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# Providing the electricity need of a house with photovoltaic panels: Kütahya case study

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**Abstract.** In this study, a techno-economic analysis of meeting the electricity need of a house from photovoltaic panels in the Central district of Kütahya was made. In order to meet the electricity needs of the house, a 3.6 $kW_p$ Off-Grid system was considered, and polycrystalline and monocrystalline panel technologies were evaluated separately. For both panel technologies, theoretical production values were calculated by using meteorological data of Kütahya province. As a result of this; The annual theoretical electricity production value of the monocrystalline system was 7832 kWh, and the annual theoretical electricity production value of the polycrystalline system was 5324 kWh. In addition, the cost analysis of the systems was carried out and the payback periods were calculated as 3.45 years for the monocrystalline system and 3.38 years for the polycrystalline system.

**Keywords:** Solar energy, photovoltaic, techno-economic analysis.

## 1. Introduction

Renewable energy usage rates are increasing day by day in Turkey and in the world. In Table 1, electricity energy production according to Turkey, Europe and World sources between the years 2019-2021 is seen [1], [2]. Electricity generation from renewable energy sources increased from 43.3 TWh to 62.7 TWh in Turkey from 2019 to 2021. In Europe, it increased from 840 TWh to 946.5 TWh. In the world, it increased from 2789.2 TWh to 3657.2 TWh.

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Table **Eroare! În document nu există text cu stilul precizat.**. Electricity generation in Turkey, Europe and the World in 2019-2021 according to sources (TWh) [1], [2].

| 2019 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Oil | Natural gas | Coal | Nuclear | Hydro | Other | Renewable | Total | Renewable (%) |
| **Turkey** | 0.3 | 57.3 | 112.9 | - | 88.8 | 1.2 | 43.3 | 303.9 | 14.25 |
| **Europe** | 53.6 | 774.2 | 689.5 | 930.0 | 627.9 | 76.9 | 840.0 | 3992.1 | 21.04 |
| **World** | 820.5 | 6323.8 | 9826.2 | 2796.6 | 4227.9 | 216.7 | 2789.2 | 27001.0 | 10.33 |
| **2020** | | | | | | | | | |
| | Oil | Natural gas | Coal | Nuclear | Hydro | Other | Renewable | Total | Renewable (%) |
| **Turkey** | 0.3 | 70.9 | 105.8 | - | 78.1 | - | 51.5 | 306.7 | 16.8 |
| **Europe** | 48.9 | 765.4 | 569.7 | 833.2 | 657.9 | 81.1 | 922.7 | 3879.0 | 23.79 |
| **World** | 661.7 | 6371.7 | 9439.3 | 2694.0 | 4346.0 | 230.0 | 3146.6 | 26889.2 | 11.7 |
| **2021** | | | | | | | | | |
| | Oil | Natural gas | Coal | Nuclear | Hydro | Other | Renewable | Total | Renewable (%) |
| **Turkey** | 0.3 | 110.4 | 104.2 | - | 55.7 | - | 62.7 | 333.3 | 18.81 |
| **Europe** | 47.9 | 799.3 | 632.0 | 882.8 | 649.7 | 74.2 | 946.5 | 4032.5 | 23.47 |
| **World** | 720.3 | 6518.5 | 10244.0 | 2800.3 | 4273.8 | 252.2 | 3657.2 | 28466.3 | 12.85 |

The licensed installed capacity of Turkey for the years 2018-2020 is shown in Table 2, and the unlicensed installed capacity is shown in Table 3 [3]. While the licensed solar energy installed power in Turkey was 81.66 MW in 2018, it reached 409.8 MW by the end of 2020. While the unlicensed solar installed power was 5017 MW at the end of 2018, it increased to approximately 6257.6 MW at the end of 2020.

Table 2. Turkey's licensed electrical energy installed capacity for the years 2018-2020 (MW) [3].

| Source | 2018 | Share (%) | 2019 | Share (%) | 2020 | Share (%) |
|---|---|---|---|---|---|---|
| Natural gas | 25731.93 | 30.93 | 25935.41 | 30.53 | 25639.26 | 28.8 |
| Hydro | 20534.80 | 24.69 | 20642.51 | 24.30 | 22925.03 | 25.7 |
| Lignite | 9597.12 | 11.54 | 10101.03 | 11.89 | 10119.92 | 11.4 |
| Imported coal | 8938.85 | 10.75 | 8966.85 | 10.55 | 8986.85 | 10.1 |
| Coal | 616.15 | 0.74 | 810.77 | 0.95 | 810.77 | 0.9 |
| Asphaltite coal | 405 | 0.49 | 405.00 | 0.48 | 405.0 | 0.5 |
| Fuel oil | 709.21 | 0.85 | 305.93 | 0.36 | 305.93 | 0.3 |
| Naphtha | 4.74 | 0.01 | 4.74 | 0.01 | 4.74 | 0.0 |
| Lng | 1.95 | 0.00 | 1.95 | 0.00 | 1.95 | 0.0 |
| Diesel | 1.04 | 0.00 | 1.04 | 0.00 | 1.04 | 0.0 |
| Biomass | 590.92 | 0.71 | 725.92 | 0.85 | 1031.88 | 1.2 |
| Stream | 7748.90 | 9.32 | 7851.85 | 9.24 | 8050.23 | 9.0 |
| Wind | 6942.27 | 8.35 | 7520.33 | 8.85 | 8761.57 | 9.8 |
| Geothermal | 1282.52 | 1.54 | 1514.69 | 1.78 | 1613.19 | 1.8 |
| **Solar** | **81.66** | **0.10** | **169.70** | **0.20** | **409.8** | **0.5** |
| **Total** | **83187.05** | **100.00** | **84957.72** | **100.00** | **89067.14** | **100.00** |

Table 3. Turkey's 2018-2020 unlicensed electrical energy installed capacity (MW) [3].

| Source | 2018 | | **2019** | | 2020 | |
|---|---|---|---|---|---|---|
| | Inst. Power | Share (%) | Inst. Power | Share (%) | Inst. Power | Share (%) |
| **Solar** | **5016.99** | **94.47** | **5825.46** | **92.33** | **6257.61** | **91.71** |
| Natural gas | 153.04 | 2.88 | 328.66 | 5.21 | 402.67 | 5.90 |
| Biomass | 79.18 | 1.49 | 75.67 | 1.20 | 83.71 | 1.23 |
| Wind | 51.95 | 0.98 | 70.83 | 1.12 | 70.83 | 1.04 |
| Hydro | 8.91 | 0.17 | 8.65 | 0.14 | 8.65 | 0.13 |
| **Total** | **5310.57** | **100.00** | **6309.27** | **100.00** | **6823.47** | **100.00** |

In this study, meeting the electricity need of a house in the Central district of Kütahya province with photovoltaic panels was investigated. There are studies in the literature about the use of photovoltaic panels in residences.

Yi et al. evaluated the use of photovoltaic in residential buildings depending on electricity cost, demand fulfillment and carbon emissions and suggested an optimum photovoltaic usage strategy [4]. Hyvönen et al. investigated energy storage methods together with the use of photovoltaic in residential buildings. The study was evaluated in terms of Scandinavian climatic conditions [5]. Domingos and Pereira evaluated the use of photovoltaic in houses in terms of energy efficiency and cost. Within the scope of the study, 576 different models were discussed. Payback periods, Net Present Values and Internal Rates of Return of the evaluated models were calculated [6]. Muhammad-Sukki et al. evaluated the use of photovoltaic in residential buildings in Malaysia. Within the scope of the study, state policies and the socio-economic status of the public's use of photovoltaic were emphasized [7]. Kijo-Kleczkowska et al. have made a techno-economic evaluation of the use of photovoltaics in combination with a heat pump in residential buildings. A cost analysis was carried out for an example in Poland [8].

Karaca and Uçar investigated the use of photovoltaic in houses and evaluated the effect of the surface on which the photovoltaic panels will be placed on the performance of the photovoltaic panel [9]. Çifci et al. evaluated the issue of meeting the electricity need of a house from photovoltaic panels in the province of Burdur. In the cost analysis, the payback period of the system was determined as 11 years [10]. Adalı and Yalılı Kılıç researched meeting the electricity need of a house in Bursa with a hybrid renewable energy system. Cost analysis was carried out by considering two separate systems, independent of the grid and connected to the grid. The net present value for the off-grid system is approximately $9160, and the net present value for the grid-connected system is approximately $1367 [11]. Öztürk et al. investigated the use of photovoltaic in residential buildings and performed a cost analysis for off-grid and grid-connected systems. As a result of the calculations, the lifetime cost for the off-grid system is 0.67$/kWh, and the lifetime cost for the grid-connected system is 0.4$/kWh [12]. Yalılı Kılıç et al. investigated the use of photovoltaic in residences in Bursa and Karaman provinces. The payback period of the systems is calculated as approximately 7 years [13]. Güngül et al. investigated the use of photovoltaic in houses and used the TOPSIS method to determine the optimum system. Cost tables of 6 different companies were prepared for system installation and optimum system selection was determined by TOPSIS method [14]. In her study, Kutlu researched meeting the electricity need of a house in Isparta province with photovoltaic panels. Techno-economic analysis of the system that can be established has been carried out [15].

## 2. Material and method

The representation of Kütahya on the map of Turkey is given in Figure 1 [16]. Within the scope of this study, a techno-economic analysis of meeting the electricity need of a house from photovoltaic panels in the Merkez district of Kütahya was made. A 3.6 $kW_p$ system has been considered in order to meet the electricity needs of the house.

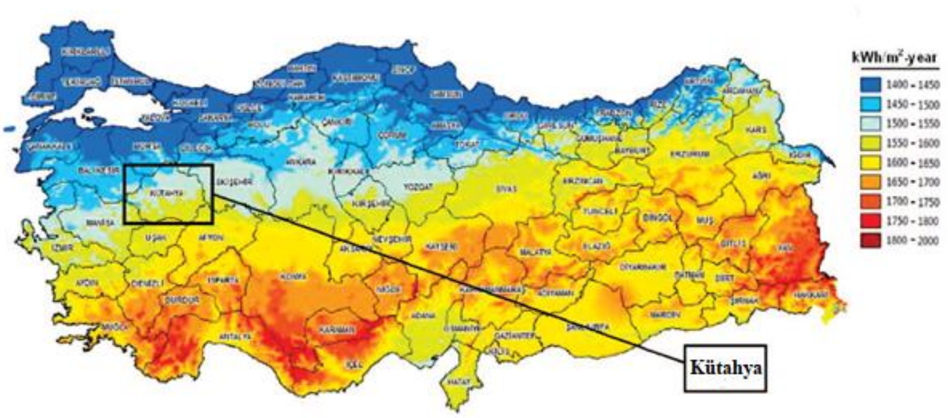


Fig. 1. Location of Kütahya province in Turkey [16].

In order to calculate the theoretical production values of the system, meteorological data of Kütahya province obtained from Meteorological Data Information Sales and Presentation System (MEVBIS) were used [17].

Table 4. Parametric properties of photovoltaic cells [18].

| | **Unit** | **c-Si** | **p-Si** |
|---|---|---|---|
| Efficiency | STC, % | 23 | 16 |
| Temp. Coeff. | β | 0.41 | 0.43 |
| $T_{NOCT}$ | °C | 47 | 45 |
| System balance losses | % | 8 | 8 |
| Dust factor | % | 5 | 5 |

In order to determine the instantaneous efficiency of photovoltaic panels, the following assumptions are taken into account for measurements made under Standard Test Conditions [18];

Acceptances under standard test conditions;
Ambient temperature, $T_{amb,NOCT}$=20 °C,
PV cell temperature, $T_{NOCT}$, (Table 4)
Temperature coefficient, β (%°C), (Table 4)
Depending on the photovoltaic cell temperature, the instantaneous efficiency of the photovoltaic panel is calculated by Equation 1 [18];

$$\eta_{PV} = \eta_{STC} - \beta(T_C - T_{NOCT}) \tag{1}$$

Annual production amounts of photovoltaic power plants are calculated with Equation 2 [18];

$$E_A = \sum_{1}^{365} A_{PV}.H_T.\eta_{PV}.(1-\lambda_{PV}).(1-\lambda_C) \tag{2}$$

In this equation; $A_{PV}$ refers to the total photovoltaic module area, $H_T$ refers to the daily amount of solar radiation coming to the panel surface, $\lambda_{PV}$ refers to the losses due to dusting, $\lambda_C$ refers to other system losses.
Photovoltaic panel cell temperature is calculated by Equation 3 [19];

$$\begin{aligned} T_c = {} & 3,4631 + T_{amb} + 0,029345.G - 0,0051.G.V_w + 0,00027035.G.V_w^2 \\ & - 2,8467.V_w + 0,55022.V_w^2 - 0,0293.V_w^3 \end{aligned} \tag{3}$$

In this expression; $T_c$ is the cell temperature in $^oC$, $T_{amb}$ is the ambient temperature in $^oC$, G is the solar radiation in $W/m^2$, $V_w$ is the wind speed in m/s.
By using the formulas given above and meteorological data of Kütahya province, the theoretical electricity generation values of the systems were calculated. Theoretical daily production values are shown in Figure 2. According to this; The annual theoretical electricity production value of the monocrystalline system was 7832 kWh, and the annual theoretical electricity production value of the polycrystalline system was 5324 kWh.
For the purpose of cost analysis of the system, the installation costs have been calculated. While calculating the costs, quotes were taken from various technology companies and average values were used. Cost parameters are shown in Table 5. According to this; The installation cost of the monocrystalline system was calculated as 107.800 TL, and the installation cost of the polycrystalline system was calculated as 106.000 TL.
The monthly average electricity consumption of the house and the monthly average electricity cost are shown in Table 6. While making the calculations, 1 month is accepted as 30 days. Consumption values of the products/items used in the residence were obtained from the catalog values of technological companies. While calculating the monthly electricity cost, cost calculations were made according to the Daytime (06:00 - 17:00), Peak (17:00 - 22:00) and Night (22:00 - 06:00) tariffs. Electricity tariff values are taken from the Energy Market Regulatory Authority (EPDK) [20]. While referencing electricity tariffs, tariffs were taken into account by EPDK for “Consumers receiving energy from the incumbent supply company” and calculations were made according to “Residential (8 kWh/day and below)” tariff values. A one-time tariff is offered to consumers by the electricity retail sales

company. In the province of Kütahya, the invoice created for a low-level electricity consumer was examined and the monthly electricity consumption cost was calculated separately.

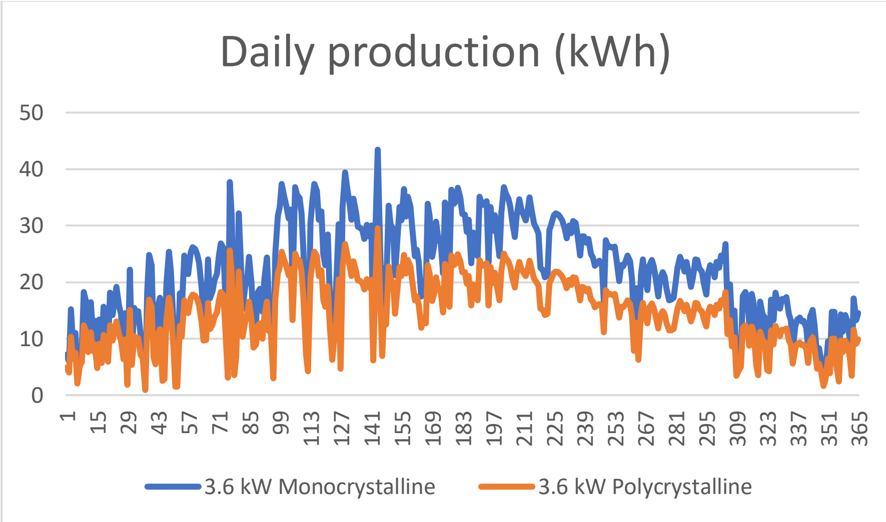


Fig. 2. Theoretical production values of the systems

Table 5. System cost parameters

| Equipment | Unit | Cost (TL) |
|---|---|---|
| 400 W Monocrystalline Panel | 9 | 37,800 |
| 300 W Polycrystalline Panel | 12 | 36,000 |
| 5000 W Off-Grid Inverter | 1 | 12,000 |
| 12V 200Ah Gel Battery | 6 | 39,000 |
| Cable, Connector, Regulator | | 4,000 |
| Other Costs | | 15,000 |
| Total (Monocrystalline) | | 107,800 |
| Total (Polycrystalline) | | 106,000 |

Table 6. Average monthly electricity consumption and electricity cost of the house

| Product/Item | Power (W) | Monthly Consumption (kWh) | | | |
|---|---|---|---|---|---|
| | | Daytime (kWh/month) | Peak (kWh/month) | Night (kWh/month) | One-time tariff (kWh/month) |
| Lighting | 100 | | 9 | 6 | 15 |
| Computer | 200 | 4.8 | 6 | 6 | 16.8 |
| Dishwasher | 1800 | 28.8 | | | 28.8 |
| Refrigerator | 45 | 14.85 | 6,75 | 10,8 | 32.4 |
| Washing machine | 650 | 10.4 | | | 10.4 |
| Vacuum cleaner | 800 | 6.4 | | | 6.4 |
| Electric oven | 2000 | 8 | | | 8 |
| Microwave oven | 700 | 5.25 | 5,25 | | 10.5 |
| Iron | 2400 | 9.6 | | | 9.6 |
| Television | 75 | 6.75 | 6.75 | 4,5 | 18 |

| Product/Item | Power (W) | Monthly Consumption (kWh) | | | |
|---|---|---|---|---|---|
| | | Daytime (kWh/month) | Peak (kWh/month) | Night (kWh/month) | One-time tariff (kWh/month) |
| Other | 250 | 7.5 | 7.5 | 7,5 | 22.5 |
| Total (kWh/month) | | 102,35 | 41.25 | 34.8 | 178,4 |
| Total (TL/month) | | 239,53 | 141.47 | 51.13 | |
| Total (TL/month) | | 432.13 | | | 309.6 |

The payback period of the system can be calculated with the following equation, taking into account the future value of money;

$$I = \sum_{t=1}^{PP} A_t.(1+i)^t \tag{4}$$

In this equation; I denotes the investment cost; PP refers to the payback period; $A_t$ refers to annual profitability; i stands for the discount rate. According to the Central Bank of the Republic of Türkiye (TCMB) data for November, the payback periods of the systems are calculated as 3.45 years for the monocrystalline system and 3.38 years for the polycrystalline system [21]. Considering the consumption costs according to the one-time tariff, the payback period is calculated as 4,53 years for the polycrystalline system and 4,58 years for the monocrystalline system.

## 3. Findings and discussions

In this study, meeting the electricity need of a house in Kütahya province with photovoltaic panels was investigated. In the house, an off-grid 3.6 $kW_p$ system was considered, and a techno-economic analysis was carried out for monocrystalline and polycrystalline panel technologies.
By using the meteorological data of Kütahya, the annual theoretical electricity production values of the system were calculated. The annual theoretical electricity production value of the monocrystalline system was 7832 kWh, and the annual theoretical electricity production value of the polycrystalline system was 5324 kWh.
In addition, cost analysis of photovoltaic systems was carried out. The installation cost of the monocrystalline system was calculated as 107.800 TL, and the installation cost of the polycrystalline system was calculated as 106.000 TL. The payback periods of the systems were calculated as 3.45 years for the monocrystalline system and 3.38 years for the polycrystalline system.

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