV panels and other required applications, the overall costs of electricity can significantly be minimized from 0.147 $/kWh to 0.105 $/kWh for a period of 20 years. The discounted payback period occurs at 9.13 years. A system change towards renewables, though, includes relatively high investment costs, as indicated in Table 2.

Indicator	**Technology**	**Capacity [kW]**	**Net Present Cost [$]**	**Cost of Electricity [$/kWh]**	**Investment Cost [$]**	**Operating Cost [$/yr]**	**Renewable Fraction [%]**
Lowest NPC	Grid	Sufficient	1.73 million	0.105	282,017	85,333	43.1
	Solar PV (kWp DC)	297					
	Inverter (kW DC)	249					
Base Case	Grid	Sufficient	2.02 million	0.147	0	0	0

Table 2 Result with lowest NPC versus base case

The monthly renewable electricity production changes quite significantly in this system, with PV producing almost all electricity during the off-season, but only a fraction in the tourist season when demand suddenly increases (see Figure 7).

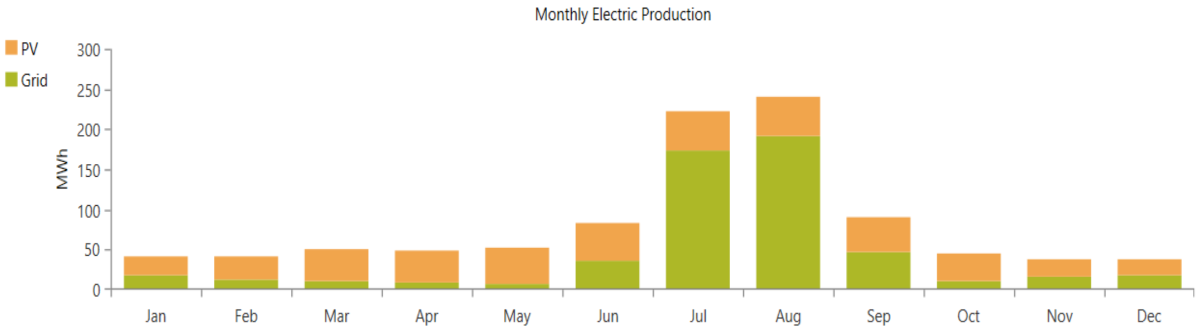

Figure 7 Monthly electrical production

The operation of the energy system for a typical day in January and August are shown in Figure 8. It shows that in January solar electricity production is many times more the required demand, resulting in excess electricity. Additionally, grid purchases are still required in the evening. In August on the other hand, solar electricity production is lower than the demand, and grid purchases are required during the day and especially in the evening.

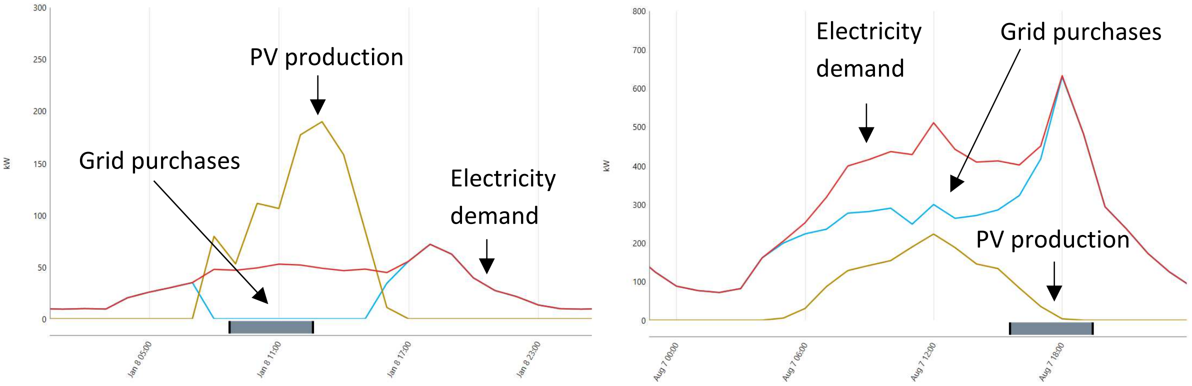

Figure 8 Energy production/usage in January (left), August (right)

The annual energy balance in Table 3 shows the total electricity produced by PV, the grid, and the excess electricity per year of the system. The capacity utilization factor of the inverters is 4,379 full load hours per year. There is also a significant amount of excess electricity by the solar production that can be used for water production.

Table 3 Annual energy balance of lowest cost system

Description	**Annual electricity input/output**
Total electricity	992,329 kWh
PV energy production	440,969 kWh
Grid energy Purchased	551,360 kWh
Electricity demand	808,300 kWh
Excess electricity	184,029 kWh

Source: Consultant analysis using Homer Pro results

Water production using excess electricity of renewables

Analysing the deviation of every hour within the one-year simulation, a remarkable excess of generated electricity by the solar panels can be determined in the off-season. In Figure 9, the daily average load and daily average wind power generation are shown. Hourly fluctuations are not noticeable in this daily resolution. After meeting the electricity demand of all consumers, the surplus electricity could be used for alternative purposes.

On Žirje, producing water and supplementing the existing water stocks is an optimal solution, if additional required investments do not exceed a reasonable amount. Costs for desalination can be kept low if energy costs for the desalination process are low. In electrically driven processes, like the one considered here, about 44% of the overall desalination costs are energy costs. Therefore, the usage of free excess electricity could reduce costs significantly. To determine the potential of producing potable water by excess electricity in Žirje, the hourly data sets are converted weekly values since water storage tanks can guarantee a reliable and constant availability of freshwater within the presented weeks.

The produced amount of water per hour results from the available excess electricity each hour divided by the energy consumption of the desalination plant, which is assumed to be 5 kWh/m^3. However, the desalination plant has an hourly nominal capacity of 8.25 m^3. Due to this restriction, not all excess solar energy can be converted and used for freshwater production. Figure 10 shows the potential of water production on the island. The dark columns in the background highlight the theoretical potential of water production using excess electricity; the light columns show the real potential based on the technical production restrictions of the desalination plant. Since the water storage is finite, filled bars of some weeks cannot be shifted to other weeks further ahead, e.g., from week 23 to 29. Figure 10 exemplifies that excess electricity generated by renewables could produce a significant amount of potable water during the off-season, more than what is currently imported from the mainland. However, it also shows that solar energy cannot guarantee a continuous and reliable water supply throughout the whole year. During the tourist season in July and August, no excess solar energy is present and hence no freshwater production using excess electricity. That means that the desalination unit can either work on electricity from the grid or additional water could be imported as is now the case. If energy from the grid is used, the operational cost to produce freshwater is 1.62 $/m^3, while the first 45 m^3 imported water from the mainland per household is only 1.38 $/m^3 due to state subsidies. Additionally, to meet the freshwater demand during the tourist season, the desalination unit would need to be sized by many times bigger than if it just met the freshwater demand of the off-season. This would increase the cost of the desalination plant needlessly, as the freshwater requirement during the tourist season can be met using the state subsidized imported water.

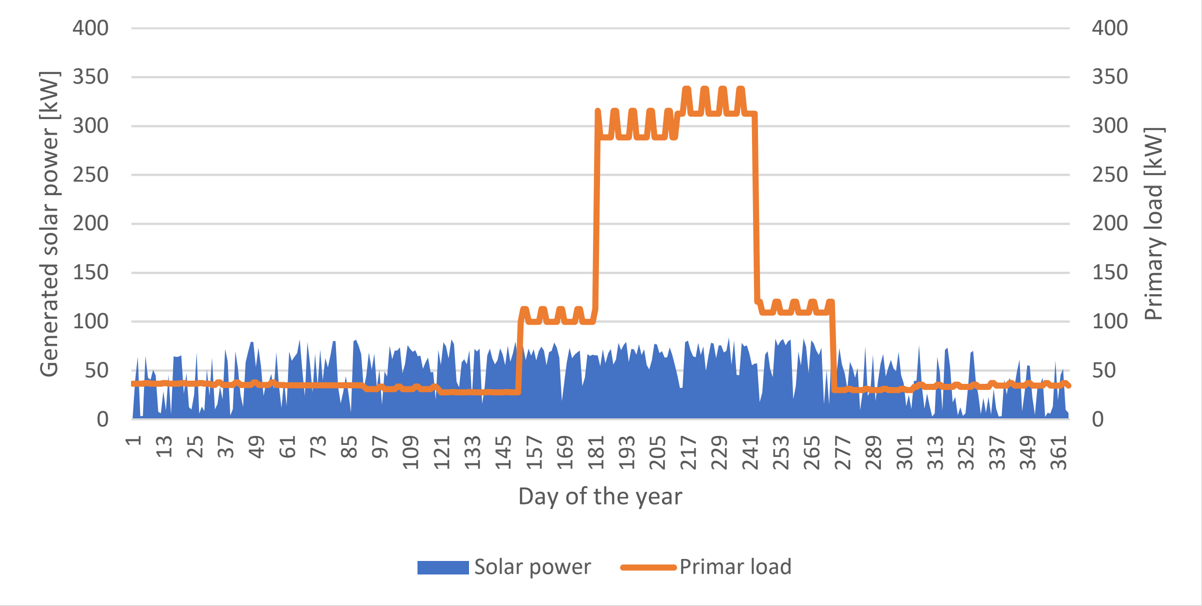

Figure 9 Load and power generation by solar panels (daily average)

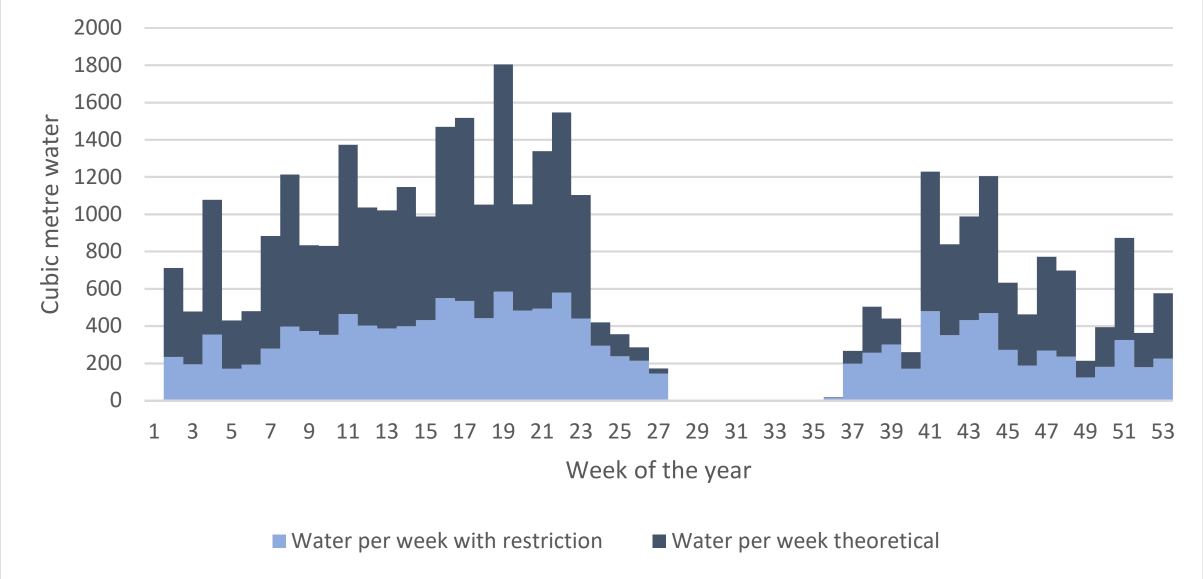

Figure 10 Water demand and production potential by excess electricity of renewable energy fraction.

As water demand during the off-season is about 16 m³/day, the desalination plant could be scaled conservatively to 20 m³/day. The levelized cost of water is then about $0.75/m³. This assumes a plant lifetime of 20 years, a daily water production of 20m³ during the off-season and state subsidized water import of three tankers per month (1440 m³ per month) during the tourist season. The levelized cost of water of continuing to import without desalination plant is about $6.2/m³. This assumes a daily water import of 20m³ during the off-season, water import of three tankers per month (1440 m³ per month) during the tourist season, and a volume of state-subsidized imported water equal to 45m³ for each of the 103 inhabitants of Žirje, the rest is bought at full price. The difference between levelized cost of water of the desalination plant versus no desalination plant is quite high. This is the case because no electricity cost needs to be attributed to levelized cost of water of the desalination plant as only excess electricity is used. Additionally, non-state subsidized water is quite expensive and Žirje still needs quite a bit.

As a concluding note, assessing the technical feasibility and cost effectiveness of renewable desalination plants requires a detailed analysis, including a variety of factors, such as quality (salinity) of feed-water input, freshwater output, operation and maintenance requirements, feed-water transportation and pre-treatment among others. This study illustrates that using excess electricity to produce freshwater has potential but requires a more detailed technical and cost-analysis before implementation.

5. Conclusion

This report investigated a mix of energy technologies that would allow Žirje to expand its electricity access to all inhabitants and to produce freshwater from excess renewable energy, in a way that is both low-cost and low-carbon. The study points out that an extension of the current energy supply system using renewable energy technologies can reduce power generation costs by almost 30% to 0.105 $/kWh. It can be concluded that the techno-economic optimal energy supply system consists of 297 kW of PV panels and a converter capacity of 249 kW, which accounts for a renewable penetration of 43%.

The renewable system can meet most of the energy demand throughout the year, albeit not during the evening and not in July and August when electricity demand skyrockets due to tourism. During these times, grid electricity is still required. The energy demand of the desalination plant is integrated to the micro grid using only renewable and free excess electricity. This allows to produce up to 200 m^3 freshwater per week throughout the year, except for July and August when no excess electricity is present. It can do this at a levelized cost of water which is significantly lower than the levelized cost of only importing water.

Žirje has the potential to combine solar PV and desalination to address their water and energy needs. A more detailed study should be conducted to investigate the technical and economic feasibility of such a system through more detailed modelling and evaluating the relationships between the different entities.

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