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CONTENT

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POSSIBILITIES FOR INSTALLATION OF PHOTOVOLTAIC SYSTEMS IN CATERING FACILITIES IN MACEDONIA

SARA ANEVA AND DRAGAN MINOVSKI

Abstract. The energy crisis that swept across Europe and the resulting electricity price impact have highlighted the need for enhanced energy resilience. To mitigate future price fluctuations and unforeseen shocks, investments in photovoltaic (PV) systems are crucial. Hospitality establishments in Macedonia hold significant potential for reducing the country's energy dependency and accelerating the energy transition. It is therefore essential to explore the feasibility of installing PV systems on these establishments and to assess the profitability of such investments. For an optimal analysis of PV system installation potential in the hospitality sector, the data from the State Statistical Office, based on the 2021 census in Macedonia, were utilized. According to the census, there are a total of 1,006 hotels and restaurants in the country. This analysis presents the total potential installed capacity of PV systems on all hotels and restaurants in Macedonia, the predicted annual electricity generation from these systems, and the resulting avoided CO_2 emissions. Since the intensity of solar radiation varies geographically, simulations were conducted for PV systems with an installed capacity of 40 kWp in each region: Vardar, Eastern, Southwestern, Southeastern, Pelagonia, Polog, Northeastern and Skopje regions. These simulations were performed using the PV*SOL premium software, which leverages the Meteonorm database for solar radiation data to estimate annual electricity production from the PV systems. The analysis also includes case studies for a hotel and a restaurant, for which techno-economic analyses were conducted to evaluate the profitability of PV system installations.

1. **Introduction**

One of the greatest challenges the world faces today is the increasing global consumption of electricity, the environmental pollution caused by the combustion of fossil fuels (coal, oil, natural gas, etc.) for electricity generation, and the need to meet the demand for electricity through clean, renewable energy sources. The EU's new set of measures aims for all member states to achieve carbon neutrality by 2050, aligning with the objectives of the Paris Agreement, to which our country is a signatory. To reach this goal, it is necessary to completely replace the use of fossil fuels, which pollute the environment, with new energy sources that are environmentally friendly, while also ensuring the stability and reliability of energy supply ([1-5]).

Given that renewable energy sources still contribute a small percentage to the overall electricity production in the country, and considering the decreased investment costs and benefits associated with photovoltaic (PV) systems, it is essential to explore the opportunities for installing PV systems on hospitality establishments in Macedonia. These establishments hold significant potential for reducing the country's energy dependency.

2. **Methodology**

For the purposes of this paper, the electricity consumption on an hourly and monthly basis of a hotel

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Keywords: *photovoltaic systems, installed capacity, electricity generation, techno-economic analyse.*

located in the city of Štip, with a total area of approximately 800m², was first analyzed. A simulation of a photovoltaic (PV) system with an installed capacity of 100 kW was then carried out using the PV*SOL premium software, resulting in hourly electricity generation data from the PV system as well as data on avoided CO_2 emissions. These data serve as the foundation for creating a proposed financial framework necessary for the construction of the PV system. Furthermore, regarding the investment payback period, financial analyses were conducted for two types of financing: a financial analysis for the PV system with 70% loan financing and 30% equity, and a financial analysis for the PV system with 100% equity. The financial analyses were performed in Excel using a custom-developed financial analysis tool, which also generated the graphs and tables presented in the study, based on the data obtained from the analyses. Since the analyzed hotel already has a PV system with an installed capacity of 40 kW on a portion of its rooftop, a comparison was made between the data provided by the investor regarding the percentage reduction in electricity bills and the analysis conducted for installing a 100 kW PV system on the same facility. Additionally, analyses were performed on the electricity generation from a 40 kW PV system in each region of North Macedonia to demonstrate the total electricity generation, total installed capacity, and avoided CO_2 emissions from installing 40 kW PV systems on all 1,006 hotels and restaurants in the country.

3. **Catering Facilities in Macedonia**

Due to the need for larger available rooftop areas for PV system installations, this study focuses on hotels and restaurants in Macedonia, of which, according to the latest census, there are totally 1,006 establishments. Figure 1 shows the percentage distribution of catering facilities across the regions of Macedonia.

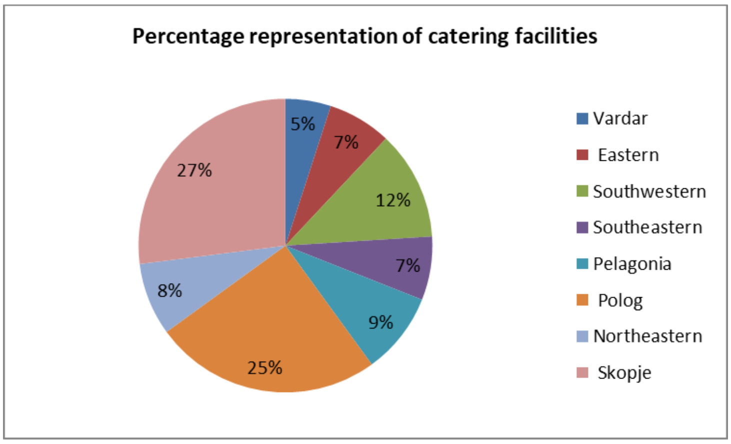
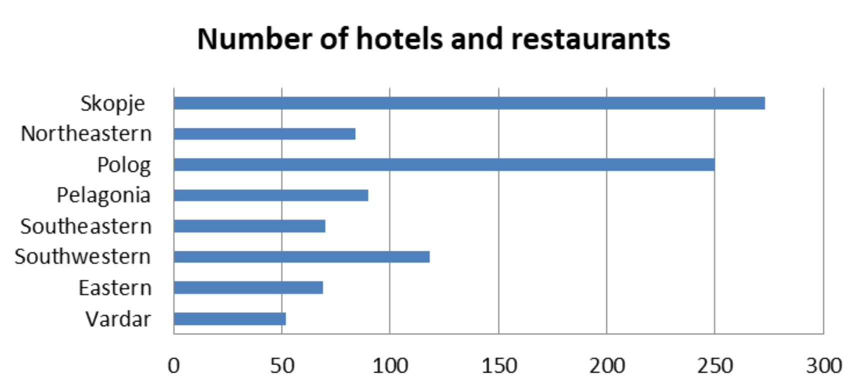


Figure 1. *Percentage representation of catering facilities in each region*

Based on the available data, specifically the regional percentage distribution and the total number of restaurants and hotels, a division of the total number of establishments by region in Macedonia was conducted and is shown in Figure 2. These data were used in the analysis of the potential for installing PV systems on hotels and restaurants in Macedonia.



	Vardar	Eastern	Southwestern	Southeastern	Pelagonia	Polog	Northeastern	Skopje
Series1	52	69	118	70	90	250	84	273

Figure 2. *Number of hotels and restaurants in each region*

4. **Hotel Analysis with a Gross Area of 800 m²**

As previously mentioned, the hotel analyzed in this paper has a total gross area of approximately 800 m², with four suites, each 45 m², and five rooms, each 20 m². The hotel also includes a restaurant with a seating capacity of 120 seats. A PV system with a capacity of 40 kW is already installed on a portion of the hotel's rooftop. Figure 3 shows a comparison of the hotel's electricity consumption before and after the installation of the PV system, where it can be observed that the hotel's electricity consumption decreased by an average of 20% annually, resulting in a reduction in the hotel's electricity bills, which is supplied through the universal supplier.

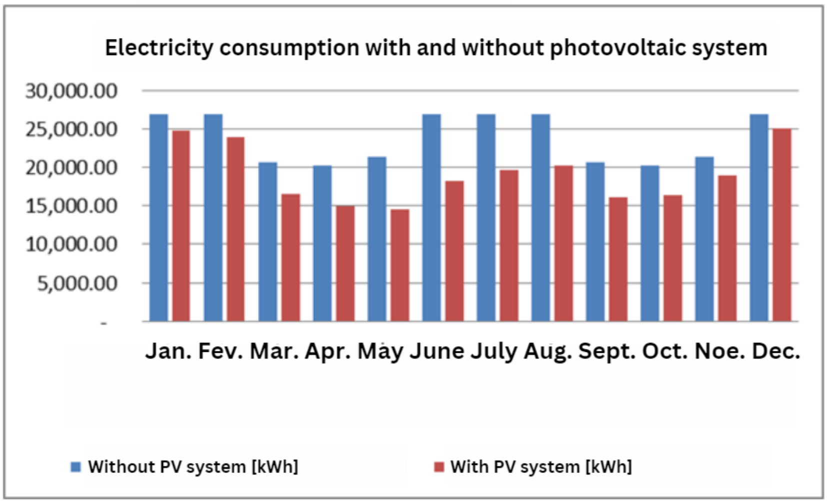


Figure 3. *Electricity consumption of the hotel with and without the photovoltaic system*

5. **Techno-Economic Analysis for a 100 kW Photovoltaic System**

To determine the feasibility of installing a photovoltaic (PV) system, the first step is to analyze the electricity consumption. Research indicates that most of the electricity consumed in hotels and restaurants is used for heating and cooling. As shown in Figure 3, the peaks in monthly electricity consumption occur during the winter and summer months, with a slight decrease in consumption during the spring and fall. Table 1 presents the monthly electricity consumption of the hotel without a PV system, where the total annual electricity consumption is approximately **286.11 MWh**.

Table 1. *Tabular presentation of the hotel's monthly electricity consumption*

Month	Consumption [kWh]
January	26,936.55
February	26,936.55
March	20,720.42
April	20,202.41
May	21,324.78
June	26,936.55
July	26,936.55
August	26,936.55
September	20,720.42
October	20,202.41
November	21,324.78
December	26,936.55
Total	**286,114.52**

To obtain the hourly energy production, a 100 kW PV system was simulated on the hotel's rooftop using PV*SOL premium software, yielding the following parameters:

- Number of PV modules: 210;
- PV module capacity: 540 Wp;
- Total installed DC capacity: 113.40 kWp;
- Number of inverters: 1;
- Total installed AC capacity: 100 kW;
- DC/AC ratio: 1.134;
- Annual energy production: 152.81 MWh;
- Avoided CO2 emissions: 74 tons/year.

Table 2. *Tabular presentation of the consumption and production analysis*

Month	Consumption [kWh]	Production [kWh]	Electricity procurement [kWh]	Surplus electricity [kWh]
January	26,936.55	5,712.88	21,243.98	20.31
February	26,936.55	7,553.39	19,597.33	214.17
March	20,720.42	12,214.58	12,486.63	3,980.79
April	20,202.41	15,556.88	11,206.96	6,561.43
May	21,324.78	19,394.15	10,760.70	8,830.06
June	26,936.55	20,567.98	13,903.94	7,535.36
July	26,936.55	20,246.13	13,994.47	7,304.05
August	26,936.55	18,136.55	14,709.54	5,909.55
September	20,720.42	13,468.38	12,046.01	4,793.97
October	20,202.41	9,525.06	13,292.60	2,615.25
November	21,324.78	5,720.49	16,079.56	475.26
December	26,936.55	4,713.24	22,234.44	11.13
Total	**286,114.52**	**152,809.69**	**181,556.16**	**48,251.33**

Table 2 shows the monthly energy production from the PV system, the hotel's energy consumption, the surplus electricity from the PV system, and the hotel's electricity needs after PV installation. It can be observed that the annual energy production of approximately **152.81 MWh** is about **45% less** than the hotel's total electricity consumption.

According to the hourly analyses, most of the energy generated by the PV system will be used for self-consumption, with excess energy at certain hours fed back into the grid, for which the hotel will receive compensation through sales on the open market. Overall, the hotel's annual electricity consumption after the PV system installation will decrease by approximately **37%**, leading to lower electricity bills, as illustrated in Figure 4.

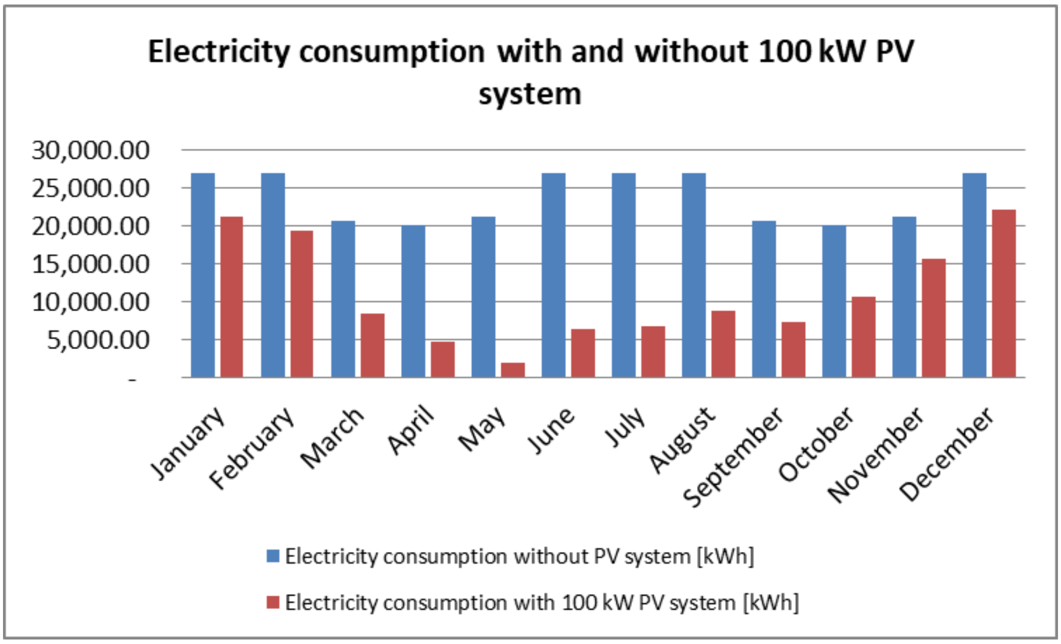


Figure 4. *Graphical presentation of electricity consumption before and after installing the photovoltaic system*

When evaluating the profitability of a PV system installation, it is essential to consider the maintenance costs. In this analysis, several key cost factors for maintaining PV systems of this size were considered:

- Inverter cost: 5 €/kWp;
- Insurance costs: 1.0 €/kWp;
- Spare parts and maintenance materials: 3.0 €/kWp;
- Cleaning equipment and panels: 1.5 €/kWp;
- Other unforeseen costs: 500 €.

When applied to the proposed PV system, the total annual maintenance and operational costs are 1,067 €. This includes the cost for replacing the inverter after the 12th year. Typically, inverters are replaced in the 13th year due to a maximum operational life of about 15 years and decreased efficiency.

Therefore, as shown in Table 3, the operating and maintenance costs for the first 12 years will be 1,067 € annually, and from the 13th year onward, they will reduce to 1,050 € per year.

Table 3. *Costs for operating and maintaining the photovoltaic system*

EXPECTED ANNUAL COSTS FOR OPERATION AND MAINTENANCE		
	Year	annual
1	2024	1,067 €
2	2025	1,067 €
3	2026	1,067 €
4	2027	1,067 €
5	2028	1,067 €
6	2029	1,067 €
7	2030	1,067 €
8	2031	1,067 €
9	2032	1,067 €
10	2033	1,067 €
11	2034	1,067 €
12	2035	1,067 €
13	2036	1,050 €
14	2037	1,050 €
15	2038	1,050 €
16	2039	1,050 €
17	2040	1,050 €
18	2041	1,050 €
19	2042	1,050 €
20	2043	1,050 €
21	2044	1,050 €
22	2045	1,050 €
23	2046	1,050 €
24	2047	1,050 €
25	2048	1,050 €

For the profitability analysis, the purchase prices of electricity to cover consumption and the sale prices for surplus electricity generated by the PV system were based on the **HUDEX** market, which is a reference electricity exchange for Macedonia. On this market, electricity prices are forecasted for both peak and off-peak periods for the next three years. The prices were taken for the years 2025, 2026, and 2027.

For the remaining 22 years (the lifetime of the PV system), prices were projected based on expectations that electricity prices will decrease by **5% annually** after the recent sharp rise. However, it should be noted that these forecasts may differ from actual market prices due to the unpredictability of electricity price fluctuations.

In terms of calculating annual savings on electricity bills and the revenue from selling surplus PV-generated electricity, the analysis took into account that the purchase prices for covering consumption are **15% higher** than HUDEX prices, while the sale prices for surplus electricity are **15% lower**. Additionally, distribution tariffs, which are uncertain for the future, were projected to increase by **2.5% annually** based on European practices.

Annual electricity consumption of the hotel will decrease from **286,114.49 kWh** to **152,809.69 kWh**, resulting in annual savings of approximately **17,400 €** on electricity costs. Furthermore, the sale of surplus electricity will generate about **4,600 €** in revenue, yielding a total annual savings of approximately **22,000 €** for the hotel.[1]

[1] The financial analysis is made under the assumption that the hotel is supplied with electricity on the free market.

Table 4. *Analysis of consumption, production, surpluses and revenues for the entire working life of the photovoltaic system*

year	Electricity consumption (kWh)	Electricity production (kWh)	Electricity consumption with PV (kWh)	Surplus electricity from PV (kWh)	year	Income from electicity savings	Income from electricity sale on the free market	TOTAL
2024	286,114.52	152,809.69	181,556.16	48,251.33	2024	17,344 €	4,580 €	**21,925 €**
2025	286,114.52	151,281.59	181,737.72	47,768.82	2025	15,920 €	4,030 €	**19,950 €**
2026	286,114.52	149,768.77	181,919.46	47,291.13	2026	14,971 €	3,647 €	**18,618 €**
2027	286,114.52	148,271.09	182,101.38	46,818.22	2027	14,505 €	3,430 €	**17,935 €**
2028	286,114.52	146,788.37	182,283.48	46,350.03	2028	14,070 €	3,226 €	**17,296 €**
2029	286,114.52	145,320.49	182,465.76	45,886.53	2029	13,664 €	3,034 €	**16,698 €**
2030	286,114.52	143,867.29	182,648.23	45,427.67	2030	13,287 €	2,854 €	**16,140 €**
2031	286,114.52	142,428.61	182,830.88	44,973.39	2031	12,937 €	2,684 €	**15,620 €**
2032	286,114.52	141,004.33	183,013.71	44,523.66	2032	12,612 €	2,524 €	**15,136 €**
2033	286,114.52	139,594.28	183,196.72	44,078.42	2033	12,313 €	2,374 €	**14,686 €**
2034	286,114.52	138,198.34	183,379.92	43,637.64	2034	12,036 €	2,233 €	**14,269 €**
2035	286,114.52	136,816.36	183,563.30	43,201.26	2035	11,783 €	2,100 €	**13,883 €**
2036	286,114.52	135,448.19	183,746.86	42,769.25	2036	11,551 €	1,975 €	**13,526 €**
2037	286,114.52	134,093.71	183,930.61	42,341.56	2037	11,340 €	1,857 €	**13,197 €**
2038	286,114.52	132,752.77	184,114.54	41,918.14	2038	11,148 €	1,747 €	**12,895 €**
2039	286,114.52	131,425.25	184,298.65	41,498.96	2039	10,976 €	1,643 €	**12,619 €**
2040	286,114.52	130,110.99	184,482.95	41,083.97	2040	10,822 €	1,545 €	**12,367 €**
2041	286,114.52	128,809.88	184,667.43	40,673.13	2041	10,685 €	1,453 €	**12,138 €**
2042	286,114.52	127,521.79	184,852.10	40,266.40	2042	10,565 €	1,367 €	**11,932 €**
2043	286,114.52	126,246.57	185,036.95	39,863.73	2043	10,461 €	1,285 €	**11,747 €**
2044	286,114.52	124,984.10	185,221.99	39,465.10	2044	10,373 €	1,209 €	**11,582 €**
2045	286,114.52	123,734.26	185,407.21	39,070.45	2045	10,300 €	1,137 €	**11,437 €**
2046	286,114.52	122,496.92	185,592.62	38,679.74	2046	10,241 €	1,069 €	**11,310 €**
2047	286,114.52	121,271.95	185,778.21	38,292.94	2047	10,196 €	1,006 €	**11,202 €**
2048	286,114.52	120,059.23	185,963.99	37,910.02	2048	10,165 €	946 €	**11,111 €**

To evaluate the investment cycle, payback period, and method of financing the PV system, two investment scenarios were considered. The first scenario involves 70% financing through a loan and 30% self-financing, while the second involves 100% self-financing. For the loan scenario, an interest rate of 6% was applied, with a payment period of 10 years.

Table 5. *Financial analysis parameters*

	70% loan + 30% own contribution	100% own contribution
Total investment	**Investment return period [years]**	**Investment return period [years]**
61,236.00	6.12	4.97

As shown in Table 6, for the first investment scenario (70% loan and 30% self-financing), the average payback period **6.12 years** (approximately 6 years and 2 months). In the second scenario (100% self-financing), the payback period is **4.97 years** (approximately 5 years). This means that the investment is profitable in both cases, as the payback period is less than 7 years. After this period, the hotel will enjoy free electricity and additional revenue from selling surplus energy.

6. **Results and Discussion**

This section compares the already installed 40 kW photovoltaic system in the analyzed hotel and its expansion to 100 kW as proposed in the above-presented techno-economic analysis. Based on the experience of the investor and our analyses, with a 40 kW photovoltaic system, the hotel achieves around 30% savings during the summer months and around 10% savings during the winter months, averaging approximately 20% savings on electricity bills annually under the current supply from the universal supplier.

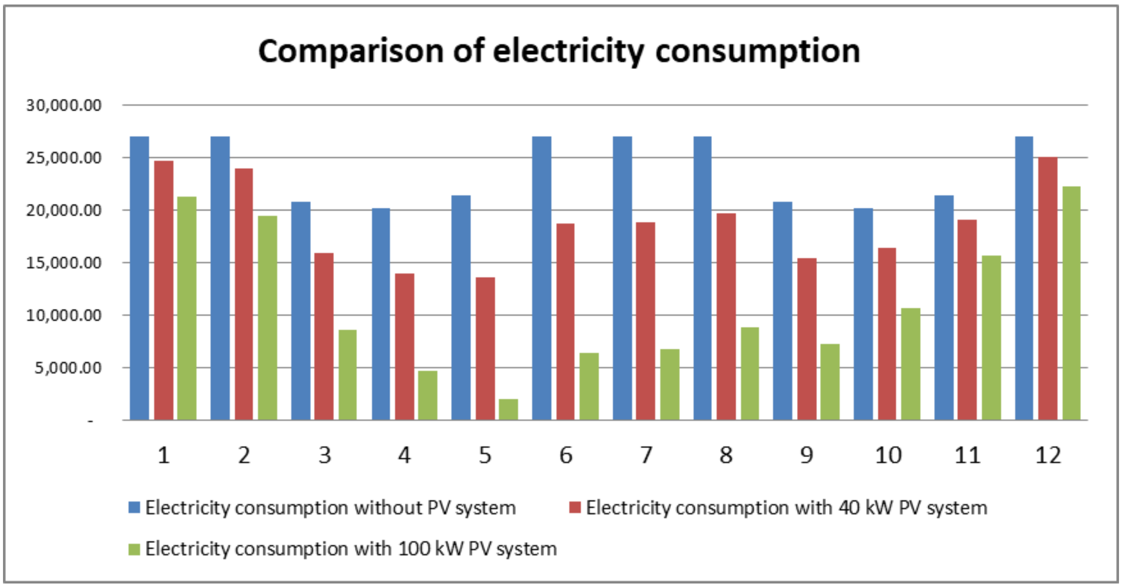


Figure 5. *Comparison of the electricity consumption of the hotel with the electricity consumption after installing a 40 kW photovoltaic system and with the electricity consumption after installing a 100 kW photovoltaic system*

Table 6. *Tabular presentation of the hotel's electricity consumption without a PV system, with a 40 kW photovoltaic system and with a 100 kW photovoltaic system*

Month	Electricity consumption without PV system	Electricity consumption with 40 kW PV system	Electricity consumption with 100 kW PV system
January	26,936.55	24,651.40	21,243.98
February	26,936.55	23,915.20	19,597.33
March	20,720.42	15,847.53	12,486.63
April	20,202.41	14,078.16	11,206.96
May	21,324.78	13,773.07	10,760.70
June	26,936.55	18,720.43	13,903.94
July	26,936.55	18,838.74	13,994.47
August	26,936.55	19,684.90	14,709.54
September	20,720.42	15,343.88	12,046.01
October	20,202.41	16,392.39	13,292.60
November	21,324.78	19,036.59	16,079.56
December	26,936.55	25,051.26	22,234.44
Total [kWh]	**286,114.49**	**225,333.53**	**181,556.16**
Total [MWh]	**286.11**	**225.33**	**181.56**

As shown in Table 7, the electricity consumption of the hotel with the 40 kW photovoltaic system will reduce from 225.3 MWh to 181.5 MWh, representing a reduction of approximately 20%.

The hotel’s electricity costs, when supplied through the universal supplier without a photovoltaic system, are about €62,230. With a 40 kW photovoltaic system, these costs decrease to approximately €49,000, meaning they are reduced by €13,220 annually. The calculations were made according to the current prices for electricity published on the site of the regulatory commission and water services, i.e. 217.49 €/MWh.

On the other hand, if the hotel is supplied with electricity from the open market, the electricity costs without a PV system would be around €47,460 and with the production of electricity from a 40 kW photovoltaic system, they would reduce to €37,400.

If the existing 40 kW photovoltaic system in the hotel is expanded to a 100 kW system, and the hotel starts procuring electricity from the free market, the current electricity costs with the 40 kW photovoltaic system will decrease from €37,400 to €25,800. The hotel would achieve savings of approximately €11,600 on electricity bills.

7. **Possibilities for Installing Photovoltaic Systems in Hotels and Restaurants**

The electricity production from photovoltaic systems directly depends on the meteorological conditions (solar radiation, air temperature, wind speed, etc.) at the location where the photovoltaic system is installed. Figure 5 shows the map of annual horizontal irradiation in Macedonia in kWh/m², from which it is evident that this varies for each region in the country.

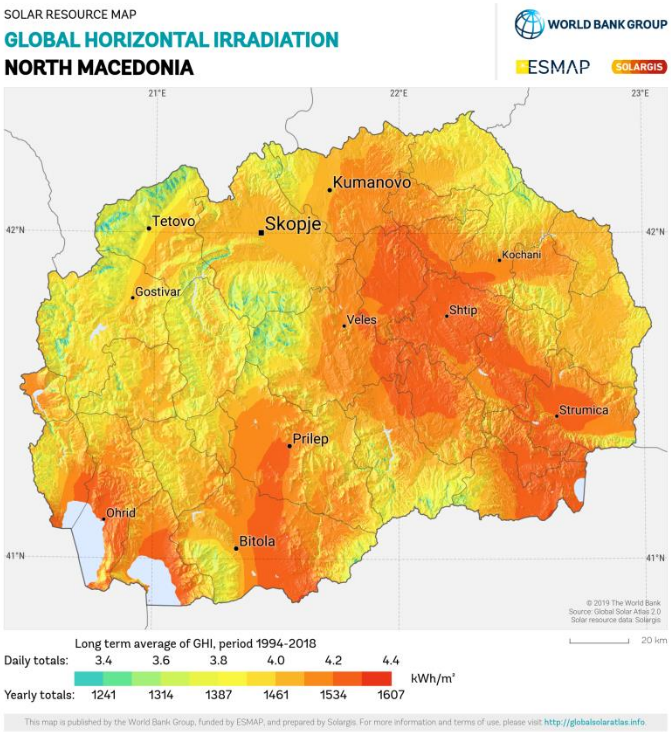


Figure 6. *Map of the annual average horizontal solar radiation in kWh/m^2*

Source: SolarGIS.http://solargis.info/doc/postermaps

For this reason, simulations were performed for photovoltaic systems with an installed capacity of 40 kW for each of the regions into which Macedonia is divided, to provide an accurate estimate of electricity production from photovoltaic systems. The obtained values for electricity production represent averages, assuming the photovoltaic modules are installed with standard orientations. It is projected that half of the hotels and restaurants will install photovoltaic systems with a southern orientation, while the rest will use an east-west orientation.

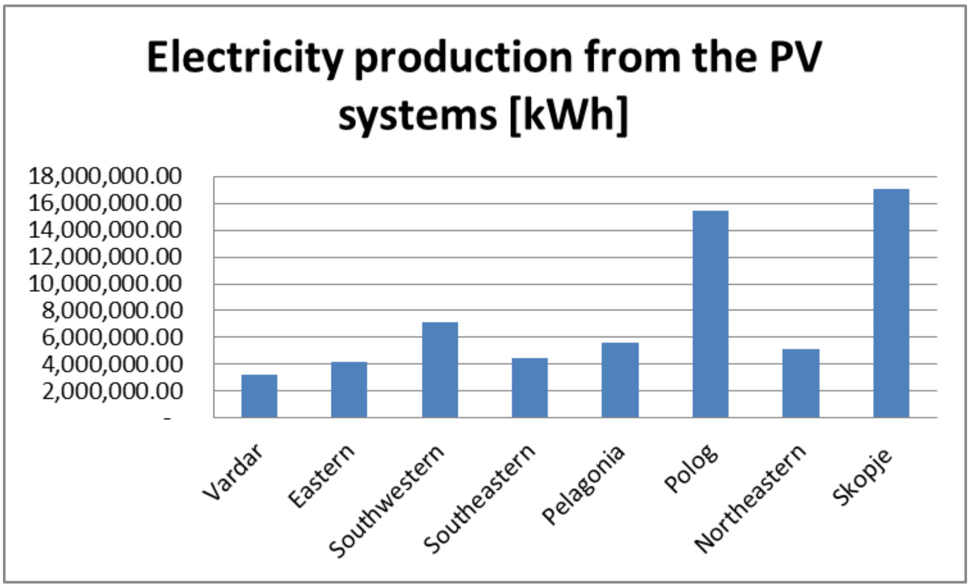


Figure 7. *Electricity production by installing 40 kW photovoltaic systems by region*

According to the analyses conducted, **the maximum installed capacity for all hotels and restaurants in Macedonia would be approximately 40 MW, with total annual electricity production of about 62,061 MWh, or approximately 62 GWh annually.** Figure 9 shows the projected electricity production by region if all 1,006 hotels and restaurants in the country were to install photovoltaic systems. It can be concluded that installing 40 kW photovoltaic systems on all hotels and restaurants in Macedonia would significantly increase domestic electricity production from clean, green sources and reduce the country's energy dependence. Moreover, hotels and restaurants would be protected from potential future electricity price shocks, and the investments would be recouped within no more than 6 years, given current market prices for electricity. Table 8 presents the results of the analysis of the potential for installing photovoltaic systems on hotels and restaurants in Macedonia.

Table 7. *Results of the analysis for the installation of photovoltaic systems in Macedonia*

Region	Number of hotels and restaurants	Installed capacity from PV systems [kW]	Electricity production from the PV systems [kWh]	Avoided CO2 emissions [t/yearly]
Vardar	52	2080	3,197,179.35	1,357.32
Eastern	69	2760	4,128,031.68	1,801.06
Southwestern	118	4720	7,105,605.14	3,080.07
Southeastern	70	2800	4,456,230.82	1,827.16
Pelagonia	90	3600	5,555,326.52	2,349.21
Polog	250	10000	15,431,846.11	6,525.57
Northeastern	84	3360	5,126,142.09	2,192.59
Skopje	273	10920	17,060,990.34	7,125.93
Total	**1006**	**40240**	**62,061,352.05**	**26,258.91**

7. Conclusion

In this analysis, simulations were performed using PV*SOL premium software to assess the potential for installing photovoltaic systems on all hotels and restaurants in Macedonia. It was determined that the total maximum possible installed capacity for hotels and restaurants that have the potential to install photovoltaic systems is around 40 MWp, while the total investment cost, based on current prices for constructing photovoltaic systems of this size, would be approximately €21,800,000.

By comparing the electricity consumption and production on an hourly level for the analyzed hotel, it was concluded that by installing a 100 kW photovoltaic system (assuming no 40 kW photovoltaic system had already been installed), the hotel would achieve total savings of approximately €17,400. This savings results from the reduction in electricity consumption due to the generation from the photovoltaic system, and from selling the surplus electricity, enabling the hotel to generate annual revenues that could be used for part of its electricity consumption and the hotel would also generate additional income from selling the surplus electricity of around €4,600 annually.

If the existing 40 kW photovoltaic system at the hotel is expanded to a 100 kW system and the hotel starts sourcing electricity from the free market, the current electricity costs for the hotel would decrease from €37,400 to €25,800, achieving savings of around €11,600 and generating additional revenue from excess electricity of around €2,100, resulting in total annual savings of approximately €13,700. If the total savings and income from surplus electricity cover the hotel's electricity consumption, the hotel's electricity cost would decrease from €37,400 to €12,140, representing a reduction of approximately **68%**.

Furthermore, simulations performed using PV*SOL premium also provided a value for avoided carbon dioxide emissions if the above-mentioned photovoltaic systems are installed. Summing up all the results from the simulations, it was determined that around 26,000 tons of CO_2 would be avoided annually. Implementing this proposal would contribute to the faster achievement of energy transition goals, with the aim of improving the quality of life for citizens and contributing to a healthier environment for everyone.

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