KOMPARACIJA POKRIVANJA POTROŠNJE ELEKTRIČNE ENERGIJE TIPIČNOG DOMAĆINSTVA ZA RAZLIČITA PODRUČJA U BOSNI I HERCEGOVINI

COMPARISON OF COVERING THE ELECTRICITY CONSUMPTION OF A TYPICAL HOUSEHOLD FOR DIFFERENT AREAS IN BOSNIA AND HERZEGOVINA

Špago Damir
Šunje Edin

Univerzitet „Džemal Bijedić" u Mostaru, Mašinski fakultet, Sjeverni logor b.b., 88 000 Mostar, Bosna i Hercegovina

Ključne riječi:
potrošnja električne energije, solarna energija, fotonaponski paneli

Keywords:
consumption of electrical energy, solar energy, photovoltaic panels

Paper received:
27.01.2022.
Paper accepted:
25.07.2022.

Stručni rad

REZIME
Potrošnja električne energije, u doba kada potražnja za energijom i novim nekonvencionalnim energentima raste, predstavlja sve veći problem, kako u zemljama EU-a tako i u Bosni i Hercegovini. Prepoznajući značaj novih tehnologija, pogotovo baziranih na obnovljivim izvorima energije, novi načini smanjenja ukupne potrošnje energije, kao i karbonskog otiska, javljaju se i u zemljama regije. U ovom će radu biti provedena usporedna analiza pokrivanja potrošnje električne energije tipičnog domaćinstva u BiH za različite geografske regije pomoću fotonaponskih panela, kao i njihova tehno-ekonomska analiza.

Professional paper

SUMMARY
Electricity consumption, at a time when the demand for energy and new unconventional energy sources increases, represents a growing problem in the EU countries and Bosnia and Herzegovina. Recognizing the importance of new technologies, especially those based on renewable energy sources, new ways to reduce total energy consumption and carbon footprint are emerging in our region. This paper will conduct a comparative analysis of the coverage of electricity consumption of a typical household in B&H for different geographical regions using photovoltaic panels and it will provide their techno-economic analysis.

1. INTRODUCTION

According to Odyssee-Mure, there is a very uneven consumption of electricity in households among the European countries. The reason for this lies in the fact that in some countries electricity is, also, used for heating purposes, as is the case in France. As for the whole EU, the average annual electricity consumption per household is about 3700 kWh [1].

Compared to the European Union countries, the average household in Bosnia and Herzegovina consumes about 4500 kWh. This primarily applies to households in urban areas, while in rural areas consumption is slightly lower. The above analysis was taken from data available from the B&H Agency for Statistics [2].

For a long time, it has been known that the use of renewable energy sources, such as solar energy, can greatly contribute to the reduction of electricity consumption as well as the reduction of greenhouse gas emissions, such as carbon dioxide [3].

Among main obstacles for installing solar systems for electricity generation, especially for households, can be high investment costs, the geographical location of the household, climate conditions or the total available irradiated energy as well as the required space for panel installation.
In order to overcome economic problems and ensure a return on investment in a reasonable time, many countries choose to encourage electricity production by small producers through various forms of subsidies and

incentives such as feed-in tariffs, investment subsidies and other [4].
In Bosnia and Herzegovina, according to the latest FERK reports, the guaranteed purchase price of electricity from micro producers, such as traditional household, is 0.12 KM/kWh, or if the household is a privileged producer, the price goes up to 0.3 KM/kWh [5].

2. SOLAR ENERGY

Solar energy is a huge energy resource available on the Earth. Currently, there are about 700 GW of power plants installed worldwide. The spectrum of sunlight on the Earth's surface is mostly spread in the visible, infrared range and, to a smaller degree, in ultraviolet range [6]. Reaching the Earth's surface, solar energy is available in the form of direct, diffusion and reflective energy. In general, for calculations of solar systems, it is necessary to know the total radiated energy on a horizontal or inclined surface.

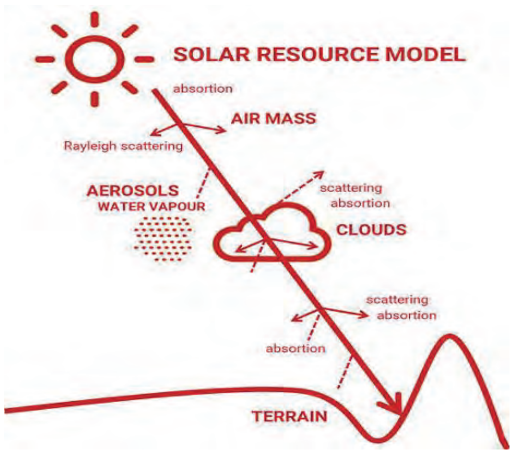

Figure 1 *Solar resource model*

As it can be seen from Figure 1, passing through the Earth's atmosphere, the radiated energy on the Earth decreases significantly. This is primarily affected by various impurities in the air, such as pollutants from emissions from the combustion of fossil fuels, clouds, etc.

Solar energy potential is not evenly distributed everywhere in the world. In general, the majority of the world's population lives in areas where the average daily radiated solar energy is between 3,5 and 7 kWh/m^2 [7].

The average annual global irradiance per square meter over the world can be seen in Figure 2.

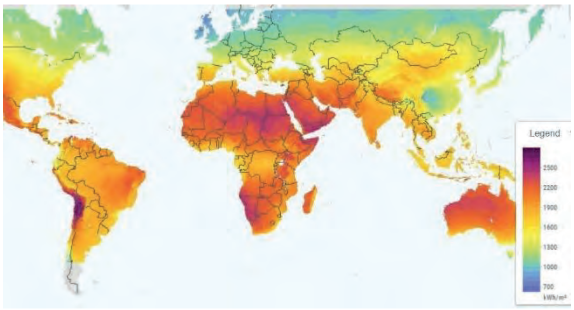

Figure 2 *Global irradiance in kWh/m^2 all over the world*

Data on solar potential for geographical areas around the world is currently available for download through various online databases as well as various pieces of software. Among the leading databases and software are:

- BSRN (Baseline surface radiation network),
- PV GIS (Photovoltaic geographical informatial system),
- NASA (Database for solar radiation and meteorogical data),
- Global solar atlas,
- Homer pro (software),
- Helioscope (software) and
- Retscreen (software).

It is important to mention the above because of the way the data is collected. Most of the available data on solar energy radiated to the Earth's surface refers to satellite images taken over a period of time. The data available in this way is accepted when calculating solar systems in a scientific society, and many data validations are performed. Deviations of measured values from data downloaded from online databases, especially PV GIS, show satisfactory matches [8].

Although it is always better to have in-situ measurements, in this paper the values of global irradiation for different areas of B&H will be taken from the PV GIS web page.

2.1 Solar potential of Bosnia and Herzegovina

Knowledge of the solar potential of Bosnia and Herzegovina is crucial for sizing the photovoltaic power plants to cover household needs for electricity. Although long-term measurements of solar radiation have not been performed and available, most of the data required for sizing the system is available from the aforementioned databases. The solar potential of B&H can be seen in Figure 3.

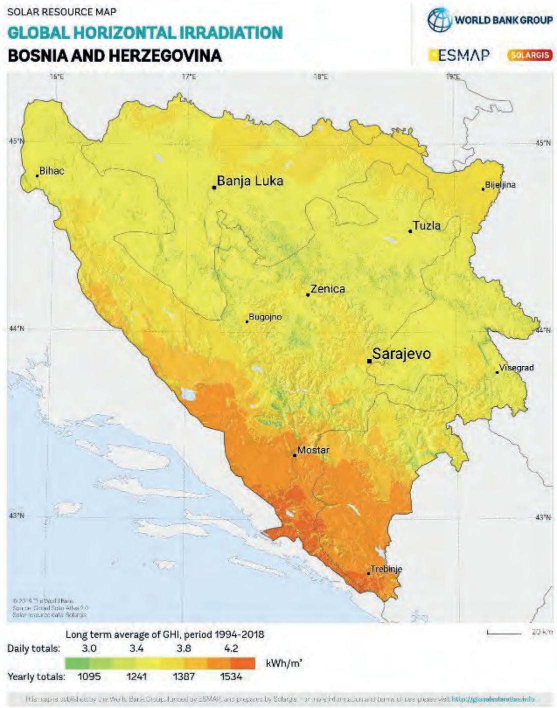

Figure 3 *Solar potential of Bosnia and Herzegovina*

By comparing the values of the total available solar energy on a horizontal surface in the countries of Central and Northern Europe, where annual averages are 1150 and 1000 kWh / m^2 per year, respectively, it can be concluded that on average Bosnia and Herzegovina gets about 15% more energy compared to Central Europe, and 30% more than Northern Europe. For the areas of Herzegovina, these percentages are even higher, so that part of our country receives up to 50% more energy compared to Northern Europe.

For the purposes of the analysis done in this paper, the values of average annual insolations for 6 cities in BiH were taken from the PV GIS page. Areas of interest were distributed according to different geographical areas and regions in Bosnia and Herzegovina. The cities of Mostar, Sarajevo, Zenica, Tuzla, Banja Luka and Bihać were taken as representatives of 6 regions. With the help of the PV GIS page, data on global horizontal irradiation (G_{hi}) and global irradiation on the optimal inclined surface (G_{oi}) were taken. Data on global irradiation for different cities as well as optimal angles of panel inclination can be seen in Table 1.

Table 1 Global anual irradiation on flat and inclined surfaces for different B&H cities

City	G_{hi} [kWh/m^2]	G_{oi} [kWh/m^2]	Optimal angle [°]
Mostar	1505,70	1768,04	37
Sarajevo	1255,37	1420,97	33
Banja Luka	1270,80	1454,13	35
Tuzla	1292,48	1474,94	34
Zenica	1263,25	1421,95	33
Bihać	1242,94	1408,38	34

As previously stated, it can be seen from the table that the southern parts of the country, i.e. the city of Mostar has the highest insolation while the northern parts, like Bihać, have the lowest. The data were analyzed for a period of over 10 years that was available on the PV GIS database from 2005 to 2016 [9].

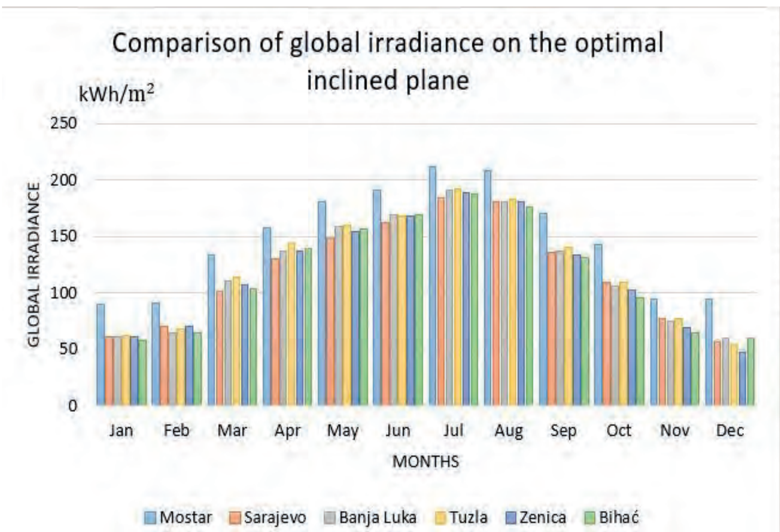

Figure 4 *Comparison of global irradiance at different cities across Bosnia and Herzegovina*

3. SIZING THE PHOTOVOLTAIC POWER PLANTS

In order to size the required number of PV panels and installed inverter power, the input parameters in the calculation will be the average household electricity consumption in B&H of approximately 4500 kWh per year and the average global irradiation to the optimally inclined surface for different cities in B&H, described in the previous chapter. Since the aim of this paper is to show a comparison of the required size of the solar power plant covering household electricity consumption for different cities in BiH as well as the required repayment period, certain assumptions are introduced:

- electricity consumption is assumed to be evenly distributed over a period of 12 months, more precisely evenly distributed over 365 days,
- a simplified calculation model will be used,
- households are located in the urban area, and are privilaged producers,
- global irradiation per day will be taken to be evenly distributed over 365 days,
- households have enough area on the roof to install the required number of PV panels.

The first thing that needs to be calculated is the average number of peak hours of sunshine for a given location, which is calculated using the formula:

$$h_{ps} = \frac{G_{oid}}{1\frac{kW}{m^2}}, \tag{1}$$

where are:
h_{ps} - sun peak hours [h],
G_{oid} - global irradiation on optimally inclined plate per day [kWh/m^2].

The required PV power size needed can be calculated using the formula:

$$P_{PV} = \frac{E_{HCD}}{h_{ps}} \cdot 1.3, \tag{2}$$

where are:
P_{PV} - required PV power size [kW],
1.3 - standard increase factor due to system losses, etc.,
E_{HCD} - average electrical energy consumption of household per day [kWh/day].

The number of PV panels is calculated using the following formula:

$$N_{PV} = \frac{P_{PV}}{P_N}, \tag{3}$$

where are:
N_{PV} - number of required PV panels,
P_N - nominal power of the panel [kW].

The inverter size will be determined using the following rule: the invertor size needs to be bigger from 20 to 30% than the P_{PV} of the PV panels.

The total costs are calculated using the following formula:

$$C_{Total} = \sum C_i, \tag{4}$$

where C_i are the costs of individual system components.

3.1. Calculated PV systems for households

Table 2 shows the calculated required power of PV power plants to cover household electricity needs. Formulas (1) and (2) were used for the purposes of the calculation. First, the number of sun hours for each city of interest was calculated, and then the required power of the PV system.

Table 2 Calculated PV power

City	Required PV power [kW]
Mostar	3,31
Sarajevo	4,12
Banja Luka	4,02
Tuzla	3,97
Zenica	4,11
Bihać	4,15

As expected, the lowest required power of photovoltaic panels to meet the electricity needs of the household is in Mostar, where the highest solar irradiation is, while the highest required PV power is in Bihać.
When calculating the required number of PV panels, it is necessary first to select the desired panel. For this purpose, a 375 Watt Longi PV panel with a price of 280 KM/piece was chosen. The number of required PV panels can be seen in Tabel 3.
When choosing an inverter, it is necessary to pay attention that the maximum input voltage V_{DC} on

the DC side (PV panel side) as well as the string current I_{SC} is lower than the allowed values recommended by the manufacturer.

Table 3 Required PV panels

City	Required PV panels
Mostar	9
Sarajevo	11
Banja Luka	11
Tuzla	11
Zenica	11
Bihać	11

Taking into account the previously mentioned rules for all cases, Fornius symo 5.0 inverter with a price of 2515,5 KM was chosen. Additional costs such as installation, cables, connectors, etc. are taken to be up to 20% of the total investment for panels and inverter. The total cost of each PV system is shown in Tabel 4.

Table 4 Total cost per PV system

City	Total cost [KM]
Mostar	6042,6
Sarajevo	6714,6
Banja Luka	6714,6
Tuzla	6714,6
Zenica	6714,6
Bihać	6714,6

4. TECHNO-ECONOMIC ANALYSIS OF PV POWER PLANTS

Techno-economic analysis of the systems was performed using the online software PV GIS. The annual production of PV systems for cities of interest was calculated as well as the average monthly production from the PV plants. Annual incomes are calculated on the assumption that households enjoy the status of privileged sellers of electricity, having a guaranteed purchase price of electricity of 0,29 KM/kWh. Return on investment periods were also calculated.

The average monthly production for PV power plants is shown in Figure 5, and the annual profit and return on investment in Tabel 5.

Table 5 Annual PV profit and return on investment

City	PV energy [kWh/a]	Income [KM/a]	Return on investment [year]
Mostar	4629,48	1342,55	4,50
Sarajevo	4618,56	1339,38	5,01
Banja Luka	4672,56	1355,04	4,96
Tuzla	4745,64	1376,24	4,88
Zenica	4551,6	1319,96	5,09
Bihać	4557,8	1321,76	5,08

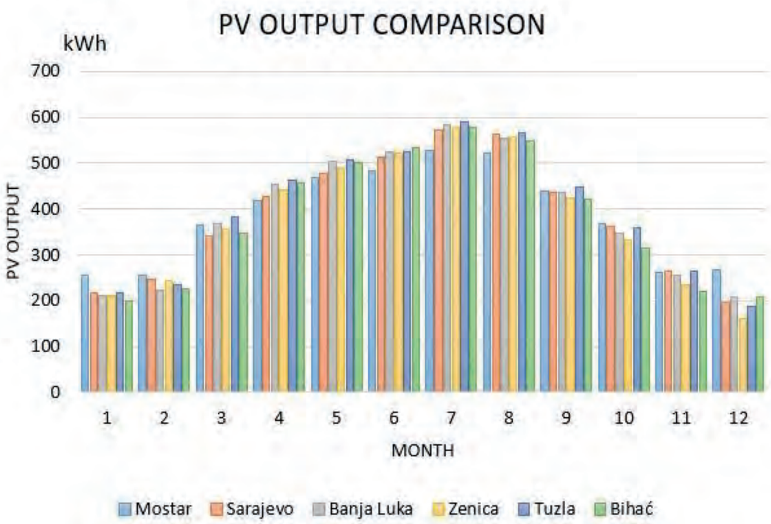

***Figure 5** Avarage monthly PV output comparison*

The return period on investment, calculated in relation to the lowest purchase price of electricity of 0.12 KM/kWh, is shown in Tabel 6.

It can be seen that the expected return on investment is the shortest for the city of Mostar. Other cities seem to have approximately the same return period.

Table 6 Annual PV profit and return on investment based on lowest purchase price

City	PV energy [kWh/a]	Income [KM/a]	Return on investment [year]
Mostar	4629,48	555,54	10,88
Sarajevo	4618,56	554,23	12,12
Banja Luka	4672,56	560,71	11,98
Tuzla	4745,64	569,48	11,79
Zenica	4551,6	546,19	12,29
Bihać	4557,8	546,94	12,28

Small anomalies can also be seen when comparing the production of electricity from PV systems for different cities. Although the city of Mostar has the highest solar irradiated energy, during the summer months some cities such as Tuzla produce more electricity. The reason for that is the total installed power in Mostar is smaller as well as the inclination of the panel, which is set for the annual optimal angle, and not the monthly one. The above mentioned statements lead to the conclusion that it would be ideal to have such installed solar panels whose inclination in relation to the horizontal surface could be adjusted to the optimal angle per month. Of course, the above-mentioned details entail negative consequences, such as increased investment cost and much greater difficulties in implementing the technical solutions of the panel carrier. Looking at the entire lifespan of solar systems, estimated at 20 years, it can be said that the investment certainly pays off. A rough estimate indicates that for a city like Bihać, even when calculated at the lowest purchase price of electricity, the profit after the payback period can be over 4000 KM, looking at the service life of the system of 20 years.

5. CONCLUSION

The paper presents a techno-economic analysis of PV power plants for different cities in Bosnia and Herzegovina. From the analysis, it can be concluded that to cover the average electricity consumption of a typical household in B&H, a power plant of about 4 kW of installed power is needed, and the average investment is from 6000 KM to 7000 KM. During the analysis, it can be seen that the southern parts of Bosnia and Herzegovina have a huge solar potential, but insufficiently used. This tells us that in the future the direction of electricity production from renewable sources should be directed towards its use. Also, in order to have an insight into a more detailed techno-economic analysis of such systems in future research, it is necessary to carry out optimizations using new technologies available for this purpose. For that purpose, software such as Homer Pro has been developed, where minimization of costs for the end user can be set as a function of optimization. Also, the use of MCDM optimization algorithms would give a broader insight into the usefulness of PV systems as well as their combination with other technologies, such as heat pumps, or the use of solar energy to heat domestic hot water.

6. LITERATURE

[1] https://www.odysseemure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling.html (accessed: January 2022)

[2] https://bhas.gov.ba/data/Publikacije/Bilteni/2016/ENE_00_2015_TB_1_HR.pdf (accessed: January 2022)

[3] Fernandez, J. M. R., Payan, M. B., Santos, J. M. R. (2021). „Profitability of household photovoltaic self-consumption in Spain“, Journal of Cleaner Production, vol. 279., https://doi.org/10.1016/j.jclepro.2020.123439

[4] Lazzeroni, P., Moretti, F., Stirano, F. (2020). „Economic potential of PV for Italian residential end-users“. Energy, vol. 200., https://doi.org/10.1016/j.energy.2020.117508

[5]https://solarno.net/solarna-elektrana isplativost-u bih/#Isplativost_solarne_elektrane_u_BiH (accessed: January 2022)

[6] Natowitz, J. B., Ngô, C. (2016). „Our energy future“. John Wiley & Sons, Inc., 111 River Street, Hoboken, New Jersey, USA

[7] https://energydata.info/ (accessed: January 2022)

[8] Mkasi, H. W., Basappa Ayanna, M., Pratt, L. E. and Roro, K. T. 2018. Global irradiance on photovoltaic array. 5th Southern African Solar Energy Conference. Durban, South Africa, 5pp.

[9] https://ec.europa.eu/jrc/en/pvgis (accessed: January 2022).

Corresponding author:
Damir Špago
Džemal Bijedić University of Mostar
Faculty of Mechanical Engineering
Email: damir.spago@unmo.ba
Phone: + 387 62 652 734