Vol. 10, No 1/2021, 19-26

DOI: 10.17512/bozpe.2021.1.02

Construction of optimized energy potential
Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Supplying low energy consuming catering trailers with solar energy

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Abstract: Catering trailers are small gastronomic points that sell food in unusual, remote locations where access to the power grid is difficult or impossible. Therefore, owners are forced to use a separate energy source to ensure continuity of operation of specialized equipment. The article presents the concept of a photovoltaic installation with an energy storage system in batteries, which is an alternative to traditional combustion generators. On the basis of the adopted assumptions, the daily demand for electricity in the trailer was determined, the elements of the installation were selected and a simple payback time was determined based on investment costs. The environmental aspects were indicated, as well.

Keywords: catering trailer, photovoltaic installation, power generator, energy

Please, quote this article as follows:

Sobol Ł., Dyjakon A., Supplying low energy consuming catering trailers with solar energy, BoZPE, Vol. 10, No 1/2021, 19-26, DOI: 10.17512/bozpe.2021.1.02

Introduction

Power generators are electrical devices, which are separate sources of energy, allowing access to electricity in a situation where it is impossible to connect the electricity receiver to the energy grid (Martyniak et. al., 2005). In order to supply power generators, diesel oil is most often used – a product of crude oil distillation, consisting mainly of a mixture of hydrocarbons.

Due to their mobility and independence, power generators are used to power catering trailers (Fig. 1) – small gastronomic points that sell food products in often remote locations, inaccessible to typical restaurants. Unfortunately, the use of a power generator is associated with the negative impact on the environment.

Chłopek et al. (2011) report that the combustion of 1 kg of diesel oil by a power generator with a nominal power of 50 kW emits approximately 5 g CO, 30 g NO_x, 2.5 g PM (particulates), 3 kg CO_2 and 0.975 g HC (hydrocarbons) to the atmosphere. In addition, during operation it emits undesirable noise, which may adversely affect employees and customers in the close vicinity of the trailer (Woźny et al., 2014).

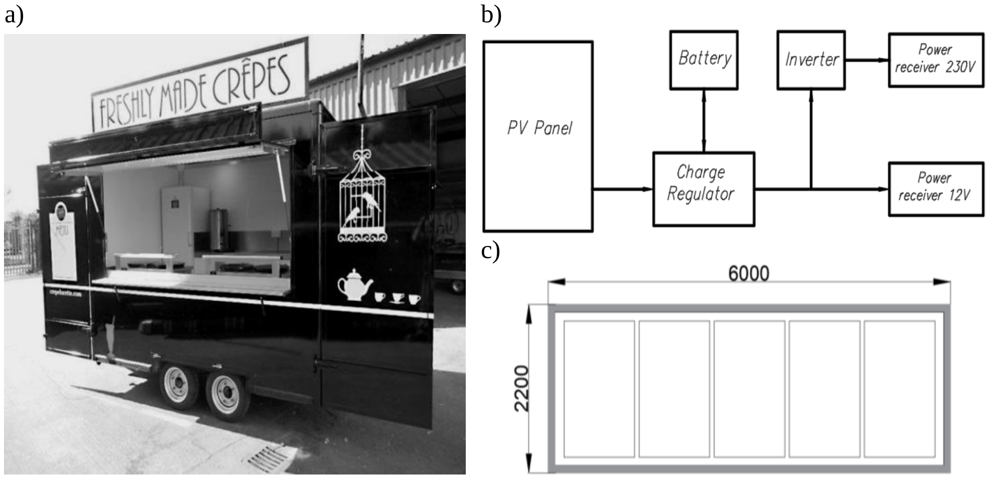

Fig. 1. a) Catering trailer (*Bingham …*), b) photovoltaic installation scheme for catering trailer (*own research*), c) arrangement of PV panels on the roof of the trailer (*own research*)

Therefore, owners of catering trailers are forced to look for alternative power sources, allowing them to ensure full energy autonomy, while minimising negative environmental effects. One of the solutions for entrepreneurs is a photovoltaic installation – a quiet source of energy, converting solar energy directly into electricity (Young, 2017).

Photovoltaic (PV) panels are the most important element of the installation (Tytko, 2020). They achieve peak efficiency for energy conversion when the sun's rays fall perpendicularly on the panel surface (Sarniak, 2008). The optimum angle of inclination of PV panels is 30-45° (in Poland). However, such an installation in a catering trailer would pose a certain obstacle to business. It would be necessary to park the vehicle properly towards the sun, which could interfere with sales. Moreover, it is also dangerous when towing a driving trailer. For these reasons, it seems a good solution to install the panels flat on an unused roof surface. This will not affect the mobility of the trailer, but to some extent it will reduce the efficiency of the installation, as the angle 0° does not provide peak efficiency for electricity generation.

The trailer should also be distributed with 12 V DC and 230 V AC. This will ensure proper and efficient operation of the PV installation (Sibiński & Znajdek, 2020). Changing the level of the voltage and the current intensity, and ensuring the proper operation of the equipment in the trailer, is possible through the use of an inverter (voltage converter) (Fig. 1).

The purpose of the article was a technical and economic analysis of the use of a photovoltaic installation to power electrical equipment in a catering trailer, characterized by low electricity demand.

1. Research methodology

1.1. Assumptions for the planned photovoltaic installation

The planned photovoltaic installation should fully cover the demand for electricity in the catering trailer. Therefore, the following assumptions were made:

- panels are installed flat on the roof of the trailer in order to avoid parking problems,
- the roof dimensions correspond to the “Bannert” catering trailer adapted for bread selling (Fig. 1),
- catering trailer is stationed in the seaside city of Kołobrzeg (54°10′40″N 15°34′37″E),
- exploitation takes place from March to September,
- calculations are made for a month with the lowest solar potential,
- the electrical installation consists of a DC (12 V) and AC (230 V) network.

1.2. Calculations for the planned photovoltaic installation

For the proper design of a photovoltaic installation in a gastronomy trailer, it is necessary to determine the daily demand for electricity based on the power and operating time of the equipment (Table 1).

Table 1. Daily electricity demand in catering trailer (*own research*)

Equipment	Power	Number	Operating time	Daily electricity demand
	W	no.	h/day	Wh/day
LED lighting	3	10	4	120
Highlighted buffet site	35	2	8	560
Refrigerated cabinet	165	1	8	1320
Card terminal	100	1	3.5	350
Radio	45	1	10	450
Water pump	40	1	2.5	100
Water heater	800	1	2	1600
Cash register	110	1	2.5	275

Total electricity demand was calculated from the equation:

$$E_A = \sum n_o \cdot N_o \cdot t_o \qquad (1)$$

where:
E_A – total electricity demand, kWh/day;
n_o – number of devices of one type, no.;
N_o – device power, kW;
t_o – device operating time, h/day.

The power of the PV installation, covering the total demand for electricity, and taking into account insolation for the adopted location and operation of PV panels, was calculated from the equation:

$$N_{PV} = \frac{E_A}{V_{LO} \cdot Z_1 \cdot Z_2 \cdot Z_3} \tag{2}$$

where:
N_{PV} – nominal power of the planned PV installation, W;
Z_1 – average daily number of sunshine hours under STC conditions, depending on geographical location and month of the year (adopted $Z_1 = 2.29$ h/day, Table 2), h/day;
Z_2 – coefficient associated with the slope of the PV panel from the horizontal plane (adopted $Z_2 = 1$, Table 3),
Z_3 – coefficient related to PV panel temperature (adopted $Z_3 = 0.98$, Table 4),
V_{LO} – coefficient taking into account electrical losses (adopted $V_{LO} = 0.76$ (Szymański, 2018)).

Table 2. Coefficient Z_1 determining the average number of sunshine hours in relation to location and month in the year (normalized to STC) (PVGIS)

Month	III	IV	V	VI	VII	VIII	IX
	h/day						
Z_1	2.29	3.99	4.72	5.06	4.67	3.90	2.80

Table 3. Coefficient Z_2 associated with the slope of the PV panel from the horizontal (Szymański, 2013)

Year		Azimuth								
		–60°	**–45°**	**–30°**	**–15°**	**0°**	**15°**	**30°**	**45°**	**60°**
Slope	**20°**	1.04	1.07	1.09	1.10	1.10	1.10	1.09	1.07	1.04
	10°	1.03	1.04	1.05	1.06	1.06	1.06	1.05	1.04	1.03
	0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4. Coefficient Z_3 related to PV panel temperature (Klugmann-Radziemska, 2018)

Month	III	IV	V	VI	VII	VIII	IX
Z_3	0.98	0.96	0.93	0.90	0.88	0.88	0.90

The reduction in diesel oil consumption L_{DL}, caused by the replacement of a power generator by a photovoltaic installation, was calculated from the equation:

$$L_{DL} = \frac{E_A \cdot t_{SEAS}}{Q_{PG}} \tag{3}$$

where:
L_{DL} – avoided diesel oil, dm^3/year;
t_{SEAS} – duration time of the season (adapted t_{SEAS} = 214 days), days;
Q_{PG} – power generator conversion efficiency (adapted Q_{PG} = 3.375 kWh/dm^3 (Lombardini, 2019)), kWh/dm^3.

The avoided cost resulting from the installation of the photovoltaic panels in the catering trailer was calculated according to the equation:

$$L_{SEAS} = C_{DL} \cdot L_{DL} \tag{4}$$

where:
L_{SEAS} – avoided cost in season, €/year;
C_{DL} – diesel oil cost (adapted C_{DL} = 0.98 €/dm^{-3} (*Ceny paliw* ..., 2020), €/dm^{-3}.

The capacity of the batteries constituting the energy storage generated from the PV installation was calculated according to the equation:

$$C_{BAT} = \frac{R \cdot P_{PV} \cdot F}{U} \tag{5}$$

where:
C_{BAT} – battery capacity, Ah;
P_{PV} – electricity produced by the photovoltaic installation, kWh/day;
R – maximum battery discharge (adapted 50% (Klugmann-Radziemska, 2018), R = 2);
F – coefficient related to energy reserve (F = 2.5-4 (Klugmann-Radziemska, 2018), adapted F = 2.5);
U – battery system voltage (adapted U = 12 V), V.

Avoided carbon dioxide emission in the season caused by the replacement of a power generator by a photovoltaic installation, was calculated from the equation (Ministerstwo Energii, 2017):

$$V_{CO2} = 360 \cdot \frac{We_{CO2}}{\eta} \cdot t_{SEAS} \cdot E_A \tag{6}$$

where:
V_{CO2} – avoided carbon dioxide emissions in the season, kg;

We_{CO2} – carbon dioxide emission coefficient for electricity produced in diesel combustion plants (adapted We_{CO2} = 74.10 kg/GJ (Ministerstwo Energii, 2017), g/MJ;

η – efficiency of electricity production in diesel combustion plants (adapted η = 0.442 (Rozp. UE, 2015).

The investment profitability analysis was made based on the SBPT index (Pastusiak, 2019), assuming investment costs and avoided diesel cost, according to the equation:

$$SPBT = \frac{K_{INV}}{C_{SEAS}} \tag{7}$$

where:
SPBT – simple pay-back time, years;
K_{INV} – investment cost, €.

2. Result and discussion

Electricity consumption depends on the specification and equipment of the catering trailer. In the analysed case, the average daily electricity demand by the catering trailer was 4775 Wh. On this basis, the nominal power of the photovoltaic installation was calculated that can cover the total demand for electricity.

Due to the strong variation in the number of sunshine hours in the season, as well as the limited roof space, it is not possible to fully supply the catering trailer with solar energy in the analysed case. However, the selected installation ensures the minimum need to provide the trailer with an additional energy source. The coverage of electricity demand is shown in Figure 2.

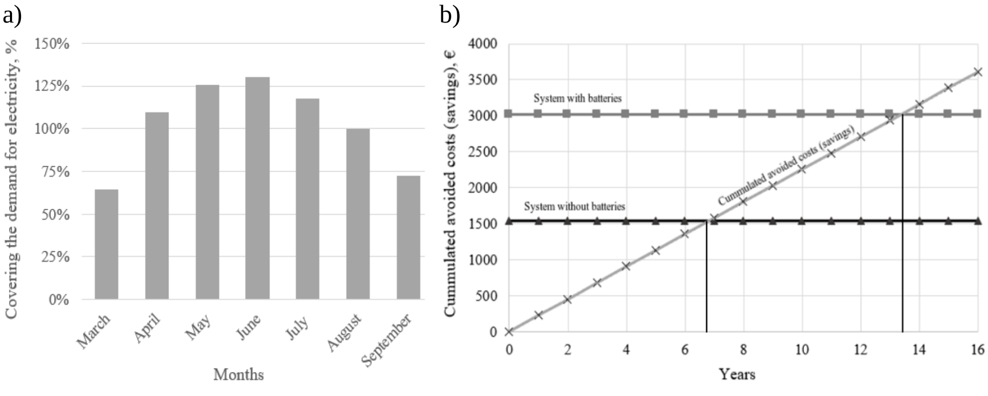

Fig. 2. a) Covering the demand on electricity (*own research*), b) SPBT index (*own research*)

The calculated nominal power of the photovoltaic installation amounted to 2800 W. However, because of the surface limitation, 5 photovoltaic panels with an unit power of 360 W were selected. As a result, the installed nominal power of PV installation was only 1800 W. They were installed on the roof of the catering trailer (Fig. 1). A photovoltaic installation is not able to cover the total demand for electricity in March and September, where only 64 and 72% of the required energy is generated. There is also a low energy shortage in August (1.7%), but the reserve energy from batteries is able to cover it. In the remaining months, the PV panels produce surplus electricity (from 109.5 to 130.5% of the required energy). Thanks to this, in the summer months it is possible to launch additional devices or use electricity for other purposes (i.e. air fans for cooling the working place inside the trailer).

The entire investment, together with other elements of the installation, amounted to ca. €3012 (Table 5). The savings in this case is the diesel oil that would be used to power the combustion generator set. In March, the daily avoided diesel oil consumption is 0.91 dm^3, in September – 1.01 dm^3, while in the remaining months it is 1.41 dm^3. In addition, due to the emission free PV system, the calculations revealed that during the season, the carbon dioxide emission can be decreased by 577.5 kg.

Table 5. The cost of planned photovoltaic installation (*own research*)

Element of the PV system	Unit cost	Number	Total cost
	€	no.	€
Photovoltaic panel 360 W	165	5	825
Charge regulator	150	1	150
Battery 1000 Ah	738	2	1476
Inverter	145	1	145
Wires	5	4	20
Montage	396	–	396
			3012

Assuming investment costs related to assembly, presented in Table 5, at the current price of diesel oil, the payback-time is about 13.5 years (Fig. 2). The result is not entirely satisfactory, but it is worth noting that a significant part of the investment is batteries, without which the payback-time would be shortened to about 6.5 years.

The profitability of the project is therefore controversial, but when analysing the investment in terms of environmental aspects and the image of the company/brand as an environment-friendly enterprise (social aspects), it can lead to the increase sales. In such a situation, significant revenues from higher sales of products may turn out to be much more economically profitable than just the saved fuel supplying the trailer.

Conclusions

PV installation is a good, ecological source of energy, which can be a source of power for low-energy catering trailers. Installation assembly not only contributes to the environment by eliminating carbon dioxide emissions to the atmosphere, but also provides financial stability that is affected by the constantly fluctuating price of diesel oil (Glinkowska et al., 2016). Although it was not possible to ensure energy autonomy in the analyzed case, the need to provide energy from a conventional source is low. In addition, the surplus electricity produced during the summer months and off-season of catering trailers can be used for other purposes, so the payback-time can be shortened considerably. The use of renewable energy sources can significantly affect the perception of the company image by consumers and increase revenues from the sales of products.

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