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Income Maximisation in a Maltese Household Photovoltaic System by Means of Output and Consumption Simulations

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Abstract: The installation of photovoltaic (PV) systems in the Maltese Islands plays an important role in allowing Malta to increase its share in renewable energy to meet the set European Union targets. In the Maltese residential sector, PV systems are generally installed on rooftops of households with a south-facing orientation and a 30° inclination angle. The scope of this study is to present a methodology to maximise the income for residents from electricity generated, by comparing the output of electricity generation with the electricity consumption patterns of different household types and consequently identifying the most favourable installation configurations of these PV systems. The research was carried out by simulating the monthly electricity generation of a 3 kilowatt-peak PV system for a year, as well as the hourly electricity generation for a day in each season of the year using the PVsyst software package. A total of 21 configurations were studied by altering the orientation and inclination angles used to install the PV system. This study confirms that a south-facing PV system inclined at 30° generates the most electricity in a year. However, when compared with electricity consumption patterns of low-, medium- and high-consumption households, it is shown that a south-facing PV system inclined at 40° provides a better income for residents.

Keywords: renewable energy; solar energy; PV system modelling; PV configurations; electricity consumption patterns; income maximisation



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1. Introduction

The installation of photovoltaic (PV) panels in residential households provides communities with many benefits that can be of both an environmental and economic nature [1]. Solar energy is a renewable energy resource that can be harnessed by PV panels to generate electricity without polluting the environment with carbon dioxide (CO₂) emissions [2]. In a residential household, a PV system offsets electricity demand from the electricity grid, allowing a reduction in electricity bills for residents [3].

The increase in demand for electricity is a challenge that both developed and less developed countries must face by increasing their power generation capacities [4]. This, coupled with the ever-rising need to switch to cleaner energy technologies that do not pollute the environment, has forced countries to develop new strategies to ensure a sustainable energy mix [5]. When including the production and end-of-life treatment of a 3 kilowatt-peak (kWp) PV system, studies have shown that the total CO₂ savings could amount to around 10,000 kg of CO₂ during the lifetime of the PV system [6]. However, to promote energy generation from renewable sources, it is important that the energy source can generate electricity at a comparable cost with fossil fuel-based sources [7].

According to the current European Union (EU) directive, Malta must generate 11.5% of its gross energy requirements from renewable sources of energy by the year 2030 [8]. Solar energy is expected to provide the largest contribution to Malta's electricity sector to help the country reach its 2030 goal. The scope of this study is thus to investigate the most favourable configurations for the installation of PV panels on residential rooftops in the Maltese Islands in order to maximise economic benefits for residents.

The two main variables for a PV system configuration are the orientation and inclination angles which govern the placement of PV panels on surfaces [9]. In the northern hemisphere, the orientation angle of a PV system may be defined as the angle at which one orients the PV panel away from the true geographical south [10]. In the northern hemisphere, a solar panel oriented at 0° will generate the most electricity at midday, when the sun's azimuth is in line with the orientation of the solar panel, meaning solar irradiation will hit the panel from directly above it [11]. At other times of the day, the sun will not be directly in front of the panels, meaning less electricity will be generated. The inclination angle, also known as the tilt angle of a PV system, can be described as the tilt of the solar panel towards the sun. The optimal inclination angle may be calculated by deducting the declination angle of the sun from 90° [12]. The optimal tilt angle will vary according to the season, since the sun is lower in the sky during the winter months, while it is higher during the summer months [13].

PVsyst simulation software is used in this study to collect electricity generation data for different PV system inclination and orientation angles in Malta. A previous study comparing simulated data with observed data in Uzbekistan found that PVsyst only underestimated the electricity output by 4.68% [14]. A study performed by Nussbaumer et al. that compared simulated and observed electricity generation for a bi-facial PV module found that the PVsyst software provides accurate simulation results when irradiance is high [15]. Such studies infer that the PVsyst simulation software used in the current study will provide reliable results, especially since the latter will collect and present hourly electricity generation data on days where cloud cover is minimal.

This research article will present the electricity generation output of several PV system configurations, which include different orientation and inclination angles for the PV panels. The results will then be compared with the electricity consumption patterns of households to see which configurations provide the best economic benefit to residents. The standard configuration adopted for PV systems in Malta is to install the system south-facing with an inclination angle of 30° [16,17]. However, this does not necessarily mean that this is the most favourable configuration to be used in all scenarios. To date, there are no published studies identifying the best configurations for residential PV systems based on the electricity consumption patterns of households. This study will thus be the first to identify households with different consumption patterns and to compare them with electricity generation from a PV system installed with various configurations. Understanding which configuration may benefit households the most, based on their consumption patterns, will allow residents to increase their income from the installed PV systems.

Households in the Maltese Islands have different consumption levels and may also consume electricity at different times of the day [18]. It is important to understand the factors that impact electricity consumption as one would need to configure the panels in a certain way to meet the demand of consumers and to reduce the mismatch between the supply and demand of electricity [19]. Electricity demand has increased over the years in Malta, amounting to the consumption of 656.8 gigawatt-hours (GWh) in 2019, from which 8.2% was generated using renewable technologies [20]. The highest demand for electricity is usually in the months of July and August, accounting for one-fifth of the electricity consumption for the year [21].

The purpose of this study is to present a methodology on how to maximise the income for residents in a Maltese household from electricity generated from their installed PV systems by means of output and consumption simulations. The methodology adopted to achieve this scope is described in Section 2 and its aim is to determine and analyse the best PV configurations that provide the most energy to households while reducing the mismatch between electricity generation and consumer demand. Based on this methodology, Section 3 then presents the results for the electricity generation of various PV system setups as well as the results of different electricity consumption patterns throughout the four seasons. The analysis of the results is presented in Section 4 and aims to identify which of the studied configurations provides the highest benefit to residents, by comparing

the electricity generation of each configuration with the cost of purchasing electricity from the grid and the income from selling electricity to the grid. A discussion of the results, highlighting the benefits of each configuration with respect to matching electricity demand and maximising income, is provided in Section 5. Finally, Section 6 summarises the key findings of this study, presents the concluding remarks and addresses future research directions.

2. Methodology

This section describes the methodology used in this study to identify different PV configurations for households with varying electricity consumption patterns, to decide on the optimal PV configurations for households in the Maltese Islands and to determine whether the electricity consumption patterns of a household impact the optimal configurations for PV panel installations. A flowchart showing the framework design for data collection and analysis is given in Figure 1.

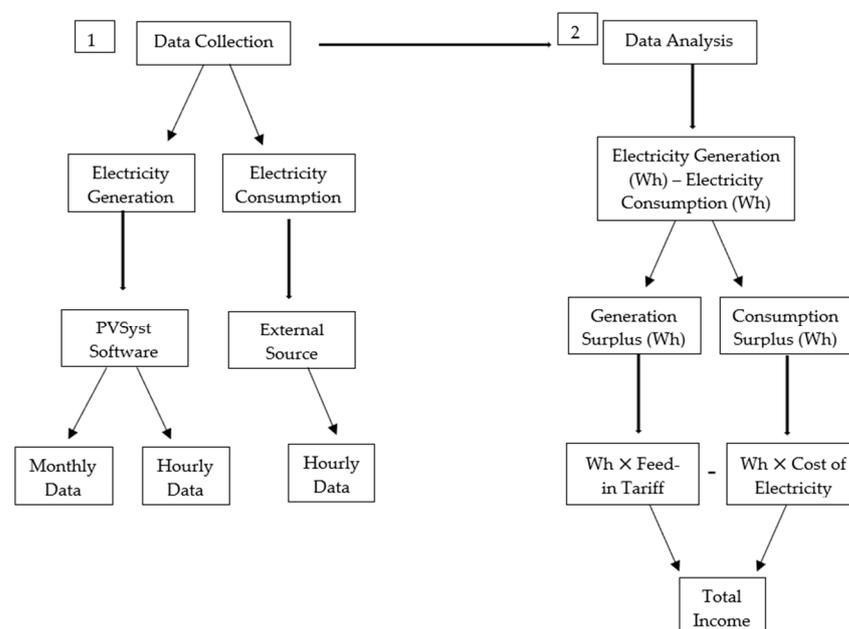


Figure 1. Flowchart of research framework design for data collection and analysis.

The software PVsyst was used in this work to simulate a grid-connected PV system installed on a rooftop with different inclination and orientation angles. PVsyst is a software package used to design, study, and predict the output of PV systems. It allows researchers to analyse a PV system's performance using different installation techniques and a variety of variables which can be modified according to the users' needs from an available database [22]. Such simulation results can be used to understand how much electricity is provided by the PV system which can then be compared to the electricity patterns of several household groups. Several factors were defined before the simulations could be performed using PVsyst, such as the location of the study, the PV system used, and the inverter required to connect the PV panels to the grid.

2.1. Data Collection

Weather data for the simulations were collected from the Meteonorm 7.3 database within PVsyst, with the latter having available weather data for the years between 1989 and 2003. Hourly irradiation values were collected for the selected site, which was Luqa, in Malta. The parameters used to calculate electricity generation were horizontal global irradiation, horizontal diffuse irradiation, ambient temperature, and wind velocity.

2.1.1. Solar Irradiation Model

The selected solar irradiation model for this study was the Perez-Ineichen model, which is a transposition model that uses the 'horizon band' as a third component of diffuse solar irradiation [23]. This model relies on a set of empirical coefficients that define the isotropic, circumsolar and horizon components of the sky diffuse model, creating a more complex model for the calculation of diffuse solar irradiation [24].

2.1.2. PV Panel Selection

A 300 watt-peak (Wp) monocrystalline PV panel, with an efficiency rating of 18.45%, was selected from within the PVsyst software. Since the aim of this study is to understand relative changes in electricity generation resulting from changes in the configuration of the PV system, and not in absolute values of electricity generation, the type of PV panel chosen does not impact the results of the study.

2.1.3. PV Array Configuration

The PV array configuration had to be defined for every run with the software. For the orientation, it was decided that the study will assess electricity generation at five different orientations, namely East, Southeast, South, Southwest, and West. Five inclination angles were also selected, starting from 0° up to 40°, with 10° intervals. A total of 21 configurations were simulated using the PVsyst software. Once all the parameters were defined, the simulations were executed to collect yearly energy yields as well as hourly data on four representative days of the year. The days chosen were representative of the four seasons, and were 15th February (winter), 14th May (spring), 15th August (summer) and 14th November (autumn). The reason behind the chosen days was that they were close to the days where electricity consumption data were available, and they were all sunny days, making sure that the data are comparable.

2.2. Data Analysis

The first step in analysing the data was to group the results for each respective configuration according to their orientation to show every inclination angle studied for that configuration. In addition, electricity consumption data for households were also included to allow the comparison between hourly electricity generation and consumption of low-, medium-, and high-consumption households within the Maltese Islands.

The next step of analysis was to compare the hourly data for electricity generation and consumption to see which of the studied configurations provided the best income opportunity for residents. First, the hourly electricity consumption data were deducted from its respective hour of electricity generation to obtain the difference between electricity generation and consumption in watt-hour (Wh). If the result of this calculation was positive, then this meant that during that hour, there was a surplus of electricity generation from the PV system, while if the answer were negative, it meant that the demand for electricity from the household was more than the PV system could provide.

The final step of the process was to multiply the result by the cost of electricity for the household if negative, or the applicable electricity feed-in tariff if the result showed a surplus in electricity generation. The cost of electricity was based on the amount of electricity the house would consume in 61 days, since in Malta, electricity bills are sent to residents every 2 months. Table 1 shows the electricity consumption tariffs chosen for each month and for each type of household. The different electricity consumption tariffs for the different households are due to the fact that in Malta there is an escalating price for different use bands. Once all the steps were completed for each month, the total values were summed up to provide the total income obtained from each configuration.

Table 1. Electricity consumption tariffs chosen according to consumption level for each season studied.

Month	Low-Consumption (€)	Medium-Consumption (€)	High-Consumption (€)
February	0.1047	0.3420	0.6076
May	0.1047	0.1607	0.6076
August	0.1298	0.3420	0.6076
November	0.1047	0.1607	0.6076

2.3. Limitations of the Study

One limitation of this study is the fact that hourly data were collected for four days of the year, which means that the benefits received from the PV system on these days may not be fully representative of all the benefits each configuration may provide during the whole year. To tackle this limitation, data were also collected monthly for a whole year to understand which configurations provide the most electricity generation yearly, and to compare these results with Malta's monthly electricity consumption figures.

Another possible limitation is that this study assumes that residents can install PV panels on their rooftop using any configuration studied, when in fact, planning guidelines, the building's orientation, and the presence of obstacles nearby, may not allow the PV system to be configured in certain ways. However, the results of this study aim to set a basis for future development of planning policies that promote the installation of PV systems using the most favourable configurations.

This study uses electricity consumption tariffs that are designed for a PV system used in the Maltese Islands, with a possible limitation is that this study is only relevant for Malta. However, the methodology presented and used in this study can be easily replicated for other countries by using the applicable electricity consumption tariffs in the relevant country.

3. Results

This section presents the results for the electricity generation of various PV system setups with different orientations and inclination angles, as well as the results for the electricity consumption patterns of low-, medium- and high-consumption households throughout the four seasons.

3.1. Electricity Generation Results

The results show that in a year's electricity generation of a PV system in Malta, a south-facing PV system inclined at 30° generates the most electricity from all the configurations studied. This system generates 5037 kilowatt-hours (kWh) of electricity in a year. The inclination angle of the PV system allows optimal energy generation in winter without significantly reducing electricity generation in summer. If the PV system is inclined at 40°, then electricity generation in winter is higher, but the energy yield in summer is reduced. The opposite is true for a PV system inclined at 20° or lower, with electricity generation being optimised for summer (Figure 2).

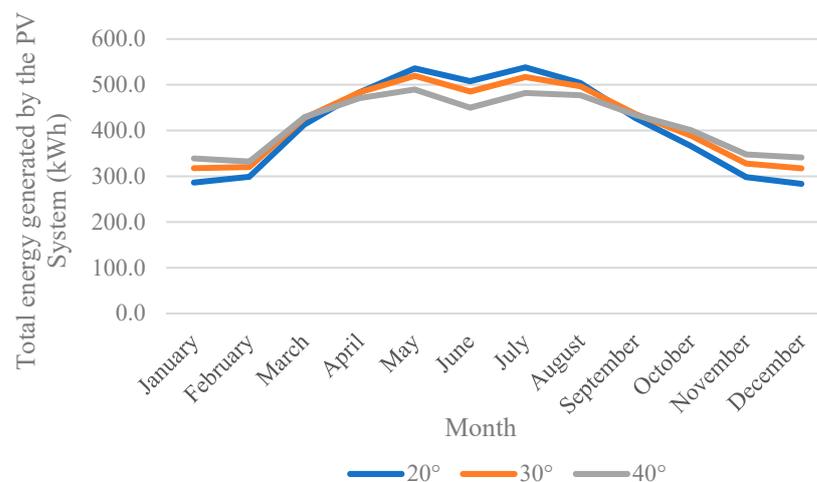


Figure 2. Comparison of the monthly electricity generation of a south-facing 3 kWp PV system with 20°, 30° and 40° inclination angles.

The results for other orientations show varying electricity generation patterns. When considering hourly data, an east-facing PV system generates considerably less electricity during a whole day. However, electricity generation in the early morning is highest for this orientation. A southeast-facing system is still optimal for morning generation of electricity, however, the energy yield during the rest of the day is not as adversely impacted as an east-facing system since the panel does not block solar irradiation as much in the afternoon. If one orients the PV system to face the southwest or west, electricity generation will be practically identical to the southeast- and east-facing counterparts, with the difference that electricity generation is optimised for the afternoon.

3.2. Household Consumption Results

Electricity consumption data were obtained from a secondary source of data for a group of households that were assessed in Malta during 2018. Data were collected for four days of the year (4th February, 6th May, 6th August and 5th November), in this way covering one day in each season for each of the categories. The following sections show a representation of the electricity consumption patterns per household in Malta, divided into three categories:

- Low-Consumption Households—Households consuming an average of 1560 kWh of electricity per year.
- Medium-Consumption Households—Households consuming an average of 12,700 kWh of electricity per year.
- High-Consumption Households—Households consuming an average of 27,100 kWh of electricity per year.

3.2.1. Low-Consumption Households

Figure 3 shows the average electricity consumption profiles for a low-consumption household during the four seasons. In February, a typical low-consumption household consumes 4.89 kWh of electricity in one day. Electricity consumption peaks in the morning and in the evening for this type of household. In May, daily electricity consumption decreases to 2.87 kWh of electricity, which may be linked with the spring weather conditions in Malta in May that do not require heating or cooling for the most part. The daily peaks of consumption also occur in the morning and evening.

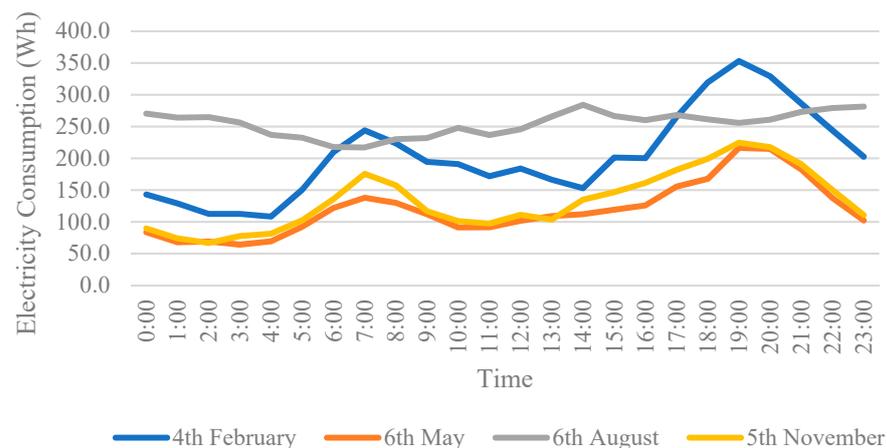


Figure 3. Comparison of the hourly average electricity consumption profiles for a low-consumption household during the four seasons.

On the other hand, in August, one may note the lack of electricity consumption peaks throughout the day. Electricity consumption increases to 6.11 kWh in a day for August, which is more than double that of May but still low to assume cooling is switched on all day. In November, electricity consumption is lower than in summer and the patterns of electricity consumption show a return of the peaks in electricity consumption in the morning and late afternoon. During this month, 3.21 kWh of electricity were consumed in a day.

3.2.2. Medium-Consumption Households

Figure 4 shows the average electricity consumption profiles for a medium-consumption household during the four seasons. It can be observed that the pattern of daily electricity consumption is very similar to that of low-consumption households (Figure 3) for all the seasons. However, in February, the electricity consumption for one day was 41.2 kWh, which is much higher than the consumption of low-consumption households. In May, the electricity consumption is also significantly lower than that of February for medium-consumption households, with the peaks of electricity consumption however remaining in the early morning and evening. The total electricity consumed in a day on the 6th May was 23.9 kWh.

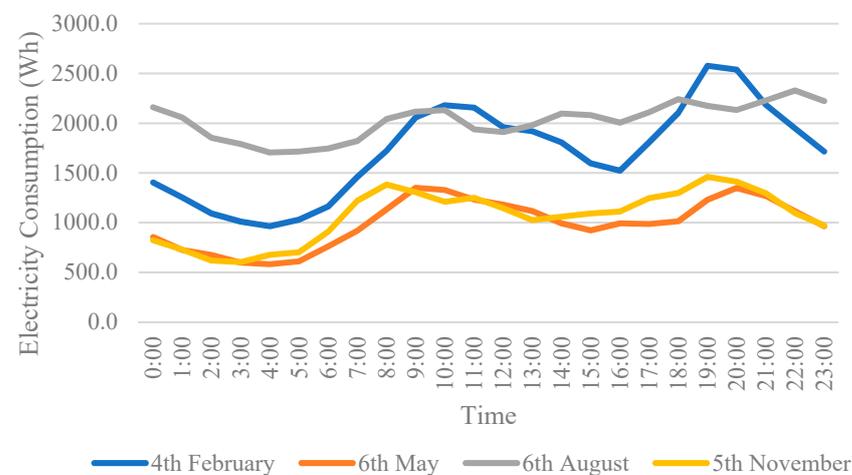


Figure 4. Comparison of the hourly average electricity consumption profiles for a medium-consumption household during the four seasons.

The daily electricity consumption in August was 48.6 kWh for a medium-consumption household, which is significantly higher than the electricity consumption in spring for

the same type of household. Once again, the peak in electricity consumption is uniform throughout the day. During November, the daily electricity consumption was 26.6 kWh, which is nearly half the electricity consumption on the 6th August.

3.2.3. High-Consumption Households

High-consumption households have different patterns of electricity consumption than households with low- and medium-consumption levels. Figure 5 shows the average electricity consumption profiles for a high-consumption household during the four seasons. In February, the morning and evening peaks are significantly reduced since electricity consumption remains high throughout the night and day. In total, 90 kWh of electricity is consumed by a high-consumption household in one day in winter, which is more than double the consumption of a medium-consumption household.

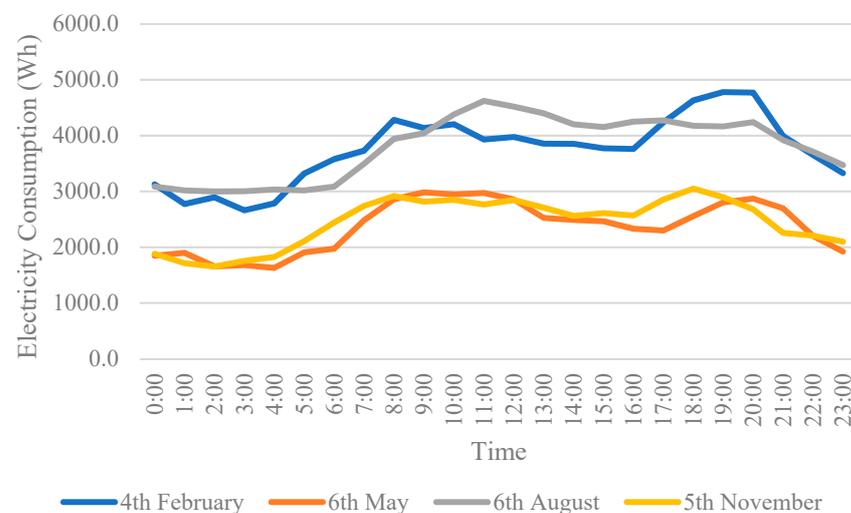


Figure 5. Comparison of the hourly average electricity consumption profiles for a high-consumption household during the four seasons.

Unlike low- and medium-consumption households, the highest peak in energy consumption in May occurs in the morning for high-consumption households, starting at 07:00 and ending at 12:00. During this month, the daily electricity consumption on the 6th May was 56.9 kWh. In August, a peak in electricity consumption occurs at 08:00, and remains high all day. In 24 h, 91.2 kWh of electricity was consumed by a high-consumption household in August. In November, electricity consumption was once again lower than summer and winter, standing at a daily consumption of 58.8 kWh. In this case, the electricity consumption pattern is similar to that of February.

4. Analysis of Results

This section will focus on presenting the results for a south-facing PV system installed for medium-consumption households since this is the most common installation scenario within the Maltese Islands. The results for different inclination angles for the south-facing orientation are grouped together to compare electricity generation patterns between each configuration. Electricity consumption data for medium-consumption households are also included in the graphs to allow for the comparison between electricity demand and supply.

4.1. Results for a South-Facing PV System

Figure 6 groups the electricity generation of south-facing PV systems with different inclinations and shows an increased difference in electricity generation in winter and summer between the five inclination angles studied. It can be observed how a high inclination angle for a south-facing PV system provides more electricity in winter, while a low inclination angle generates the most electricity in summer. A 30° PV system provides

the most energy over the whole year (0.87% more than a 40°-inclined system), since electricity generation is similar to a 40° panel in winter, but higher in summer. The flat panel, and the 10°-inclined PV system are the two configurations that provide the least energy yield in a year, generating 12.4% and 6% less than a 30°-inclined system, respectively.

	0° kWh	10° kWh	20° kWh	30° kWh	40° kWh
Year	4413.5	4733.8	4941.6	5036.4	4992.8

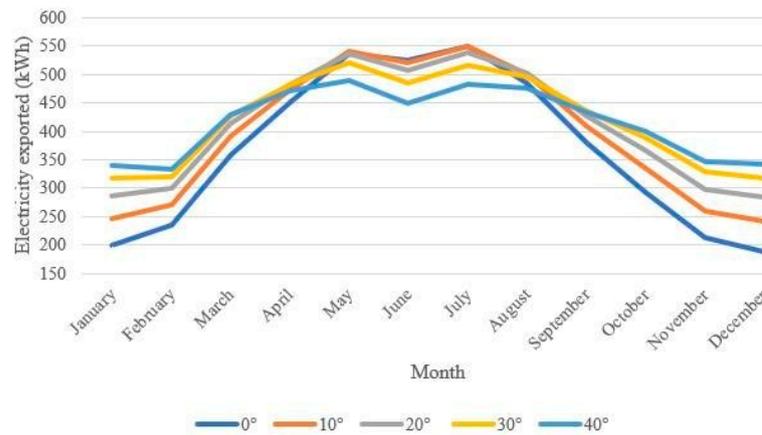


Figure 6. Monthly electricity generation of a 3 kWp south-facing PV system installed with different inclination angles.

When analysing the hourly electricity generation of a south-facing PV system, one may observe a symmetrical energy generation output, with the latter increasing in the morning, reaching a maximum at midday, and decreasing at a similar rate in the afternoon (Figure 7). In February, a panel inclined at 40° provides the most energy during a day, followed by a panel inclined at 30°. If a panel is installed at 10°, electricity generation will only match the demand of medium-consumption households between 12:00 and 13:00, while a flat panel will never provide enough energy as required to cover electricity demand.

	Flat Wh	10° Wh	20° Wh	30° Wh	40° Wh	Low Wh	Medium Wh
Day	10,940	13,135	14,894	16,202	17,068	4893	41,173

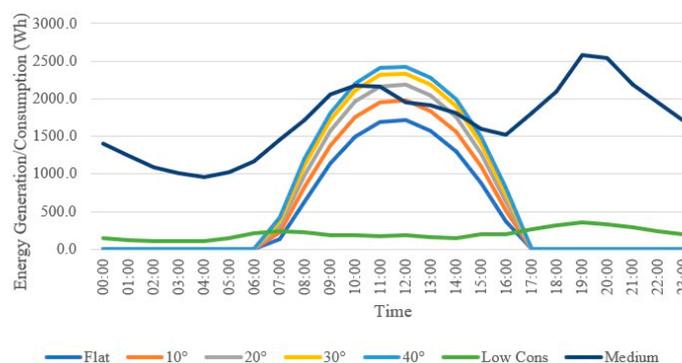


Figure 7. Comparison between hourly electricity generation of a 3 kWp PV system and the patterns of low- and medium-consumption households for a south-facing system in February.

In May, a south-facing PV system with different inclination angles shows a similarity in the electricity generation patterns of each configuration. Although a PV system with 30° inclination provides the most energy in a day, the other inclinations studied also provide a

similar amount of daily electricity. The PV system with a 40° inclination angle provides the least electricity, and when compared with medium-consumption households, this system is the last to match energy requirements in the morning and the first to stop providing enough electricity to cover demand in the afternoon (Figure 8).

	Flat kWh	10° kWh	20° kWh	30° kWh	40° kWh	Low kWh	Medium kWh
Day	18,210	18,491	18,346	17,778	16,793	2872	23,900

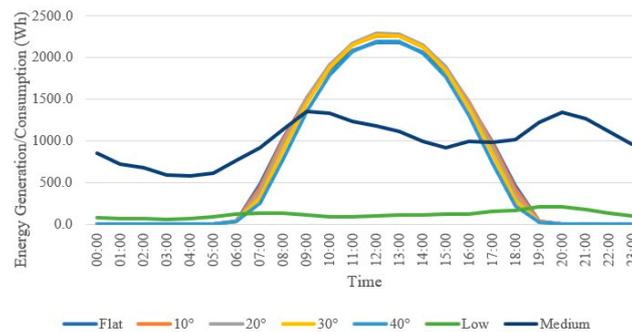


Figure 8. Comparison between hourly electricity generation of a 3 kWp PV system and the patterns of low-, and medium-consumption households for a south-facing system in May.

Electricity generation in August does not match the electricity demand of a medium-consumption household for most of the day, especially since electricity consumption in August remains high all day. The inclination angle does not have a significant impact on electricity generation during the day. Only the flat panel shows an observable reduction in electricity generation at midday (Figure 9). In this case, a panel inclined at 20° provides the most electricity, followed by a panel inclined at 10° and 30° respectively.

	Flat kWh	10° kWh	20° kWh	30° kWh	40° kWh	Low kWh	Medium kWh
Day	16,356	16,885	17,004	16,732	16,066	6107	48,590

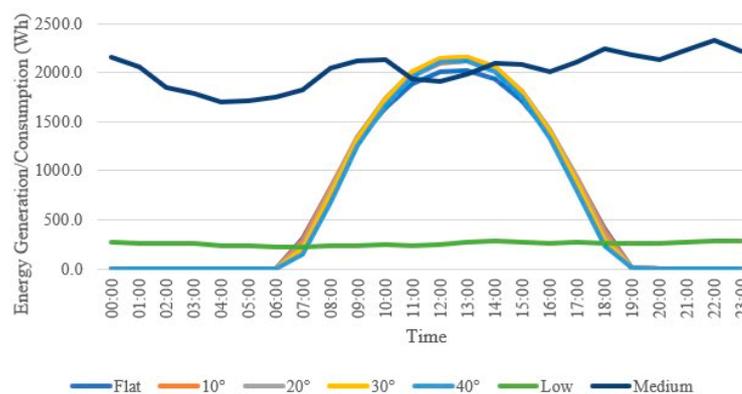


Figure 9. Comparison between hourly electricity generation of a 3 kWp PV system and the patterns of low-, and medium-consumption households for a south-facing system in August.

In November, the electricity consumption of medium-consumption households reduces significantly, permitting electricity generation from inclined PV systems to match demand for several hours. The electricity supply from PV systems with higher inclination angles is the first to match with demand in the morning and the last to drop below demand in the afternoon (Figure 10). A 40° system provides the most electricity in November.

Decreasing the inclination angle causes a decrease in electricity generation, with a flat panel providing the least energy yield for the day.

	Flat kWh	10° kWh	20° kWh	30° kWh	40° kWh	Low kWh	Medium kWh
Day	8118	10,213	11,930	13,265	14,211	3207	25,637

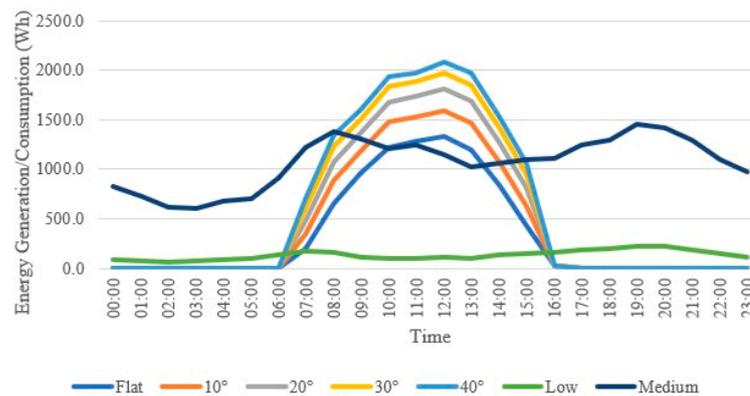


Figure 10. Comparison between hourly electricity generation of a 3 kWp PV system and the patterns of low-, and medium-consumption households for a south-facing system in November.

4.2. Analysis of Income for Each Configuration

To understand which configurations provide the best income for residents, the next step was to compare electricity generation and consumption with the cost of electricity and the feed-in tariff available. During hours where electricity generation was higher than electricity consumption, the excess energy was multiplied by the feed-in tariff (€0.155) to export electricity to the grid. Conversely, if electricity consumption was higher than the supply of electricity from the PV system, the amount of electricity required was multiplied by the cost of electricity, which varied depending on the consumption level of the households. The most common scenario in the Maltese Islands are households with a consumption between low and medium thresholds. Although the medium-consumption scenario might be a bit higher than the average consumption, it is the one that most closely approaches it and thus, for this reason, this section once again shows the results obtained for medium-consumption households. In the case of medium-consumption households, a 3 kWp PV system does not generate enough electricity to allow residents to cover the expenditure on electricity imported from the grid. The PV system only comes close to providing enough electricity to cover costs for residents in May, with a south-facing system, inclined at 10°, providing the best result.

Table 2 shows that when considering all four days studied, a south-facing system with a 40° inclination provides residents with the least expenditure of €22.46, followed by a south-facing system inclined at 30° with an expenditure of €22.54. East- and west-facing configurations result in a significantly higher expenditure on all four days studied, especially when the PV system is installed with a high inclination angle. For many of the configurations, the difference in income from the PV system is less than 10%, while for an east- and west-facing system, the difference increases to around 20%.

Table 2. Daily cost of electricity per month for medium-consumption households.

		Daily Cost of Electricity per Month (€)				
Orientation	Inclination (°)	February	May	August	November	Total
Flat	0	−10.34	−0.95	−11.06	−2.82	−25.16
East	10	−10.32	−0.98	−11.08	−2.81	−25.18
	20	−10.34	−1.06	−11.20	−2.81	−25.41
	30	−10.41	−1.18	−11.37	−2.82	−25.78
	40	−10.51	−1.33	−11.57	−2.85	−26.26
Southeast	10	−9.78	−0.93	−10.96	−2.57	−24.24
	20	−9.37	−0.97	−10.97	−2.38	−23.68
	30	−9.08	−1.06	−11.06	−2.24	−23.45
	40	−8.92	−1.19	−11.23	−2.16	−23.50
South	10	−9.59	−0.91	−10.91	−2.49	−23.89
	20	−8.99	−0.93	−10.89	−2.22	−23.02
	30	−8.54	−1.02	−10.98	−2.00	−22.54
	40	−8.24	−1.17	−11.19	−1.86	−22.46
Southwest	10	−9.84	−0.92	−10.97	−2.60	−24.33
	20	−9.47	−0.96	−10.98	−2.43	−23.84
	30	−9.22	−1.05	−11.09	−2.31	−23.66
	40	−9.11	−1.17	−11.25	−2.23	−23.77
West	10	−10.38	−0.97	−11.10	−2.83	−25.27
	20	−10.47	−1.05	−11.23	−2.84	−25.59
	30	−10.58	−1.17	−11.40	−2.86	−26.01
	40	−10.71	−1.31	−11.60	−2.90	−26.52

Once the income from each configuration was calculated as listed in Table 2, an attempt at finding a combination of configurations that may increase the overall income from the PV system was made. The results of combining configurations and comparing electricity generation with the consumption of medium-consumption households can be seen in Table 3. The results show no increased benefit from combining two orientations with each other when installing a PV system. A 3 kWp south-facing system provides an overall better income for residents than a PV system installed with 1.5 kWp facing the southeast, and 1.5 kWp facing the southwest on all the days studied.

Table 3. Daily cost of electricity per month for medium-consumption households when combining configurations.

		Daily Cost of Electricity per Month (€)				
Orientation	Inclination (°)	February	May	August	November	Total
East-West	10	−10.35	−0.97	−11.09	−2.82	−25.23
	20	−10.40	−1.05	−11.21	−2.83	−25.50
	30	−10.49	−1.18	−11.38	−2.84	−25.90
	40	−10.61	−1.32	−11.59	−2.87	−26.39
Southeast Southwest	10	−9.81	−0.93	−10.97	−2.58	−24.29
	20	−9.42	−0.96	−10.98	−2.40	−23.76
	30	−9.15	−1.05	−11.08	−2.28	−23.56
	40	−9.02	−1.18	−11.24	−2.20	−23.63

5. Discussion

The results collected from PVsyst and presented in Sections 3 and 4 show that a south-facing system with a 30° inclination provides the most electricity during the whole year. However, when considering the electricity consumption patterns of low-, medium- and high-consumption households, it has been concluded that a south-facing PV system, inclined at 40°, provides better income for residents throughout the four seasons. This

does not mean that these configurations are the only ones that should be considered. This section will provide a discussion of the results, with the aim of understanding the benefits of each configuration to allow residents to make an informed decision when installing a PV system in their home.

5.1. Matching Electricity Demand

The demand for electricity in Malta changes according to the time of the year, with summer and winter being periods of high demand, and autumn and spring being periods of low demand. For this reason, it is important for Malta to generate as much electricity as possible during times of high demand to reduce the load placed on the country's electricity generation plants. For instance, while a south-facing PV system with a 30° inclination generates the most electricity over a whole year, a PV system with the same orientation but a 40° inclination angle may prove to be more beneficial since the electricity generated in winter helps residents reduce their consumption during a period of high demand.

One possibility to improve electricity generation in winter, while also preventing a drop in electricity supply in summer could be to install a system that changes its inclination according to the season. For example, if one could install a south-facing system with 40° inclination in winter that can be adjusted to 20° in summer, one would obtain the best electricity generation when the sun is low in the sky, while not inhibiting energy yield during the summer months. In this case, the expenditure of medium-consumption households will decrease to €21.92. Besides allowing residents to generate more electricity and reduce their electricity bills even further, this installation technique will thus help any country reduce its demand for electricity from the electricity generation plants during the months when the demand is highest since it serves to maximise electricity generation in both the summer and winter months.

When considering hourly electricity consumption patterns, it is important to understand that each household has varying consumption patterns, which means that one configuration may never be the solution for all. Since for most of the year, demand for electricity is high in the morning, a southeast-facing PV system may allow the residents to benefit from increased supply during the times of highest demand. The reason for electricity supply being higher in the morning is that the sun rises from the east, which means that since the PV system is facing that direction, it will receive more direct solar irradiation in the morning.

Another possibility to decrease the mismatch between demand and supply is to install a PV system using two orientations. For example, one could cater for the morning increase in demand by installing a set of PV panels facing the southeast, while also installing a set of PV panels facing the south or southwest to prevent a decrease in electricity supply during the second part of the day. While this may not prove to be the most economical solution for residents, it may help reduce their dependency on imported electricity during times of high demand.

5.2. Maximising Income

If one considers solely electricity generation, a south-facing PV system, inclined at 30° provides residents with the most electricity, and therefore the most income from the PV system. However, the cost of electricity during the four seasons must be considered to understand the true income that the PV system provides. This study showed that a south-facing PV system inclined at 40° may provide more income for residents during a whole year, since the increased generation of electricity prevents residents from paying a higher tariff during winter, when demand is high. It is important to note that the calculations for this study were based on the presence of a feed-in tariff (€0.155) that is given to residents for several years. Once the feed-in tariff expires, electricity generated from the PV system and sold to the grid will be sold at a lower price, suggesting that it would make even more sense for residents to reduce the gap between energy generation and demand through self-consumption.

5.3. Energy Storage

The possibility of energy storage was not considered in this study since with the implementation of an energy storage system, the need to configure the PV system in certain ways will be removed. The authors believe that the installation of energy storage systems such as batteries is the way forward. However, at the time of writing, the installation of such systems is still not economically feasible on a residential scale and requires the introduction of more grants to aid residents to reduce the cost of installing such systems [25]. In 2020, Malta introduced the first of its kind grant for energy storage systems that however covered only up to 25% of the cost of the system [26].

If a high-consumption household had to install a PV system able to cover its entire daily energy requirements (90 kWh in February), a 17 kWp PV system would be required. This, of course, must be coupled with a battery-storage system since electricity generation from PV systems only occurs during sunlight hours. If one considers that the battery's depth of discharge (DoD) should be 55% [27] and full self-reliance for one day, then the battery storage system must have a capacity of 101 kWh of electricity to allow the household to get through all the hours where electricity generation is less than electricity demand. Medium-consumption households have a daily consumption of 41 kWh in February. In this case, the required size of the PV system to cater for an entire day should be at least 8 kWp. The battery storage capacity, when considering the same factors as high-consumption households, should be at least 46 kWh.

In an article written by Comello and Reichelstein [28], it is estimated that the levelized cost of electricity of a rooftop PV system installed with battery storage may reduce to €0.065 within the next four years if the cost of lithium-ion batteries continues to decrease with the current trend. This suggests that the possibility of investing in battery storage systems in the future will allow residents to increase the benefits received from their PV system, while also reducing their dependency on the country's electricity generation plants for energy. In fact, recent government grants in Malta have already started to include specific grants of battery storage to incentivise such an investment.

6. Conclusions

This study has presented the results for the production profile of various PV system setups and their income potential, followed by a comparison of the electricity generation from each configuration with electricity consumption patterns of households. Such results have ascertained which configurations provide the most economic benefit to residents. This section aims to conclude this study by discussing the key findings, as well as by presenting a summary of the results together with a few recommendations and suggestions for future research. Government regulators, planning authorities as well as installation companies may find the results of this study useful to understand how to increase the benefits related with solar technologies, while researchers and students may wish to use this study to further develop their skills and to understand what further research may be conducted to increase the benefits of solar energy.

6.1. Key Findings

The results of this study have confirmed that a south-facing PV system provides the most income to residents for each inclination angle studied. However, both a southeast-facing and a southwest-facing PV system were found to still provide a similar income during the four seasons studied. A southeast-facing PV system with 20° inclination or higher also allows the peak of electricity generation to shift slightly to the morning, which is a time where electricity demand from the country's electricity generation plants is high. This suggests that, although a south-facing system may provide the most income for residents, a southeast-facing system may help residents reduce their dependency on imported electricity during times of high demand, which in turn, will allow Malta to reduce the mismatch between electricity supply from renewable energy and demand.

Another aim of this study was to determine whether the electricity consumption patterns of households may impact the optimal configurations for PV systems in Malta. The results have shown that a south-facing PV system inclined at 30° generates the most electricity in a year in Malta. However, when the hourly electricity generation on four days of the year (one day in each season) is compared with the electricity consumption patterns of households, a south-facing PV system inclined at 40° generates the most income for residents.

By observing the graphs for each inclination angle studied in Section 4.1, and by comparing the income of each configuration in different months, one may note how changing the inclination angle of the PV system during the four seasons may help residents generate the most income over one whole year. This study has found that a 40°-inclined PV system generates the most electricity on the days studied in February and November, while a 10°-or 20°-inclined PV system captures the most energy in May and August.

6.2. Recommendations

It is recommended that residents consider various configurations depending on their requirements before deciding on which configuration to use for installing their PV system. One possibility for future investment schemes is to provide a higher feed-in tariff for electricity generated in times of high demand on the country's electricity generation plants. This will help improve the income of PV systems installed while maximising energy yield during these times.

Another recommendation is to consider PV systems that can vary their inclination angle during the year. The results show that a PV system with a high inclination helps to improve income significantly in winter, while the opposite is true for summer. A manual system that allows for this change twice a year (40° in winter and 20° in summer) could probably be included in future installations at a minimal cost, while increasing potential generation by around 3–5%.

An interesting possibility for future research will be to compare the income that can be obtained by opting for an energy storage system with that obtained by opting to sell electricity to the grid. Since the government scheme for energy storage systems introduced in Malta [26] was closed in December 2020, such an analysis should be performed upon the success of this grant to determine if future schemes can help residents increase the income potential from investing in a PV system.

A possibility for future studies is to analyse the economic benefit of installing PV systems that can change their inclination to fixed points during the year by comparing the increase in electricity generation with the increase in costs related to the installation and maintenance of the additional moving parts.

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