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Eco-friendly technology to reduce CO_2 emissions of passenger cars based on innovative solutions

Streszczenie**. W ostatnim czasie obserwujemy bardzo dynamiczny wzrost udziału w rynku urządzeń służących do konwersji energii słonecznej. Duże zainteresowanie odnawialnymi źródłami energii powoduje, że technologie stosowane do pozyskiwania energii z tych źródeł odnawialnych są coraz bardziej powszechne i ciągle udoskonalane. Zasadniczą zaletą ogniw fotowoltaicznych jest to, że przetwarzają energię elektryczną, bez ubocznej produkcji zanieczyszczeń, hałasu oraz innych czynników wywołujących niekorzystne zmiany w środowisku naturalnym. Panele fotowoltaiczne (panele PV) należą do najszybciej rozwijającej się technologii pozyskiwania energii odnawialnej na świecie. Dzięki rozwojowi fotowoltaiki i technologii magazynowania energii elektrycznej otwierają się nowe możliwości dla gospodarki niskoemisyjnej. Połączenie tych technologii pozwala nie tylko na magazynowanie niestabilnej „zielonej energii", ale również przyczynia się do rozwoju niskoemisyjnego transportu (samochody energetyczne). Sektor motoryzacji jest dużym konsumentem energii. W artykule autorzy zaprezentowali ekologiczna technologię zmniejszenia CO_2 poprzez zastosowanie fotowoltaicznego szyberdachu wspomagającego ładowanie akumulatora w samochodach typu. M1 uznaną przez Komisję Europejską, jako innowacyjne rozwiązanie (kod ekoinnowacji 7). Ponadto przedstawiono metodę badań redukcji emisji CO_2 fotowoltaicznych szyberdachów wspomagających ładowanie akumulatora. **Ekologiczna technologia zmniejszenia CO_2 poprzez zastosowanie fotowoltaicznego szyberdachu wspomagającego ładowanie akumulatora w samochodach typu. M1

***Abstract**. In recent times, we have observed a very dynamic market growth in the presence of devices for solar energy conversion. Strong interest in renewable energy sources makes the technologies used to generate energy from the renewable sources become more common and thus they continuously improve. The principal advantage of photovoltaic cells is that they process energy without producing secondary pollution, noise and other factors that cause adverse effects in the environment. Photovoltaic panels (PV panels) rank amongst the fastest growing renewable energy technologies in the world. Thanks to photovoltaics and energy storage technology new possibilities for a low-carbon economy open up. The combination of these technologies allows not only for the storage of unstable "green energy" but it also contributes to the development of low-carbon transport (energy cars). The automotive sector is a large consumer of energy. In this paper, we present a technique for the reduction in CO_2 emissions of a battery charging solar roof in M1 cars, which is approved by the European Commission as an innovative solution (eco-innovation code 7). In addition, the research presents a method to research the reduction of CO_2 emission of photovoltaic battery charging solar roofs.*

Słowa kluczowe: Ogniwa fotowoltaiczne, emisja CO_2.
Keywords: photovoltaic cells, emission CO_2.

Introduction

The automotive sector is a large consumer of energy. [28],[14],[15] Solar electricity (photovoltaic-PV), considered one of the most promising and environmentally friendly energy sources, is unique among new sources because of the wide opportunities available to achieve benefits beyond energy and power. [4],[18],[5],[2],[8],[16]. Because of its huge potential for direct conversion of commercially available solar radiation into electrical energy, it is likely to become a serious alternative to fossil fuels in the future. [7],[17],[13],[11]. There is no doubt that photovoltaics will be the primary source of electricity in the world after 2050. [2],[16],[12] Not only the development of the market, but also research related to the use of renewable energy, in particular photovoltaics, is one of the thematic priorities in European plans for the coming years. [9],[24],[10].

The European Commission has approved innovative photovoltaic technologies supporting a Webasto sunroof battery to charge M1 class vehicles (vehicles licensed to transport 8 passengers in addition to the driver). Webasto Roof & Components SE showed that the emission reduction achieved through this innovative technology is at least 1g CO_2/km.

The sunroof consists of a photovoltaic (PV) panel which is mounted on the roof of the vehicle. This panel converts radiant energy into electrical energy through the DC-DC converter; generated energy is stored in the battery located in the vehicle [1],[23],[25],[26],[27].

In order to determine the CO_2 savings that the innovative technology will deliver when fitted to a vehicle, it is necessary to define the baseline vehicle against which the efficiency of the vehicle equipped with the innovative technology should be compared as provided for in Articles 5 and 8 of Implementing Regulation (EU) No 725/2011.

The reference vehicle should be a variant of a vehicle which is in all respects identical to the eco-innovative vehicle, with the exception of the photovoltaic sunroof, and in cases without a secondary battery or other equipment necessary for the energy conversion. With regard to the new version of the vehicle with a sunroof installed, the photovoltaic reference vehicle should be the vehicle in which the photovoltaic sunroof is disconnected, and the weight change due to installing the photovoltaic sunroof is taken into account.

Methodology for research in the reduction in CO_2 emissions of a battery charging solar roof

The peak power output (PP) of the PV panel is to be determined experimentally for each vehicle variant. Measurements are to be done in accordance with the testing methodology specified in the international standard IEC 61215:2005 [6]. The four corner points of the panel are to touch the horizontal measurement panel. The measurements are to be done at least five times.

The angle of inclination of the longitudinal and storage capacity is associated with the correction coefficient for solar energy storage (Solar Correction Coefficient SCC). These figures should be provided by the vehicle manufacturer. The possible lengthwise inclination of the car roof is to be corrected mathematically by applying a cosine function.

The standard deviation of arithmetic mean of the peak power output is to be calculated by Formula (1).

$$(1)\qquad \Delta\overline{P_P} = \sqrt{\frac{\sum_{i=1}^{n}(P_{P_i} - \overline{P_P}}{n(n-1)}}$$

where: $\Delta\overline{P_P}$ Standard deviation of arithmetic mean of the peak power output [Wp], P_{P_i} Measurement value of the peak power output [Wp], $\overline{P_P}$ Arithmetic mean of the peak power output [Wp], n Number of measurements.

The gain of additional electric power depends on the available electric on-board storage capacity. If the capacity is below 0,666 Ah per Watt peak power of the PV panel, the solar radiation arising on sunny and clear summer days cannot be used completely because of fully charged batteries. In this case the solar correction coefficient referred is to be applied to derive the usable solar energy.

The following input data for the calculation of CO_2 savings potential are to be used:

- mean solar irradiation P_{SR} i.e. 120 W/m2,
- usage factor/shading effect UF_{IR}, i.e. 0,51,
- efficiency of the solar system η_{SS} i.e. 0.76,
- solar correction coefficient SCC specified in table 1,

Table 1. Solar correction coefficient SCC [21]

Total available storage capacity (12V)/ PV peak power [Ah/Wp]	0,10	0,20	0,30	0,40	0,50	0,60	>0,666
Solar correction coefficient (SCC)	0,481	0,656	0,784	0,873	0,934	0,977	1

The total storage capacity includes a mean usable storage capacity of the starter battery of 10 Ah (12 V). All values refer to a mean annual solar radiation of 120 W/m2, a shading share of 0,49 and a mean vehicle driving time of 1 hour per day at 750 W electric power requirement.

- consumption of effective power for petrol V_{Pe-P} and diesel-fuelled vehicles V_{Pe-D} specified in Table 2

Table 2. Consumption of effective power for petrol and diesel-fuelled vehicles [21]

Type of engine	Consumption of effective power V_{Pe} [1/kWh]
Petrol (V_{Pe-P})	0,264
Diesel (V_{Pe-D})	0,22

- efficiency of the alternator ηA, 0,67

For the conversion factors *CF* the data in table 3:

Table 3. Conversion factor *CF* [3]

Type of fuel	Conversion factor (l/100km)→gCO_2/km)[100g/l]
Petrol (CF_P)	23,3(=2330 gCO_2/l)
Diesel (CF_D)	26,4(=2640 gCO_2/l)

For the mean annual mileage the data in table 4 [$km/year$]:

Table 4. Annual mileage the data [3]

Type of fuel	Mean annual mileage ($km/year$)
Petrol (M_P)	12700
Diesel (M_D)	17000

With these input data the CO_2 savings for a petrol-fuelled vehicle are to be calculated by Formula 2

The difference in mass between the baseline vehicle and the eco-innovation vehicle due to the installation of the solar roof and where relevant, the extra battery, is to be taken into account by applying the mass correction coefficient [19] The baseline vehicle is to be a vehicle variant that in all aspects is identical to the eco-innovation vehicle with the exception of the solar roof and, where applicable, without the additional battery and other appliances needed specifically for the conversion of the solar energy into electricity and its storage.

For a new version of a vehicle in which the solar roof panel is installed the baseline vehicle is to be specified as follows: it is the vehicle in which the solar roof panel is disconnected and the change in mass due to the installation of the solar roof is taken into account. In case the solar roof panel is made of glass a correction for the change in mass is to be introduced, i.e. an extra mass of 3,4 kg. In case the solar roof panel is made of low weight synthetic material no correction for the change in mass has to be made. On this case change of mass the manufacturer must hand over verified documentation to the Type-Approval Authority.
Formula (2)

$$C_{CO_2} = P_{SR} \cdot UF_{IR} \cdot \eta_{SS} \cdot P_P \cdot SCC \cdot \frac{V_{Pe-P}}{\eta_A} \cdot \frac{CF_P}{M_P} \cdot cos\,\phi - \Delta CO_{2mP} \quad (2)$$

CO_2 savings CO_2 [$g\ CO_2/km$]; P_{SR} Mean solar irradiation [$W/m2$]; UF_{IR} Usage factor/shading effect [–]; η_{SS} Efficiency of the solar system [–]; P_P Peak power output [Wp]; SCC Solar correction coefficient [–]; V_{Pe-P} Consumption of effective power for petrol vehicles [l/kWh]; η_A Efficiency of the alternator [–]; CF_P Conversion factor for petrol vehicles [$100\ g/l$]; M_P Mean annual mileage for petrol vehicles [$km/year$]; ϕ Lengthwise inclination of the solar panel [°]; ΔCO_{2mP}, CO_2 correction coefficient due to the change in mass following the installation of the solar roof and, where applicable, the additional battery and other appliances needed specifically for the conversion of the solar energy into electricity and its storage for petrol vehicles [$g\ CO_2/km$].

The savings for diesel-fuelled vehicles are to be calculated by Formula (3).

$$C_{CO_2} = P_{SR} \cdot UF_{IR} \cdot \eta_{SS} \cdot P_P \cdot SCC \cdot \frac{V_{Pe-D}}{\eta_A} \cdot \frac{CF_D}{M_D} \cdot \cos\phi - \Delta CO_{2mD} \quad (3)$$

where: V_{Pe-D} Consumption of effective power for diesel vehicles [l/kWh]; CF_D: Conversion factor for diesel vehicles [$100\ g/l$]; M_D: Mean annual mileage for diesel vehicles [$km/year$]; ΔCO_{2mD}, CO_2 correction coefficient due to the change in mass following the installation of the solar roof and, where applicable, the additional battery and other appliances needed specifically for the conversion of the solar energy into electricity and its storage for diesel vehicles[g CO_2/km].

The CO_2 correction coefficient due to the change in mass is to be calculated by Formulas. (4) i (5).

(4) $\Delta CO_{2mP} = 0{,}02777 \cdot \Delta m$ for a petrol-fuelled vehicle

(5) $\Delta CO_{2mD} = 0{,}0383 \cdot \Delta m$ for a diesel-fuelled vehicle

where: Δm: Change in mass due to the installation of the solar roof and, where applicable, the additional battery and other appliances needed specifically for the conversion of the solar energy into electricity and its storage. (e. g 5 kg).

The error in the CO_2 savings should be calculated using Formula (6).

$$\overline{\Delta C_{CO_2}} = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial C_{CO_2}}{\partial P_{P_i}} \Delta \overline{P_P}\right)^2} \quad (6)$$

ΔCO_2 Error of the total CO_2 saving [$g\ CO_2/km$].

$\frac{\partial C_{CO_2}}{\partial P_{P_i}}$ Sensitivity of calculated CO_2 saving related to the measured during the test I
n Number of measurements.

In order to calculate the error in the CO_2 savings for a petrol-fuelled vehicle, the results of Formula (6) are to be applied in the Formula (2) in accordance with the following Formula (7):

(7) $$\Delta\overline{C_{CO_2}} = P_{SR} \cdot UF_{IR} \cdot \eta_{SS} \cdot SCC \cdot \frac{V_{Pe-P}}{\eta_A} \cdot \frac{CF_P}{M_P} \cdot \Delta\overline{P} \cdot cos\,\phi$$

In order to calculate the error in the CO_2 savings for a diesel-fuelled vehicle, the results of Formula (6) are to be applied in the Formula (3) which leads to Formula (8). This is the error in the CO_2 savings for a diesel-fuelled vehicle.

(8) $$\Delta\overline{C_{CO_2}} = P_{SR} \cdot UF_{IR} \cdot \eta_{SS} \cdot SCC \cdot \frac{V_{Pe-D}}{\eta_A} \cdot \frac{CF_D}{M_D} \cdot \Delta\overline{P} \cdot cos\,\phi$$

In order to demonstrate that the minimum threshold of 1 [$g\ CO_2\ /km$]. is exceeded in a statistically significant way the following Formula (9) is to be used:

(9) $$MT \le C_{CO_2} - \overline{\Delta C_{CO_2}}$$

where: MT: Minimum threshold [$g\ CO_2/km$], i.e. 1 [$g\ CO_2/km$].
CO_2: Total CO_2 saving [$g\ CO_2/km$];
$\overline{\Delta C_{CO_2}}$: Error of the total CO_2 saving [$g\ CO_2/km$].

Where the CO_2, emission savings, as a result of the calculation using Formula (9), are below the threshold specified in Article 9(1) of Implementing Regulation (EU) No 725/2011, the second subparagraph of Article 11(2) of that Regulation shall apply.[20]

Applications

Automotive is a large consumer of energy. The level of consumption is approximately 25% of global energy. The growing demand for energy threatens not only depletion of fossil fuels but will also result in an additional increase in environmental pollution. Solar cells can be used as a secondary source of energy. Therefore, Webasto Sunroof photovoltaic battery charging aid, the European Commission approved as an innovative technology within the meaning of Art. 12 of Regulation (EC) No 443/2009. Reduction in emissions due to the use of photovoltaic battery charging supporting sunroof, determined using the method explained in this publication. Individual eco-innovation to enter the code in the documentation of approval, which is to be used for the needs of innovative technologies approved under the European Commission Implementing Decision is "7". Strong interest in renewable energy sources makes the technologies used to generate energy from the renewable sources are becoming more common and continuously improved.

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