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COMPENSATION OF CO_2 EMISSIONS FROM PETROL STATIONS WITH PHOTOVOLTAIC PARKS: COST-BENEFIT AND RISK ANALYSIS

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This paper presents a new approach for reducing the CO_2 emissions in the transport sector based on emission compensation. A cost-benefit analysis method of investments in photovoltaic parks at petrol stations is used, which accounts for all the initial investments and maintenance costs in terms of expenses. The benefits are divided into financial and ecological. The method has been implemented in the specialised cost-benefit analysis tool, and an analysis has been performed for the city of Ruse, Bulgaria. Risk analysis on the influence of the main risk factors – the price of conventional energy and the buying price of energy from renewable energy sources is also performed. The results showed that investments in photovoltaic parks at petrol stations could pay off within 6 to 9 years in the more likely scenarios. The investment could reduce the CO_2 emissions, related to the petrol station, by 10% to 37% depending on the scenario and the criterion used.

Keywords: transport; carbon emissions; renewable energy sources; cost-benefit; net present value; return on investment

Making the European economy more climate-friendly and less energy consuming has been set as a major goal by the European Commission. According to the roadmap, the emissions should be cut to 40% below the 1990 levels by 2030 and to 80% below the 1990 levels by 2050. Globally, the road transport sector is one of the main sources of carbon dioxide emissions and pollution (Lenďák et al., 2013; Szabó et al., 2013); therefore, the reduction of emissions from this sector is one of the key objectives in order to meet the Kyoto Protocol and create a sustainable transport system (Fontaras and Samaras, 2007). In the European Commission's roadmap, the share of the transport sector is set to be reduced by 60% by 2050 from the 1990 levels.

Three major ways of reducing the carbon dioxide emissions in the transport sector have been acknowledged: improving the efficiency of petrol and diesel engines, introduction of plug-in hybrid and electric cars and increasing the share of biofuels (Fontaras and Samaras, 2007; EC, 2011; Liaquat et al., 2010).

The first objective was stimulated by increasing the requirements for the newly sold cars in terms of emission production. Although the CO_2 emissions were reduced from 172 $g \cdot km^{-1}$ to 153 $g \cdot km^{-1}$ by 2008 (EC, 2008), the set goal of average 120 $g \cdot km^{-1}$ by 2012 was not met. The conclusion was that further measures are required (EC, 2007). Thereby in 2009, the EU adopted new regulations and set the new goal – 120 $g \cdot km^{-1}$ by 2015 (EU, 2009). The development of electric vehicles, plug-in vehicles and other fuel-efficient vehicles has also been supported by legislation, which adopted "super-credits" (International Energy Agency, 2010).

The third major opportunity for reduction of greenhouse emissions is the increase in low-carbon biofuel usage, mostly bioethanol and biodiesel. The main issue related to biofuels is that so far they have been more expensive than petroleum fuels so government incentive programmes are required in order to promote them (GSI, 2007). Another problem with biofuels is that agricultural areas are used for production of fuel, which could be used for other means, and as a result greatly affects the price on these products (Ajanovic and Haas, 2010).

Even though by 2012 there was a reduction of reduced emissions in the EU (Rosu et al., 2016), that is not the case with the transport sector. Despite all of the above measures and incentives taken, the greenhouse emissions from the transport sector increased from 1990 to 2007 by 36%. Only after 2008 emissions started to decrease and by 2012 emissions were 20% above the 1990 levels (EU, 2015). This means that the taken measure was not sufficient and alternative measure should be considered.

The goal of this paper is to propose an alternative way for indirect reduction of the CO_2 emissions related to the transport sector and in particular to petrol stations (PS). The approach includes compensating emissions related to the transport sector through usage of renewable energy sources (RES). However, the initial investment in RES is quite high, which makes such an approach a question of cost and benefits. Blanco-Silva et al. (2016) estimated how the price per kWh of energy from photovoltaic (PV) generators changes annually from the moment of investment. But the return on investment would greatly depend on the price of energy from conventional sources, which is an uncertainty factor. A cost-benefit analysis is required in order to assess the risks related to such an investment, as well as the potential benefits.

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Material and methods

Cost-benefit analysis

The investigation object of this paper is a petrol station powered by PV power as well as by conventional energy sources, and selling gasoline and diesel fuels. The input data to be analysed can be divided into two groups: information about the investment and information flows. The information flows could be summarised in 6 categories:

- Information about the sold fuels;
- RES production;
- Energy consumption of the petrol station for own needs;
- Price and carbon emissions of the energy from conventional energy sources;
- Buyout prices of carbon emissions and renewable energy;
- Economic parameters like nominal rate of return and inflation.

Energy production and consumption

The daily energy balance of a petrol station with two rates tariff electricity meter is:

$$E_{PV_G} + E_{B_D} + E_{B_N} = E_{OWN_D} + E_{OWN_N} + E_{S_{PV}} \quad (1)$$

where:
E_{PV_G} – generated daily energy by PV sources, kWh
E_{B_D} – bought electrical energy during the daytime rate tariff, kWh
E_{B_N} – bought electrical energy during the night-time rate tariff, kWh
E_{OWN_D} – energy consumption of the PS for own needs during the daytime rate tariff, kWh
E_{OWN_N} – energy consumption of the PS for own needs during the night-time rate tariff, kWh
$E_{S_{PV}}$ – excess energy produced by PV sources, kWh

A sample daily PV production-consumption diagram in the time domain is presented in Fig. 1. It shows the rates of instantaneous production/consumption of energy and allows estimations of the excess and shortage of electrical energy.

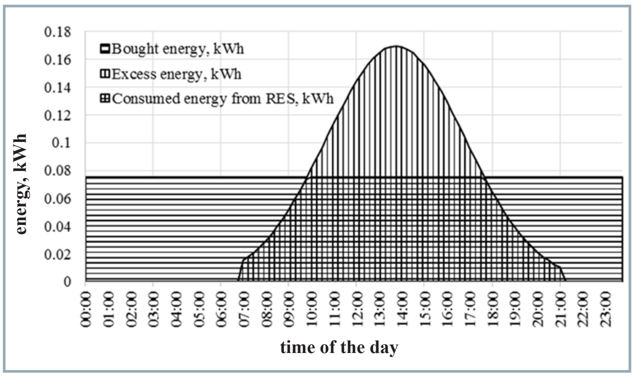

Fig. 1 Daily production-consumption model

Carbon emissions

A petrol station selling gasoline and diesel fuel, measured in *l*, was investigated in the presented study. The total emissions linked directly or indirectly to the petrol station are:

$$CO2 = \sum_{i=1}^{n} CO2_l + CO2_{OWN}, \ \text{g} \quad (2)$$

where:
n – number of vehicles loaded at the station
$CO2_l$ – carbon emissions of loaded vehicles, g
$CO2_{OWN}$ – carbon emissions from the production of electrical energy used by the PS, g

Carbon emissions from vehicles can be obtained with:

$$CO2_l = \frac{G_l \times CO2_r}{R_l}, \ \text{g} \quad (3)$$

where:
$CO2_r$ – relative combined carbon emissions for a certain vehicle, g·km^{-1}
G_l – amount of loaded fuel in *l*
R_l – combined fuel consumption of the vehicle, in *l*/100 km

The carbon emissions of the petrol station from electricity for own needs depends on the emissions resulting from the production of electrical energy:

$$CO2_{OWN} = (E_{OWN_D} + E_{OWN_N}) \times CO2_{E0}, \ \text{g} \quad (4)$$

In the above equation, $CO2_{E0}$ expresses the relative value of carbon emissions in g·kWh^{-1}, which depends on the source of energy:

$$CO2_{E0} = f \times CO2_{PV} + k \times CO2_{BE}, \ \text{g·kWh}^{-1} \quad (5)$$

where:
$CO2_{PV}$ – emissions from production of 1 kWh energy by a PV source, g CO_2·kWh^{-1}
$CO2_{BE}$ – emissions of purchased electrical energy, g CO_2·kWh^{-1}

The coefficients *f* and *k* represent the shares of energy sources in the total consumed energy. Note that in the presented study, it is assumed that emissions from electrical energy are caused by the consumer and not by the producer. Therefore, the sold/excess PV energy is not used to obtain the shares as it is not consumed by the PS.

Costs related to the investment

The investment information includes the installed PV power, maintenance expenses and additional expenses related to the investment. The costs can be divided into three categories:

- investment for PV modules;
- other investments;
- maintenance costs related to the investment.

The initial investment cost for PV generators could be estimated with:

$$I_{RES} = (C_{RES} + C_{RES_{INS}}) \times P_{RES}, \ € \quad (6)$$

where:
C_{RES} – price of RES with 1 kW rated power, €·kWp^{-1}
$C_{RES_{INS}}$ – additional price related to transport and installation of 1 kW rated power, €·kWp^{-1}
P_{RES} – installed rated power, kWp

The analysis was performed for one life cycle (life expectancy) of the PV generator in the presented study. The category "other investments" includes all other expenses for equipment and services like transformers, invertors, electricity meters, etc.:

$$I_O = \sum C_{EQ} + \sum C_{SRV}, \ \text{€} \quad (7)$$

where:
C_{EQ} – price for a certain equipment, €
C_{SRV} – price for a certain service, €

Then, the total initial investment is:

$$I = I_{RES} + I_O, \ \text{€} \quad (8)$$

RES require monthly maintenance expenses C_{MN}:

$$C_{MN} = P_{RES} \times C_{MN_0}, \ \text{€·mnt}^{-1} \quad (9)$$

where:
C_{MN_0} – is the monthly maintenance cost for 1 kW rated power in €·kWp^{-1}

The maintenance of PV systems is related mainly to surface cleaning and according to Rhyne and Klein (2014), the annual maintenance of 1 kW rated PV power in 2013 varies between \$28 and \$53.

Financial benefits

The financial benefits could be divided into the following categories:

– Money savings from buying of a lower amount of electrical energy;
– Incomes from selling of excess energy.

The money savings from buying less electrical energy are estimated with:

$$C_{EN_{SAV}} = (C_{B_D} - C_{E0_D}) \times E_{OWN_D} + (C_{B_N} - C_{E0_N}) \times E_{OWN_N} \quad (10)$$

where:
C_{B_D} and C_{B_N} – are the prices of energy for daytime and night-time rate tariff in €·kWh^{-1}

The relative daytime and night-time prices C_{E0_D} and C_{E0_N} are estimated by taking into account the prices and shares of different types of energy. The financial benefits are assessed using the Net present value (NPV) and the Return on investment (ROI) indicators:

$$NPV(t) = \sum_{k=1}^{n} \frac{B_k(t)}{(1+r)^n} - I, \ \text{€} \quad (11)$$

$$ROI = \frac{\sum C_i(t)}{I + I_{ADD}} \times 100, \ \% \quad (12)$$

where:
$B_k(t)$ – net cash flow for the k^{th} month in €
$C_i(t)$ – cash flow of the investment for the i^{th} day in €
r – cost of capital, which depends on the nominal rate of return and monthly inflation

Ecological benefits

Due to electrical energy consumption of the PS, the carbon emissions $CO2_{EC}$ are:

$$CO2_{EC} = CO2_{E0} \times (E_{OWN_D} + E_{OWN_N}) \quad (13)$$

If there was no investment in PV generators, the potential carbon emissions $CO2_{EC_P}$ are:

$$CO2_{EC_P} = CO2_{BO} \times (E_{OWN_D} + E_{OWN_N}), \ \text{g} \quad (14)$$

where:
$CO2_{BO}$ – are the emissions from 1 kWh of purchased energy

The total emission savings are:

$$CO2_{SAV} = CO2_{EC_P} - CO2_{EC}, \ \text{g} \quad (15)$$

Note that the saved emissions could be used as an additional source of income if corresponding legislation is available. In this paper, the ecological benefits of the investment are assessed in two ways in terms of emissions reduction related to the petrol station:

- by accounting only for the carbon emissions directly linked to the petrol station (electrical consumption for own needs);
- by accounting for all carbon emissions linked to the petrol station, including the sold fuels.

The first coefficient $K_{CO2_{EC}}$ returns the ratio between the real and the potential emissions and shows the percentile reduction:

$$K_{CO2_{EC}} = \frac{\sum CO2_{SAV}}{\sum CO2_{EC_P}} \times 100 \quad (16)$$

The second coefficient $K_{CO2_{AE}}$ returns the ratio between the carbon savings and the total direct (energy consumption) and indirect (sold fuels) potential emissions in percentages:

$$K_{CO2_{AE}} = \frac{\sum CO2_{SAV}}{\sum \left(\sum_{i=1}^{n} CO2_I + CO2_{EC_P} \right)} \times 100 \quad (17)$$

Results

The specialised software tool GasStationInvest v.1.0 has been developed, implementing the presented method for cost-benefit analysis. The software has been used to simulate a number of scenarios. The data which have been used during the simulations include:

- mean 15 minute energy consumption of a PS in Ruse (Bulgaria) for each month of the year;
- mean daily sold fuel and diesel of the petrol station for each month of the year;

- mean 15 minute energy production from 1 kW installed power of the PV park Zita Ruse (Bulgaria) for each month of the year.

Additional input data used in the simulations is presented in Table 1.

Using the cost-benefit analysis tool, the following scenarios have been simulated for a PS located in Ruse. In both scenarios, it is assumed that the company has the required money and will either invest them in a PV park or deposit them in a bank with interest rate 1%.

Scenario 1:
Investment: 50 kW PV park
Annual nominal rate of return: 1%
Annual inflation: 2%
Buying price of PV energy: 0.2 €·kWh^{-1}

Scenario 2:
Investment: 10 kW PV park
Annual nominal rate of return: 1%
Annual inflation: 2%
Buying price of PV energy: 0 €·kWh^{-1}

Additionally, the following risk factors have been investigated for Scenario 1:

- Purchasing price of renewable energy;
- Selling price of conventional energy.

For Scenario 2, only the influence of the selling price of conventional energy is investigated since the energy excess is not sold. The risks have been investigated by performing the simulations for three values of the risk factor: the expected value of the risk factor, the expected value is increased by 50% and the expected value is decreased by 50%.

Table 1 Additional parameters used in simulation

Parameter	Value
CO_2 emissions for production of conventional energy	906 g CO_2·kWh^{-1}
Selling price of electrical energy at daytime rate	0.14 €·kWh^{-1}
Price for 1 kW installed rated PV power	660 €·kWp^{-1}
Additional price for 1 kW installed rated PV power	960 €·kWp^{-1}
Monthly maintenance fee of 1 kW rated PV power	1 €·kWh^{-1}
CO_2 emissions for one life cycle of the PV modules	30 g·kWh^{-1}
Life expectancy of the PV modules	20 years
Combined fuel consumption of gasoline cars (GAAI, 2014)	6.2 l per 100 km
Combined fuel consumption of diesel cars (GAAI, 2014)	5.2 l per 100 km
Carbon emissions from gasoline cars (GAAI, 2014)	155 g CO_2·km^{-1}
Carbon emissions from diesel cars (GAAI, 2014)	150 g CO_2·km^{-1}

Results for Scenario 1

The investment price for Scenario 1 has been estimated as €81000, and the ROI has been evaluated to be 150%. The influence of the purchase price of RES energy has been investigated (Fig. 2). For Scenario 1, the NPV at the end of the period is €144,000 with the purchase price of RES energy at 0.2 €·kWh^{-1}, €74,000 with purchase price 0.1 €·kWh^{-1} and €214,000 with purchase price 0.3 €·kWh^{-1}. The investment will return in 5 years in the most optimistic and in 10 years in the most pessimistic scenario.

The influence of the selling price of conventional energy on the NPV of the investment is presented in Fig. 3. The NPV at the end of the period is €144,000 with the daytime selling price of conventional energy at 0.14 €·kWh^{-1}, €95,000 with selling price 0.07 €·kWh^{-1} and €193,000 with the selling price of 0.21 €·kWh^{-1}. The investment will return in 6 years in the most optimistic and in 9 years in the most pessimistic scenario.

The benefits of this investment also include emission savings. According to criterion 1 (only the electrical consumption of the PS is accounted), the carbon savings for the different

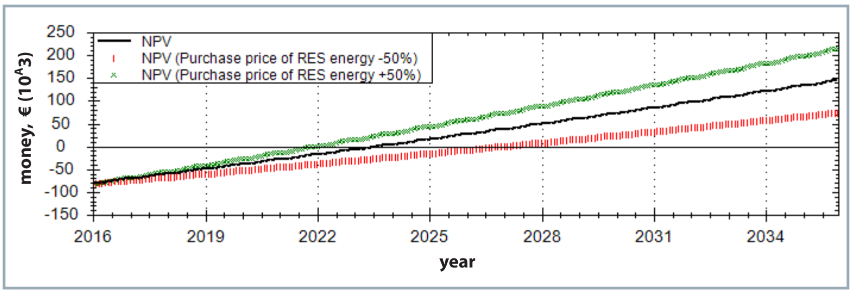

Fig. 2 NPV for Scenario 1 with risk factor for the purchase price of renewable energy

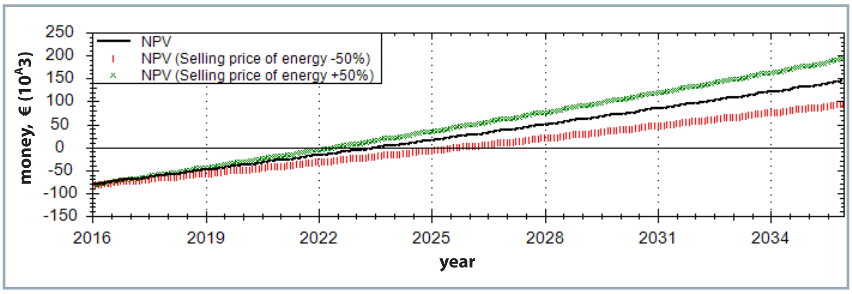

Fig. 3 NPV for Scenario 1 with risk factor for the selling price of conventional energy

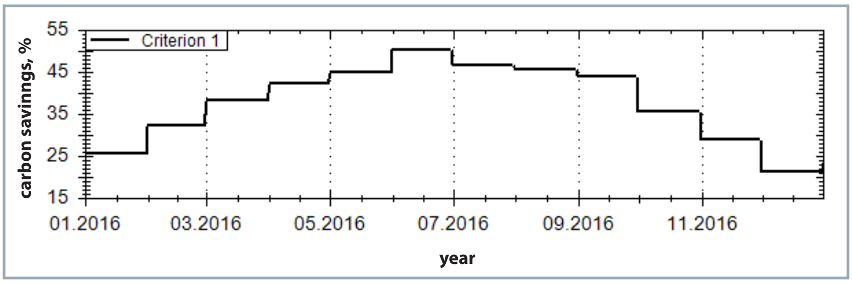

Fig. 4 Annual carbon savings for Scenario 1 according to criterion 1

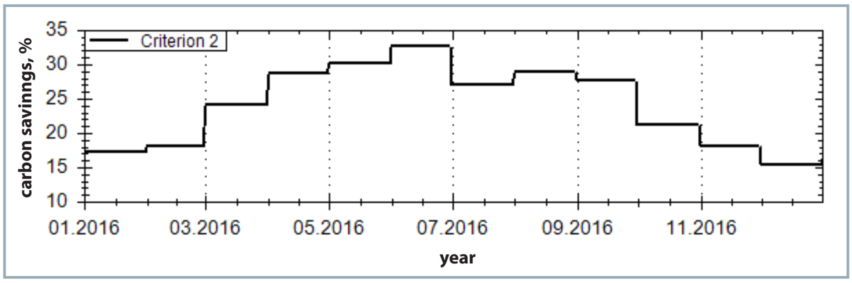

Fig. 5 Annual carbon savings for Scenario 1 according to criterion 2

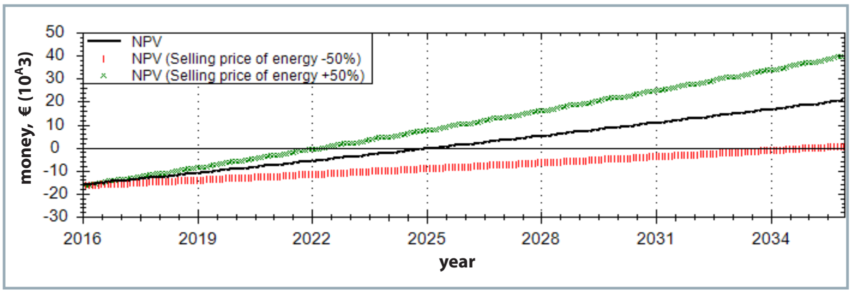

Fig. 6 NPV for Scenario 2 with risk factor for the selling price of conventional energy

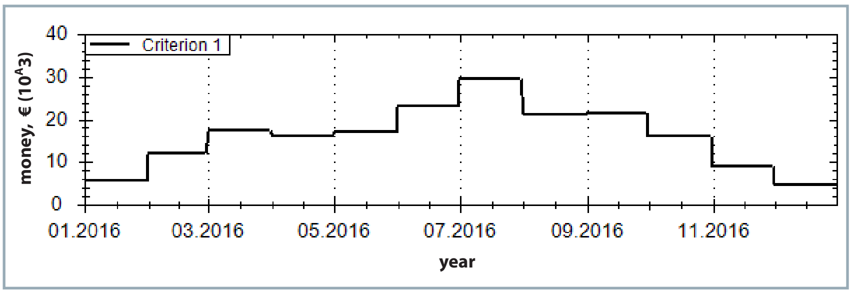

Fig. 7 Annual carbon savings for Scenario 2 according to criterion 1

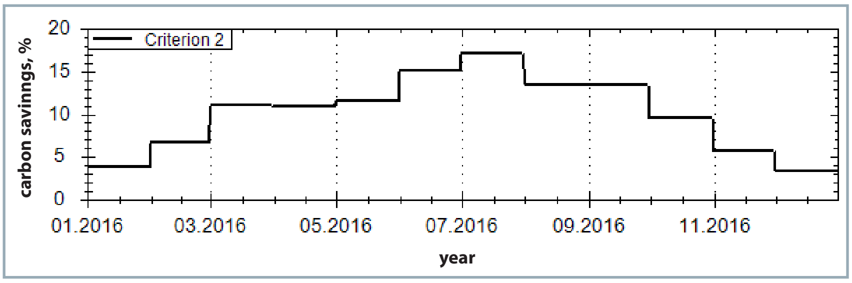

Fig. 8 Annual carbon savings for Scenario 2 according to criterion 2

months vary from 21% in December to 50% in June (Fig. 4). If the emissions from the sold liquid fuel are also included (criterion 2), the carbon savings vary from 15% in December to 32% in June (Fig. 5).

The annual carbon savings of the petrol station have been estimated to be 27 tons/year, which is a reduction of 37.4% and 24.0% respectively according to the two criteria.

Results for Scenario 2

The investment price for Scenario 2 has been estimated as €16,000, and the ROI has been evaluated to be 103%. The results for this scenario are presented in Fig. 6. The NPV at the end of the period is €20,000 with the selling price of conventional energy 0.14 €·kWh^{-1}, €720 with selling price 0.07 €·kWh^{-1} and €40,000 with selling price 0.21 €·kWh^{-1}. The investment will return in 6 years in the most optimistic and in 20 years in the most pessimistic scenario.

According to criterion 1, the emission savings for the different months vary from 4.5% in December to 29% in July (Fig. 7). The savings according to criterion 2 vary from 3% in December to 17% in July (Fig. 8). The annual carbon savings of the PS have been estimated to be 11.1 t·year^{-1}, which is a reduction of 15.4% and 9.9% respectively, according to the criteria.

Conslusion

The results obtained in this study show different aspects of investing in RES at petrol stations. The purchase price of RES energy has a significant influence on the NPV if there is a lot of excess energy from RES. Lower purchase prices reduces the NPV, and higher ones increase it. The buying prices of renewable energy in Bulgaria are expected to significantly drop in the near future, which would decrease the payoff of the investment.

The selling price of conventional energy is another factor having a significant influence on the NPV. Here, the relation is also proportional to the higher selling prices increasing the NPV at the end of the period and lower – decreasing it. In the near and foreseeable future, the energy prices are expected to increase, which is explained by the increased consumption.

The obtained results show that, with careful planning, the investment in RES could be a very beneficial idea even if no RES energy is sold but is used for own needs instead. If the current selling prices of energy from conventional sources maintain their level, the investment would pay off in approximately 9 years, and if they increase (which is quite possible), the payoff period could become even shorter. A 50% increase in the selling price of conventional energy would reduce the payoff period to 6 years.

However, the above conclusions are only valid if there is no energy excess. In other words, the PV park should be carefully designed so that all produced energy is used, even in the sunny summer days when the energy production reaches its rated values.

Another important conclusion from this study is that installing RES at a PS could significantly reduce the carbon emissions related to it. This is a new opportunity to reduce the emissions in the transport sector through compensation. The obtained results show the petrol station could compensate a significant amount of the carbon emissions from the fuel sold. The obtained results in this study could very well be applied in other sectors such as industry, social, domestic, etc.

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