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Using of Green Energy from Sustainable Pavement Plates for Lighting Bikeways

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Abstract

In the frame of current paper authors show the significance of lighting of bike ways. Paper outlines a new approach application of green energy, using innovative technologies. This paper examines investigates how to solve the problem of additional lightening of bikeways, using innovative sustainable pavement plates for green energy production. The aim of this study is to offer innovative solution of sustainable pavement plates enable to produce green energy for additional lightening of the paved bikeways using considerable technologies. This paper sheds new light on the way of application and production of green energy. In this context authors of current research tried to offer innovative solution of sustainable pavement plates enable to produce green energy for lighting bikeways. Authors have performed this research also to initiate debates in scientific world and society about significance of such kind of solutions for sustainable green and clean cities.
KEY WORDS: *green energy, lighting, bikeways, energy conversion, safety, sustainable pavement plates, green transport, bicycle, infrastructure, solar energy.*

1. Introduction

Green energy is commonly discussed and it must become among the most widely used types of energy. This kind of energy widely considered to be the most important source of energy in nearest future, so it is very significant to find new ways and innovative technologies to produce and apply green energy - the energy of our future [4]4. Green energy is increasingly becoming a most discussible kind of energy not only between politics, society and market players, but also in scientific world. It generating considerable interest in terms of unlimited opportunities to research and develop innovative solutions for energy production [3].

The great report about green energy has been done by [5]. In 2015, following the results of the 21st Framework Convention on Climate Change, the Paris Agreement on Climate Change was adopted. It determines that specific measures to reduce climate change should be aimed at decreasing greenhouse gas emissions. Those, the world aspires to clean, green energy, and, consequently, to a better future. In many countries, the development of alternative energy is one of the important components of public policy. For example, as of 2011, more than 50 countries have enacted laws to stimulate electricity generation through green tariffs [6, 7]. It is clear, that green energy solutions become more topical every year. Applications and new ways of usage innovative technologies are also welcome to discuss from different points of view. Not only technologies, but also green way of life become more popular and are welcome across the world.

2. Bicycles – Green and Clean Transport

Bicycles – green and clean transport and its popularity increases from year to year. One of the limitation factors of the fast increasing of the popularity - not enough developed infrastructure.

Bikeway is a path or lane for the use of bicycles. It is significant part of the transport infrastructure in modern world. The trend line of popularization of cycling in the world last decades is huge.

As stated in [1], the Mayor of London set the task of increasing the number of bicycles by 400% in 2026 compared to 2001 levels, and Transport for London (TfL) recognizes that providing a world class infrastructure in London will require a serious study of world practice, to successfully apply the tested methods in the London context and, if necessary, to make innovations.

In «Mayor's Vision for Cycling» 2013, it described how the development of bicycle transport in London will be transformed. It is emphasized that the infrastructure will contribute to the creation of better, safer, more convenient and efficient facilities for cyclists. Let's see some quotes from the «Mayor's Vision for Cycling - 2013»:

"There will be more Dutch-style, fully-segregated lanes and junctions; more mandatory cycle lanes, semi-segregated from general traffic; and a network of direct back-street Quiet ways, with segregation and junction improvements over the hard parts."

"Where it is not possible to segregate without substantially interfering with buses, we will install semi-segregation: shared bus and bike lanes, better separated from the rest of the traffic with means such as French-style ridges, cats' eyes, rumble strips or traffic wands in the road."

Transport for London (TfL) is interested in study of others experience - how others worked to make their cities more attractive for cycling. They believes that study of an international best practice can help make the right choice when deciding on the future development of London's bicycle transport infrastructure. [1].

We have an interesting statistics for European countries and cities. For example, we met high 'walking' percentages in South European cities, for instance San Sebastian in Spain: ~3% bicycle against 'only' ~34% car, it is significant to say, that public transport plays an important role in San Sebastian ~19%, but mainly walking - a striking 44% of all trips.

Talking about London: ~1% bicycle, ~18% public transport, ~37% walking, and ~44% car.

If cities have high possibilities for walking, cycling and public transports - then often lowest car percentages are found in such kind of cities.

For example, a lot of cities in Switzerland: over 20% walking, over 10% bicycle and approx. 30% public transport – and as a result- a relatively low car use (~ 30% in Zürich, Bern and Basel).

Of course, average bicycle use is lower in most other European countries, but there are some interesting statistical examples could be found:

• In all the Great Britain use of bicycle is average 2% (in London even lower), but there are some interesting cases with higher percent of bicycle use (Oxford and Cambridge ~ 20%, but Hull and York ~11%,). A little bit more extreme differences could be found in Italy and Sweden:

In Italy average bicycle use is ~5%, (Rome shows less than 1%), but extremely different percentages are in cities of Ferrara ~ 30%, Florence - over 20% and Parma - over 15%.

• In Sweden bicycle use ~ 7%, for cities average percentage is ~ 10%. But Malmö and Lund shows 20%. Totally extreme percentage comes from Västerås with only 115,000 inhabitants - it shows an incredible percentage of 33% bicycle.

• Ireland shows 3% - 4%, Dublin 5%.

• Czech Republic, as other Eastern European countries, has a few cities with more or less popular bicycle use - Ceské Budejovice, Olomouc and Ostrava shows between 5% and 10%, but city Prostejov shows approximately ~20%. But if we talk about the entire region - average use is quite low- less than 5%.

• Switzerland shows ~ 11% for bicycle use in average, with some differences in cities: Winterthur ~20%, Basel ~17% and Bern ~15%.

• Austria ~ 9% in average, with Salzburg ~19% and Graz ~14%.

• France has an average ~5%, with Avignon ~10% and Strasbourg ~12%.

This statistics is really interesting - it shows how much bicycle use varies within Europe, by country and in particular by town. It is also possible to mention, that nowhere are the Dutch levels of bicycle use even approached. It is possible also to conclude, that Nordrhein-Westfalen and Denmark are coming closest. It is also significant to remark, that even in non-cycling countries there are some cities with respectable percentage of bicycle use, for instance in Sweden, Czech Republic, Italy and Great Britain. [2].

Bicycles – not only green and clean transport, but also healthy one. In many cities, there are significant problem with bicycles infrastructure. There are not enough paved bikeways, but if bikeways are paved, often lighting is not guaranteed enough for safe rides.

3. Green Energy from Sustainable Pavement Plates for Lighting Bikeways

Sustainable pavement plates, offered in current article, refer to alternative sources of electricity and to bikeway construction. It can be used for prefabricated pavement building and to transform the kinetic energy from the pressure of bikes on the bikeway and solar energy into electrical energy.

Sustainable pavement plates are integrated into a single system and assume autonomous operation of the bikeway irrespective of energy sources (see Fig. 1). This decentralized system is able to fully provide itself with energy, and give surpluses to other consumers [adopted from 3].

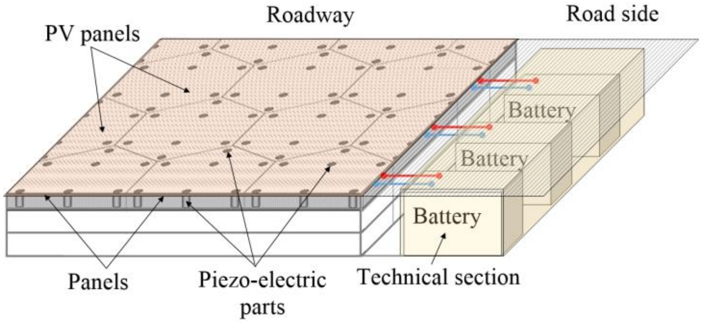

Fig. 1 Sustainable pavement plates [3]

Each panel of the sustainable pavement plates consists of 3 basic components. As it is described in [3], the first is the protective top cover. This element of the panel is made of high-strength transparent plexiglas, on the inside of which there is an electric heating element in the form of heating fibers (analog - car glass heating). At the base of the supports, on which the protective top cover is located, piezoelectric elements (piezo-generators) are installed. They generate electricity when pressed.

The second element of the panel is solar panels (PV panels) with built-in LEDs. In this element, the LEDs and PV panels are located on the entire plane of the panel. The third element of the panel is the base with electronic control boards and a cable channel. To the one accumulator batteries (Battery) from five hundred to a thousand such panels are connected. The battery is located in the technological compartment next to the sustainable pavement plates - on the bikeway side (see Fig. 1).

3.1. The Principle of Operation of the Sustainable Pavement Plates System

During the day, solar energy is converted into electrical energy through PV panels and accumulated in the battery. The energy comes also from piezo-electric parts when bicycles are driving above panels. In the dark, the accumulated energy from the battery is expended on the work of the pavement plates itself and on the LEDs that draw the pavement markings and highlight (if necessary) certain parts of the bikeway. Excess electrical energy is sent to other consumers of electricity (bikeways adjacent to the bikeway, houses, businesses, gas stations, etc.). If necessary, the sustainable pavement plates system is capable of dynamically lighting the road in front of the bicycle. This is determined by the software.

Piezo-electric parts are installed in the top cover supports, generating energy when pressed and signaling that the panel is under load. The value of the signal determines the weight of the load. That is, if necessary, the sustainable pavement plates system can track traffic on a certain bikeway segment, as well as its mass and speed of the object.

The functional of the sustainable pavement plates system is quite extensive and can include (depending on the needs and the corresponding software) the following functions: bikeway illumination both day and night (dynamic LED marking, informing signs, warning signs); heating panels in the cold season (melting snow, ice); drying of the panel due to heating (after rain); alarm system (warning about panel breakage); Determination of the load on the panel (bicycle weight); determining the speed of movement of the bicycle; charging of electric bicycle from PV panels (through special charging stations); generation of electricity; warning of the need to decrease the speed (works with Piezo-electric parts).

Also, here we should mention the analogues of the proposed sustainable pavement plates system. Among them, the SolaRoad bicycle track, consisting of PV panels (see Fig. 2) [9], and the clever road Solar Roadways (see Fig. 3) are the closest in nature and principle of operation [10].

Fig. 2 SolaRoad system [9]

In November 2014, 25 km from Amsterdam (see Fig. 2) TNO built 70 m of the SolaRoad cycle track. It consists of modules measuring 2.5 × 3.5 m. The solar panels themselves are protected by a layer of tempered glass 1 cm thick, which is capable of withstanding the weight of the truck. It was noted that for 6 months of operation this bike path generated 3000 kW·h. This is enough to provide electricity to one average household during the year.

As for the American clever road Solar Roadways (see Fig. 3) [10], in terms of its design features, it resembles the proposed sustainable pavement plates system. Each slab of the Solar Roadways system is rated for a nominal solar panel 230 W with an efficiency of 18.5%. According to calculations and experimental studies by American engineers, for a road length of 1 mile and a width of 12 feet, 15840 panels are needed. Within one year this section of the road will generate 302.506 MW·h. According to data of [10] in the US, one residential utility customer consumes 10,837 kW·h. That is to say, the 1 mile road Solar Roadways can provide approximately 30 private households with electricity for one year.

The above data show that in roads of this type there is a great potential and in the near future they can become an alternative source of electric energy.

But the considered roads have significant disadvantages, which are as follows:

- SolaRoad system - these are ordinary PV panels, which are protected by high-strength glass. This system is only able to generate electricity and does not have other functions;

• Solar Roadways system - designed for roads; each panel includes a lithium-ion battery; does not include piezoelectric elements (piezo-generators); cannot detect the weight of the vehicle, its direction and speed of movement; LEDs are designed only for the designation of road markings and warning labels.

a b c

Fig. 3 Solar Roadways system [10]: a - Artist's conception of an Solar Roadways panel; b - Actual Solar Roadways prototypes; c - upper layer of panel designed from high-strength glass.

Unlike analogues, the proposed sustainable pavement plates system is able not only to draw the necessary road markings and generate electricity, but also to illuminate the bike path in the dark. In more detail all the functional of sustainable pavement plates is described in the publications [3, 8].

Based on the presented calculations and experimental data of analogs, it is proposed to carry out calculations for the sustainable pavement plates. These panels will be integrated into a single system that forms a bicycle path.

3.2. Assessment of the Sustainable Pavement Plates System Electricity Generation

Filling one panel of the sustainable pavement plates PV panel is 75%. To generate 1 kW · h of energy at 100% coverage by the solar panel, it is necessary to 6.6 m^2 of sustainable pavement plates. Then 75% of the filling of the panel corresponds to the area:

$$6.6 \cdot 25/100 = 1.65 \ \text{m}^2. \quad (1)$$

Therefore, 1 kW · h of electrical energy can be generated by a bikeway section with an area of:

$$6.6 + 1.65 = 8.25 \ \text{m}^2. \quad (2)$$

Accordingly, to generate 100 kW · h of electricity, 825 m^2 of sustainable pavement plates is needed. The radius R of the hexagonal sustainable pavement plates is 0.46 m, and then its area is determined by:

$$S = \frac{3\sqrt{3} \cdot R^2}{2} = \frac{3\sqrt{3} \cdot 0.46^2}{2} = 0.55 \ \text{m}^2. \quad (3)$$

To generate 100 kWh of electrical energy from (3), let`s determine the number of sustainable pavement plates:

$$825/0.55 = 1500 \, . \quad (4)$$

The width of bilateral bicycle paths in European countries is 3 - 4 m. Therefore, we will carry out calculations for these boundary values. For greater clarity and convenience, both in the analysis of the results obtained and in comparing them, we will recalculate the generated energy of the sustainable pavement plates for the length of the 1-mile bicycle path.

Let`s define the length of the section of the chosen bikeway with sustainable pavement plates (width – 3 m and 4 m), which is able to generate 100 kW · h of electrical energy:

$$825/3 = 275 \ \text{m}; \quad (5)$$

$$825/4 = 206.25 \ \text{m}. \quad (6)$$

This means that a section of the bikeway of (3 × 275) m is capable of generating 100 kW of electricity in one hour of its operation. And the bikeway of (4 × 206.25) m is capable of generating 100 kW of electricity in one hour of its operation.

Similar to calculations and experimental studies for the Solar Roadways panel [10], we calculate the actual (taking into account the specific location of the panel) generated electricity. That is to say, let us calculate the angle of incidence of the sun's rays ~ 72°. This corresponds to the northern latitude of 48.19°. In fact, this northern latitude is the geographical center of Europe. Experimental data show that if the panel is in a horizontal plane, then its efficiency is 69% [10].

Then, taking into account the real conditions, we will determine the amount of generated electricity in the selected sections of the bicycle paths.

The section of the bicycle path of (3 × 275) m will generate 69 kW · h., as well as a section of (4 × 206.25) m and a length of 206.25 m.

Next, we will recalculate the generated electricity for a 1 mile bicycle path:

- 3 m wide:

$$69 \cdot 1609/275 = 403.7 \ \text{kW} \cdot \text{h}; \tag{7}$$

- 4 m wide:

$$69 \cdot 1609/206.25 = 538.3 \ \text{kW} \cdot \text{h}. \tag{8}$$

Let`s calculate the necessary number of plates, for a bicycle path 1 mile long:

- 3 m wide:

$$1500 \cdot 403.7/69 = 8776\,; \tag{9}$$

- 4 m wide:

$$1500 \cdot 538.3/69 = 11702\,. \tag{10}$$

One sustainable pavement plate includes 150 LED RGB, which consume 9.6 W · h of electricity. This will allow us to evaluate the work of sustainable pavement plates in conditions of maximum power consumption and draw conclusions about its capabilities. Each sustainable pavement plate has also a heating element of 25 W. Accordingly, in the winter months, a section of the bikeway, generating 69 kW of electricity, will consume in one hour of work in the dark, less amount of energy, then produce.

So, for own needs in the winter season, one sustainable pavement plate will spend 34.6 W · h. Then one section of the 1 mile long and 3m wide bicycle path, consisting of 8776 sustainable pavement plates, will consume:

$$34.6 \cdot 8776 = 303.65 \ \text{kW} \cdot \text{h}. \tag{11}$$

In turn, one section of the 1 mile long and 4m wide bicycle path, consisting of 11705 sustainable pavement plates, will consume:

$$34.6 \cdot 11702 = 404.89 \ \text{kW} \cdot \text{h}. \tag{12}$$

The above calculations show that for their own needs in the winter, the bicycle path will consume ~ 75% of the generated electricity. It should be noted that the power of the generated electricity from piezo-electric parts was not taken into account here. In the case of piezo-electric parts, the traffic intensity directly determines the amount of electricity that is capable of generating sustainable pavement plates. In view of such uncertain circumstances and assumptions, it is suggested not to consider the amount of generated electricity from piezo-electric parts. These elements are used as sensors, the indications of which can determine the weight of the bicycle, the direction and speed of its movement. And the generated energy from the piezo-electric parts will be directed to the operation of the electronic circuit boards of the panel.

The calculations carried out are indicative and show possible potential for sustainable pavement plates for bikeways. So, for example, the results of the calculations allow estimating the amount of generated electricity by any arbitrary segment of the bikeway.

4. The Significant Role of Energy Consumption Minimization and Efficient Lighting

The artificial lighting is one of major electrical energy consumers, which shares about fifth part of the global electricity market. At the regular rise of electricity price, the total cost of consumed energy by any electrical appliance during its lifetime is getting more noticeable in contrast to initial expenditures. From this perspective, the efficiency of whole street lighting infrastructure should be optimized from the point of view of energy consumption minimization. [11].

As the research results from [12] that saving 1 kWh of electrical energy, potentially could save the equivalent of 2 kWh of fossil fuel. It relates with the total system efficiency of energy delivery to end-user from mining site, which includes energy loses at middle stages, like use of energy during mining fossil fuels, energy conversion and transmission (mechanical and electrical) losses, as well as end-device efficiency. Consequently, locally generated energy (especially from renewable energy sources) is much preferable, because it excludes the major of mentioned losses. For this reason, enhancement of street lighting infrastructure is an important task, leading to minimization of global energy demand and reduction of municipal expenditures on illumination of public places and streets [11].

As it was described at [13], the main problem related with all „free" energy sources is its unpredictability and inconstancy that requires using of some energy storage elements providing constant output voltage. It is clear, that the design of power supply unit should meet the following claims: efficient harvesting; efficient conversion; minimized leakage currents in standby mode or in off state. In this case, solar energy harvesting system is proposed as the most suitable solution and autonomous data logger design describes several steps of system development. Specific ICs are used to implement an uninterruptable power supply which uses also Li-ion battery. Several features of program code design which uses microcontroller's internal peripheral modules and significantly affecting energy consumption are described.

5. Conclusions

The green way of life gains its popularity across the world. Green and clean technologies, as well green and clean transport will be used wider. Bicycle is clean transport, which become more popular each year, but need better infrastructure development at every city. Sustainable pavement plates - is green way - how to produce energy for lighting bikeways, making it safer. Green and clean energy must become among the most widely used types of energy.

The evaluation of the possible work of the sustainable pavement plates in real operating conditions was carried out. The results of the assessment show that for own needs in the winter time the bicycle path will spend ~ 75% of the generated electricity. Thus, one section of 1 mile long (3 m wide), bilateral bicycle track, can generate about 403.7 kW · h of electricity. At the same time, up to 303.65 kW · h will be used for own needs. So, it is possible to assume, that roads of this type has a great potential and in the near future they can become an alternative source of electric energy.

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