On the Feasibility of Using Photovoltaic Panels to Produce the Electricity Required at a Chemical Treatment Plant on Industrial Company

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Abstract. This work consists of a study focusing on the feasibility of using photovoltaic panels to produce the electricity required by plant operations at a chemical treatment plant belonging to an industrial company. Using available statistical data, it provides estimates relative to the amount of solar radiation received by the Eskişehir region, a large proportion of which is exposed to sunlight every day. The study reveals in detail the operating periods and power of the pumps used to pump the wastewater and the chemicals, and performs daily and instantaneous measurements of the power used at the plant over a one week time period. Following these evaluations, the study determines the instantaneous maximum power used by the system and provides the calculations necessary for photovoltaic panels and equipment.

Keywords: Photovoltaic · Panel · Solar · Sun

1 Introduction

When we look at the International Energy Agency (IEA), US Energy Information Administration (EIA) and the European Environment Agency resources, we estimate that human need will be around 400,000 TWh by 2016. Below, renewable energy potentials are given

*Solar energy 1575 EJ (438,000 TWh),
*Wind energy 640 EJ (180,000 TWh),
*Geothermal energy 5000 EJ (1,400,000 TWh),
*Biomasses 276 EJ (77,000 TWh),
*Hydropower 50 EJ (14,000 TWh)
*Ocean energy 1 EJ (280 TWh).

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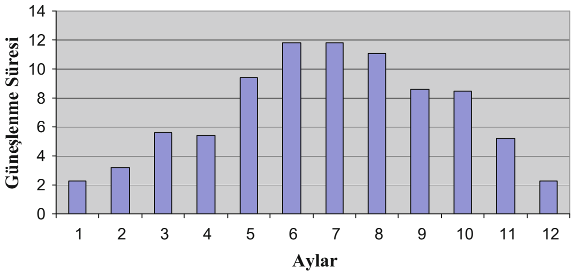

Fig. 1. Average hourly sunlight periods of the province. (*Source* EYEKPA, p. 7)

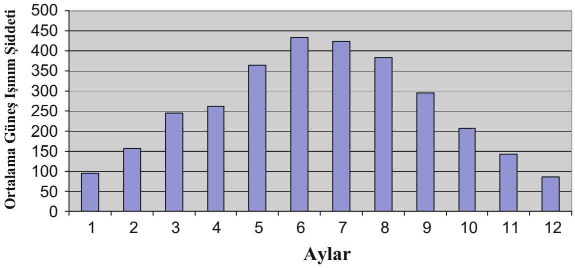

Fig. 2. Intensity of solar radiation in the Eskişehir province. (*Source* EYEKPA, p. 7)

Solar energy potentials of Eskişehir are displayed in Fig. 1, which provides the average hourly sunlight periods of Eskişehir and Fig. 2, which provides the monthly solar radiation intensity values.

As seen in Fig. 1, the months of June and July provide the longest periods of solar energy availability, followed by May, August, September, and October. From these data which show us that the region receives a monthly average of 300–400 km/m^2 of solar radiation and an average daily sunlight period of 8 h, we may conclude that Eskişehir will be an amenable location for the harnessing of solar energy.

The radiation intensity values and daily average of hours of sunlight of the Eskişehir region are seen to exceed national averages [1].

2 Available Technologies for the Production of Electricity from Solar Energy

This section of the paper reviews the methods and technologies used in the conversion of solar energy into electricity, with special focus on photovoltaic cells and solar radiation power generation systems. This section also provides general technical information and capacity volumes of these systems.

2.1 Photovoltaic (PV) Systems

2.1.1 Photovoltaic (PV) Panels [2, 3]

Photovoltaic Cells (PV batteries) are composed of semi-conductor materials that can directly convert surface solar rays into electric energy. In accordance with photovoltaic principles, when direct sunlight strikes the cell, an electric charge occurs on its terminals. The photovoltaic process is that in which two dissimilar materials in close contact produce an electric potential in the space between them when struck by photon rays. The photovoltaic cells are interconnected in a parallel series and formed into panels protected from the elements with glass, polymers or other kinds of other kind of surface materials to form panels. Today there are many different kinds of PV cells. These have been summarized below:

(a) **Crystallized silicon**: Mono-crystallized silicon blocks are first grown and then sliced into 200 micron thick wafers. Under laboratory conditions it has been determined that PV cells made out of blocks of these fine wafers have efficiency of 24%, while the commercial models have efficiency rates of 15%.
(b) **Gallium Arsenide (GaAs)**: This material provides 25% efficiency under laboratory conditions and 28% as an optical concentrator.
(c) **Amorphous Silicon**: SI (thin-film) photovoltaic cells made up of this non-crystalline form of silicone have efficiency rates of approximately 10%, while the commercial models rate at around 5–7%.
(d) **Cadmium Telluride (CdTe)**: CdTE is a poly-crystalline material that is expected to significantly lower the costs of photovoltaic cells. Under laboratory conditions small CdTe cells provide efficiency rates of 16%, and approximately 7% in commercial applications.
(e) **Copper Indium Gallium Selenide (CuInSe2)**: Under laboratory conditions cells made of this poly-crystalline materials provide efficiency rates of 17.7% and 10.2% efficiency of prototypes built as energy converters.
(f) **Optic Concentrator Cells**: Models of devices with lenses or mirrors that can concentrate light at 10–500 magnitudes have model efficiency of 17% and cell efficiency that can attain as much as 30%. These concentrators are made up of simple and inexpensive plastic materials.

2.1.2 Other Equipment Included in PV Systems [4]

(a) **Inverter**: inverters, which are referred to as the heart of the systems, are used to convert direct current outputs of PC cells into utility frequency alternating current. The 12 or 24 DC current produced by the panels are converted into 24 volts of alternating current. It does so by taking the constant DC voltage and changing it to a sine wave curve (or a curve that approximates a sine wave). The power of the inverter used has to accord with the type of system established.
(b) **Charge Regulator**: A charge regulator or controller is the device used to lower or limit to desired levels the rate of the current derived from the solar energy. Generally used in off-grid systems, the most important criterium in the selection of this device is the efficiency value.

(c) **Accumulator**: The accumulator is used in off-grid systems to store the energy from the system in a chemical environment. When desired, the device releases the energy from its terminals in the form of electricity. The batteries used are lead-acid permanently placed and can withstand several emptying and filling processes; however, the location of their placement is important as these batteries may emit dangerous gases. However, if they are to be used indoors dry batteries have to be used.

(d) **Peak Power Monitor**: The power derived from a PV cell is in direct ratio to the amount of solar radiation to which it is exposed; i.e.,as the solar radiation increases so does the wattage power. This is the maximum power that can be produced by the cell or panel, and is termed the "peak power." It is measured in WP (watt peak).

(e) **Installation Set**: These sets are needed to install the PV panels on roofs, in fields, or in other applications. Currently there are two types of such sets, permanent and trackers.

2.1.3 Off-Grid and on-Grid Systems [5]

Off-grid systems are used to provide electricity to isolated farms and mountain facilities that are not connected to the electrical power network, to run well motors, transmission antenna, and boats. These are also referred to as island systems. The electric energy generated by these PV panels is stored in batteries and then converted into alternating current with inverters. The generated energy can also be used as direct current (Fig. 3).

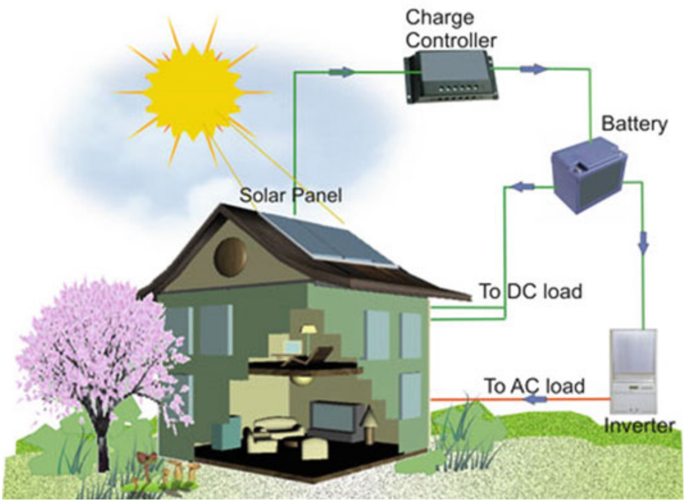

Fig. 3. Off-Grid PV applications. (*Source* https://solenturk.com)

2.1.4 On Grid PV Systems [5]

On-Grid systems are used in connection with municipal electrical distribution stations. The most significant difference between on-grid and off-grid systems is that the on-grid systems do not use groups of accumulators. Additionally, the inverters used in on-grid systems do not have the same technical features as the off-grid accumulators. As known, inverters are used to convert DC current to the kind of alternative current used by household appliances and devices. However, the inverters used with on-grid systems are synchronized so as to accord with the power networks and just as these inverters can be connected to the household distribution panel boxes, their paired meter counters allow them to be tied into the power network itself (Fig. 4).

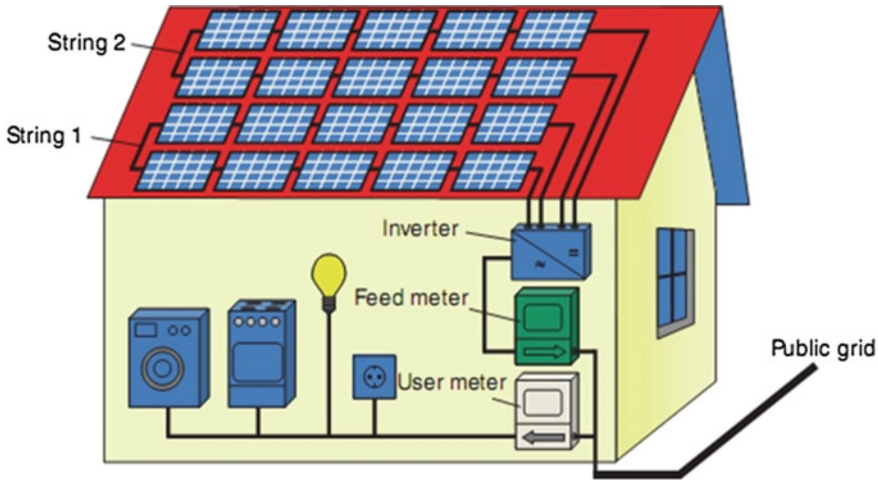

Fig. 4. On-grid system. (*Source* https://solenturk.com)

2.2 Concentrated Solar Power (CSP) Systems [6]

2.2.1 Dish Systems

Dish systems concentrate on the solar focalization point by tracking the sun from two axises. Thermal energy is harnessed by using a suitable working fluid at the concentrated point on the dish. Once the energy has been converted to heat, it is sent to the generator via thermodynamic heat transfer, or a Stirling engine is positioned at the focalization point to convert the solar energy to electricity, providing an efficiency rate of approximately 30%.

2.2.2 Power Tower Systems

Single-focused flat, movable mirrors (also called heliostats) are mounted onto a solar-energy receiver called a tower. Solar heat is reflected onto the heat exchanger and is concentrated. Mounted on the tower is a collection of pipes filled with a viscous fluid that absorbs the solar energy in a three-dimensional mass. This fluid is then pumped to the Rankin machine where it is converted to electricity.

2.2.3 Solar Chimney

A tower containing soil and air and covered with solar-exposed transparent material is allowed to heat to a temperature that exceeds the outside temperature. Because hot air rises it forms a roof slope and if this air is directed towards a high chimney an air flow is created within the chimney. A horizontal wind turbine placed at the entrance to the chimney converts this wind to electricity.

2.2.4 Solar Pool Systems

The black colored floors of these 5–6 m deep pools absorb solar rays and provide water heated to 90 °C. Just as this hot water can be pumped with a heat exchanger and used for heat, it can also be used in the production of electricity when a Rakın inverter is used.

2.2.5 Parabolic Trough Systems

This system is one of the most commonly used linear concentrator thermal systems. The collectors are composed of series of parabolic cross-sections. The inner parts of the collector have mirrored, reflective surfaces. The solar energy focuses on an absorbent pipe that runs the length of the inner surface. Generally speaking, the collectors are situated in along a single axis that tracks the sun as it moves from east to west. The collected heat is sent to a power station where it is converted into electricity.

3 Turkey's Legal Regulations and Current Situation [7]

Turkey's energy policies call for the amount of renewable energy to make up 30% of all of Turkey's energy needs by the year 2023. In line with these targets, beginning in 2010 various legal modifications and reforms have been made to the country's energy sectors and energy sector investors are being provided with certain incentives.

Legal Provisions and Laws

- Number 4628: Law Governing Electricity Markets
- Number 5346: Law Governing the Use of Renewable Energy Resources in the Production of Energy
- Number 5627: Law Governing Energy Efficiency
- Number 6446: Law Governing Electricity Markets

Regulations

- Regulations Governing the Licensing of Electricity Markets
- Regulations Governing the Rules and Procedures Relative to the Provision of Renewal Energy Resource
- Regulations Regarding the Manufacture of Parts and Accessories Used at Facilities Producing Electric Energy from Renewable Energy Resources,
- Regulations Governing Solar Energy Production Plants
- Regulations Governing the Production of Non-Licensed Electricity Plants in the Electricity Market

The laws and regulations mentioned above have been investigated so as to illuminate the work carried out at the trial study of an industrial plant located in Eskişehir with emphasis on the subjects discussed below:

3.1 Non-licensed Electricity Production

Limited to the meeting of personal energy requirements: Co-generation Plant—Micro Cogeneration Plant—Those actual individuals or corporations that establish a energy production plant producing a minimum of 500 kw of energy to be used for personal requirements and obtained from renewable energy resources are excused from the requirement to obtain a license. Any person (actual individual or corporation) that is a subscriber to the electricity network may establish a non-licensed electricity production plant. These individuals must have at least one consumption entity registered in their own name, meaning they must be subscribers to the state's network. Those individuals who are not subscribers are not permitted to establish a non-licensed electricity production plant. Those who are not actual individual or corporate subscribers (such as apartment managers) are not permitted to establish a non-licensed electricity production plant.

Non-licensed electricity production plants must be established so as to accord with the relative laws and regulations. Those individuals and/or corporations who apply and meet the above stipulations are then given the right to produce the electricity needed to meet their own energy requirements. Of these, actual individuals are only authorized to establish micro-cogeneration plants, while actual individuals and/or corporations are allowed to establish cogeneration plants, but both of these are only authorized to produce the electricity needed to meet their own needs. The excess energy generated by those individuals who establish micro-cogeneration facilities and those actual individuals and corporations that establish facilities based on renewable energy resources are given ten-year long rights within the framework of the YEK (renewal energy) Support Mechanism to sell this excess energy to a retail-licensed energy distribution company. Appendix I of the YEK Law provides a scaled listing of the proposed prices of such energy as per resource employed. Those individuals who establish micro-generation facilities use the lowest price on the scale. **What this means is that the government only guarantees the oversight of the system, but does not guarantee sales or purchase of the electricity.**

3.2 Sale of Produced Electricity

The excess energy produced from an electricity producing facility based on renewable energy resources is evaluated via the YEK Support Mechanism for sale to a local retail-sales licensed energy distribution company. While there is no limit on volume of sales, there has to be an ongoing consumption process that proceeds between the subscribed energy generation facility and the consumer supplier company to which it has been attached.

And while the YEK Support Mechanism operated by TEİAŞ (Turkish Electricity Transmission Corporation) is a market-based purchasing mechanism, it does not engender sales to the state, but only rather guarantees that it will oversee the operating of the government monitored system.

According to Appendix I of the YEK Law, excess electricity produced by renewable energy based systems will be purchased for a period of ten years according to the scaled price list. Following this ten year period new modifications to the Law will clarify how the process will be implemented in the future.

3.3 Sample Calculation

To benefit from the regulations legislating non-licensed electrical generation, 132 m^{2}’ of a 180 m^2 roof will be exposed to the sun and it is in this area that a solar energy harnessing facility will be installed. Assuming that we will need 6.6 m^2 to obtain 1 kW, a 20 kw power photovoltaic solar panel will need to be established.

Now, assuming that the facility has been built and is operable:

Also assuming that the plant will receive, on average, 7 h of sunshine daily, we may conclude that the plant can produce 7 × 20 kW = 140 kWh of electric energy daily. Assuming that the plant consumes 70 kWh on a single day, we can calculate that each day the system will generate 140–70 = 70 kWh of excess energy. Let us now assume that the next day is cloudy and the plant receives low levels of radiation. In this kind of instance, if the plant receives 4 h of solar radiation it will produce 4 × 20 = 80 kWh of electricity and will thus produce 80–70 = 10 kWh of energy that surpasses the system’s requirements.

Accordingly, let us calculate the amount of 13.3 cents (USD) of support incentives to be received per two days of solar energy.

Let us assume that each case outlined above occurred 15 days per month.

(15 × 70 = 1050) + (15 × 10 = 150) = 1200 × 0.133 × 1.85 = 159.6 TL (not including dskb/energy distribution utilization charges and other legal obligations).

Added to this calculation is this plant’s electricity consumption which equals 15 days of 10 kWh and 15 days of 15 kWh. According to this calculation, (30 × 70) or 2100 kWh of electricity is consumed monthly. If this individual had not built this generating plant, electric consumption would have to be paid by subscription rate, which would mean that 2100 × 26 Kuruş = 546 TL of energy charges would have had to be remitted. In addition, the individual would also have to have paid dskb and other legal obligations. In conclusion, this plant:

– Setting aside costs due to feasibility, investments, and operating, the facility will receive 159.6 TL of support (not including dskb and other legal obligations) and will also be exempted from paying an electric bill of 546 TL (dskb and other obligations not added).

4 An Operation’s Chemical Waste Water Treatment Plant in Eskişehir

Table 1

Table 1. Installation power consumption operating hours

Equipment	P	Tot.	Time	Energy	P (% 80)	Daily total comp.
	kW	kW	Saat	kW	kW	kW
Mixer	0.75	0.75	1	0.75	0.6	0.6
Oily wastewater pump	2.2	4.4	20	2.2	1.76	35.2
Wastewater equalization pumps	2.2	4.4	12	2.2	1.76	21.12
Acidification tank mixer	0.37	0.37	20	0.37	0.296	5.92
Daf tank stripper	0.25	0.25	12	0.25	0.20	2.4
Daf tank pumps	2.2	4.4	24	2.2	1.76	42.24
Coagulation tank mixer	0.75	0.75	20	0.75	0.6	12
Neutralization tank mixer	0.75	0.75	20	0.75	0.6	12
Flocculation tank mixer	0.55	0.55	20	0.55	0.44	8.8
Sludge removal pumps	1.1	2.2	1	1.1	0.88	0.88
Finned settling tank sludge pumps	1.1	2.2	1	1.1	0.88	0.88
Filter press feeding pumps	3	6	3	3	2.4	7.2
P. tank mixer	0.37	0.74	1	0.74	0.592	0.592
Anionic pump	0.25	0.5	20	0.25	0.2	4
Lime tank mixer	0.55	0.55	1	0.55	0.44	0.44
Clean water discharging mixer	2.2	2.2	10	2.2	1.76	17.6
Installed power	kW-Saat	1		23.1936	**19.328**	
Total consumption	kW-Gün					**171.272**

Source An industrial company
Significance of bold type to specify the total amount

4.1 Expected Developments

A treatment plant was designed to treat the waste water of a 200 m^3/daily capacity, four furnace plant. If three of the furnaces are working, no extra work on the treatment center will be required, even if there is an increase in capacity. Quite the opposite, in coming periods some of the pumps and motors will be exchanged with new and more efficient models, thus further decreasing energy requirements.

The panels to be mounted on the roof have an average weight of two tons. The roof weight bearing capacities will be recalculated and any necessary supports will be added (Fig. 5).

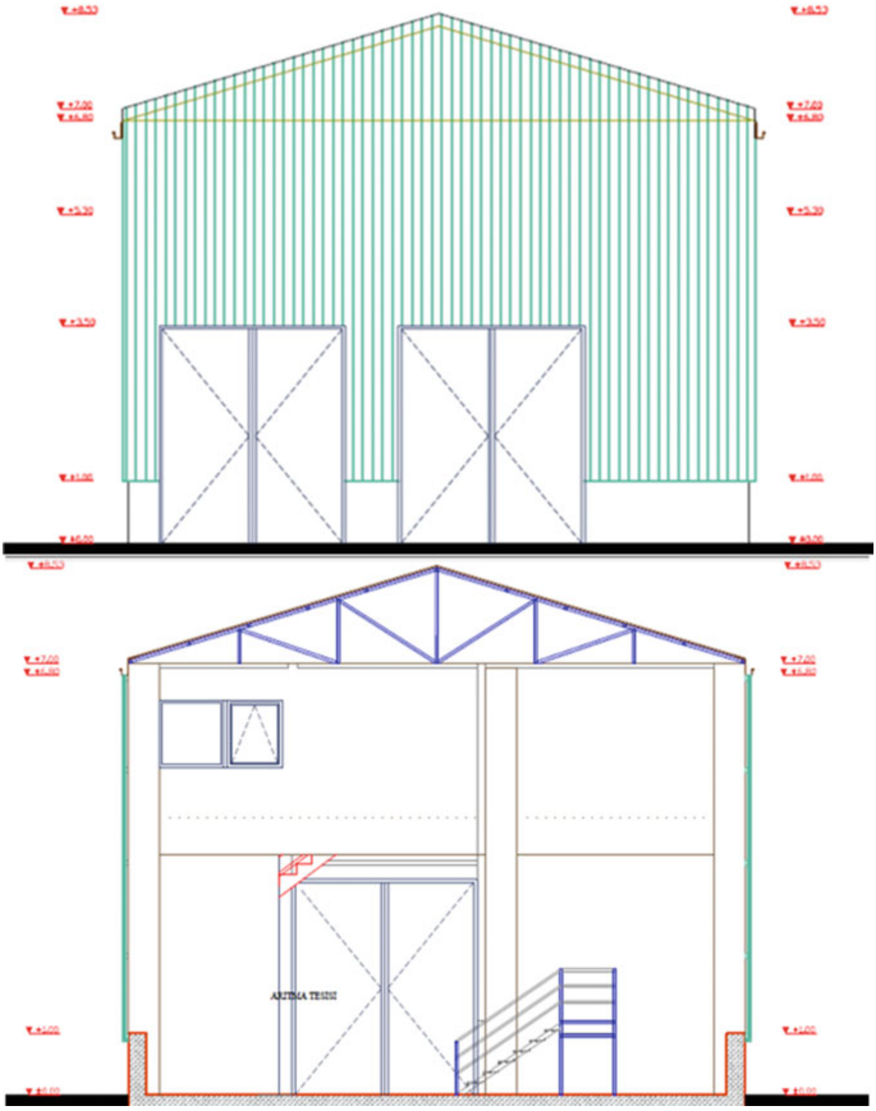

Fig. 5. Design of treatment plant. (*Source* An industrial company)

4.2 Pitch of Design and Roof

4.3 Actual Measurements

One-week long measurements were carried out of instantaneous and 24 h long electricity consumption rates as provided by the electric panel box belonging to the treatment facility and located in the factory's power supply room. The instantaneous consumption during the day were found to be at an average level of 14 kw, while the 24 h total average consumption was approximately 160 Kwh (Table 2).

Table 2. Actual instantaneous and daily measurements

Date	28.02	29.02	01.03	02.03	03.03
24 h	158 kw	160 kw	178 kw	150 kw	158 kw
Ins. cons.	14 kwh	8 kwh	4 kwh	12 kwh	14 kwh

Source An industrial company

5 Feasibility and Equipment Selection

Daily Consumption = 172 kW = 172,000 W

1 h Maximum Expended Power = 20 kW = 20,000 W

5.1 Panel Selection

Because the calculations are done according to the highest generating power of the facility, a 250 W generating power photovoltaic cell will be selected. Each panel is 1.65 m^2 and weighs 20 kg.

Eighty panels will be needed to meet daily consumption requirements. These 80 panels will be situated on the roof, as shown below, one a space of 13.2 × 10 m, thus covering a 132 m^2 area.

The roof covers a 180 m^2 area and is in the shape of an 18 m × 10 m rectangle. The 10 m area will be completely covered by panels, while there will be a 1.6 m wide overlay. Panels will also be installed on the 9 m slope to the east with a 0.5 overlay.

Offers for 250 W capacity panels were received from 5 separate companies. The Y firm was selected as it has a good reputation and also gave the lowest offer.

X company: 74,000 TL
Y company: 53,760 TL
Z company: 52,800 TL
W company: 57,600 TL
U company: 47,360 TL

5.2 Battery Selection

A: W/V

172,000/12 V = 14,333 Ah

1 day storage = 72 batteries

200 Ah 12 V Jel Akü
X company: 1500 TL
Y company: 1750 TL
Z company: 1800 TL

Considering that Eskişehir is located in the continental (cold winter) meteorological region with low nighttime temperatures, the facility will need batteries in which to store the energy. Also considering the size of the area and number of panels, calculations called for the use of 72, 200 Ah 12 V gel batteries. The battery group will be interconnected on the roof of the 8 story building both parallel to each other and in a series. The batteries will be stored in the command room located on the second floor of the treatment center.

Total Costs of the Battery Group: 108,000 TL

5.3 Inverter Selection

Calculations call for a one hour total drawn power (20,000 W) and thus a total of four inverters will be needed.

X company: 5000 TL 5000 W/24 V
Y company: 7500 TL 5000 W/24 V

İnverter Costs: **20,000 TL**

5.4 Charge Regulator Solar Cable (6 mm)

MPPT	50 m
350 TL	**500 TL**

Other miscellaneous expenditures: **17,000 TL**
Total Investment Expenditures:
53,760 + 108,000 + 20,000 + 500 + 350 + 17,000 = 199,610 TL
Amortization Period:
Electricity Unit Cost: **0.39 TL/kWh**
Annual Electricity Consumption: 172 * 365 days = 62.780 Kwh
Annual Electricity Costs: **25,000 TL/year Amortization will thus be achieved in a period of 8 years.**

6 Conclusion

This feasibility study suggests that the operation of a waste water treatment plant with solar panels may be considered as a workable alternative. Such a system with a one-day storage capacity will cost approximately 200,000 TL to establish. Another alternative to consider would be a system that does not include a battery group. On days that the solar radiation is insufficient, this system could work with back-up electricity supplied by the central distribution network. In this case, the plant will utilize energy supplied from two different systems. In such a case, even if the hour maximum of kw electric energy is drawn from the system (feasibility used 20 kW/h), but still sufficient energy is not generated from the system, the system will automatically begin to pull electricity from the central energy distribution system. If such a system is utilized, the total investment costs will decrease by almost one half, to approximately 100,000 TL. And, since the system will be shut off during the nights and during long and cold winter periods, there will be no change to the amortization period. One of the biggest advantages of such a system is that because batteries only have a working life of 5 years, the owners will not have to deal with batteries, their operations and their replacements.

The calculations are based on assumptions that the panels will work at 100% efficiency, but in actuality, work carried out thus far has shown that with today's technology and conditions, these panels can not yet work at total efficiency. Taking current unit electricity prices into consideration, the amortization period for all solar energy systems range between 7 and 8 years. This kind of long period is due to the fact that investment costs remain very high and that the equipment and accessories used do not all supply the same 24 h efficiency rates. Still, it must be remembered that the demands for electricity in Turkey are continuously rising and the prices are sure to also rise as other generation resources are depleted. In these cases, the amortization period will decrease in a few years time.

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