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Photovoltaic systems for road networks

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ABSTRACT

Decarbonization, energy supply security and sustainability has gained increased attentions globally. This has resulted in increasing integration of renewable energy sources. For instance, a significant penetration of renewable energy both in production and use can be observed in Europe, as its goal is to achieve carbon neutrality by 2050. This is also in line with other strategies proposed to reduce the use of virgin land to be taken and aims for a "no net land take" Europe 2050. The use of renewable energy sources such as solar energy requires significantly more land to generate electricity. This paper presents solutions where already utilised land area for road infrastructure can also be used for solar energy-based power production. Based on extensive review of literature on different concepts for solar cell systems linked to road transport infrastructure, an overall picture of the state-of-the-art and current challenges within this field has been created. Solar roads, PV integrated noise barriers along the motorway and solar roofs for roads are presented with their advantages and technical challenges. Solar PVs and road networks can be a perfect combination to contribute in mitigating the climate impact caused by road transport sector, increased lifespan of road networks and efficient use of land area.

Keywords: Renewable energy; climate; solar roads; solar noise barriers; solar roof.

1. INTRODUCTION

If the ambitious climate targets embraced by the Paris Agreement are to be achieved, a significant reduction in global CO2 emissions are needed. This will mean a substantial change of the existing energy system which will require a colossal investment on environmentally friendly energy technology and increased use of renewable sources. A good example along this line is, for example, the vision presented by European union [1]. Worldwide, the share of renewables in the energy supply system is increasing. For instance, it is estimated that by 2025 renewable energy will account for a third of the world's energy production, exceeding coal as the main source of energy [2]. Although hydropower accounts for around half of renewable energy generation, wind and sun show a sharp increase. Even with the aftermath of Covid-19, where electricity demand is expected to drop by 2% compared to 2019, electricity generation from renewable sources is expected to increase by almost 7% in 2020 compared to 2019 [2].

Solar energy is one of the most environmentally friendly sources of energy. The use of solar energy is not a novelty, but it is only recently that more attention has been paid to it, mainly due to the maturity of the necessary technologies which has enabled to capture the solar energy and convert it to electricity and heat. Photovoltaic (PV) systems are one of the ways in which energy can be obtained from solar radiation. The solar radiation on the earth's surface varies depending on the position on the earth's surface and the relative movement of the sun and earth. The availability of solar energy varies depending on the geographical location of site and is the highest in regions closest to the equator as depicted in Figure 1.

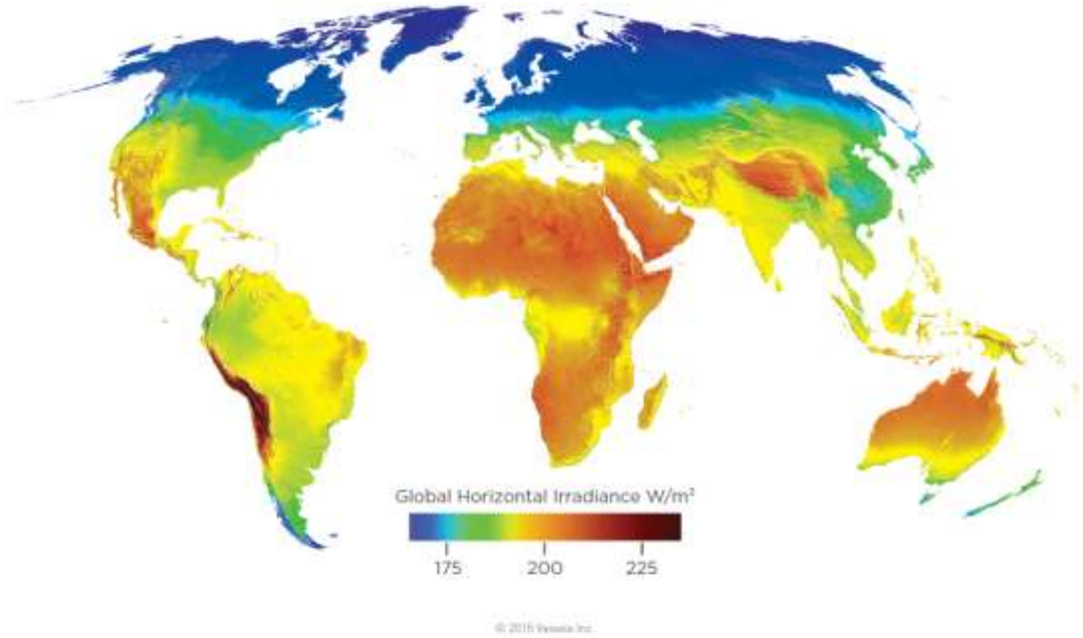

Figure 1. Global distribution of solar potential [3]

Owing to a continues cost reductions during the years, solar energy is now proved to be one of the renewable energy forms with the highest potential for growth. For instance, in Norway with predominantly hydropower in the power generation mix, the use of solar energy is continuously increasing, which is also seen in solar power capacity growth by 40 % as a result of new solar PV installation of 40 MW in 2020 [4]. On the other hand, the use of solar energy for large scale energy generation is area demanding. It is therefore of importance to utilise existing and future artificial area for multipurpose objectives such as power generation. This will help to reduce the use of additional land area. A recent study, where available rooftop area for PV systems are estimated by using spatial information of the EU building stock, shows that rooftop PV can produce up to 680 TWh electricity annually [5]. One innovative solution regarding the use of solar energy is offshore PVs known as floating PV that can utilise areas such as reservoirs and dams. In a system analysis conducted by authors in [6], floating PV in one of the Albanian hydropower dams is considered. Using artificial areas is also very attractive particularly in densely inhabited areas with space scarcity and where land needs to be used wisely and in an efficient way.

Road infrastructures play vital role for socio-economic advance of a society by connecting the different elements, for instance job opportunity, resources etc. On the other hand, these infrastructures cause various environmental impacts both during construction and usage. One way to reduce the climate impact of these infrastructures is to use the surface area efficiently, for instance, by enabling the networks to meet the traffic demand and at the same time produce power.

Artificial surfaces make up 4% of the land area in Europe. Artificial surfaces include buildings, roads and the like that cover the earth [7]. Of the artificial surfaces in Europe, 3% are categorised as transport, networks, infrastructures, and the like. Although there is no accurate data, it is estimated that there were 64.2 million km of roads in the world in 2018 [8]. The transport systems use considerable land space where road transport infrastructure used by vehicles occupies land in cities, towns and villages. The land area that roads occupy depends on length and width of the road and on the category of the road type. Based on European Union Road Federation (ERF), the total length of the road network in EU-27, members countries of European Free Trade Association (EFTA) and UK was 5,07 million km in 2017 [9]. Another source from 2018 shows that the network of motorways in EU-27, which form only a small part of the total road network, was 71 423 kilometres (excluding Greece). This represents some of the highest density of motorways in the world [10]. In addition, a vast road network and railway network is distributed through Europe. Although most of the land area in Europe is used for agricultural and forestry, the use of land for road networks has increased significantly over the past 30 years [11]. The European commission has proposed policies to reach a goal of "no net land take" by 2050 and calls for smarter use of land [12]. Some of the key reasons behind such policies is to protect biodiversity and reduce soil sealing which is recognised to be a main contributor to Urban Heat Island (UHI) effect [13].

The road surface is usually exposed to natural elements, and experiences negative effects from natural conditions, such as water, snow, wind and solar. Solar radiant energy ages and deteriorates the pavements causing cracks and shortening the lifespan [14]. While solar panels are area demanding, the European road network is large and expanding. Instead of trying to extend the lifespan of the pavement by improving the materials used for pavement, a change of perspective can provide new approaches to solving these problems. Finding a common solution can potentially benefit the lifespan of roads, while helping the European union in the transition to sustainable energy system.

Europe has one of the worlds densest network of roads that occupies a vast area of land [10, 11]. Scarcity in available land area for investing in land area-intensive renewable energy systems like photovoltaic systems, requires stakeholders to look after for a new approach to address the issues associated to land area use.

The objective of this study is to present, examine and evaluate some of the options of implementing PV on existing road networks. The options considered in this paper are the implementation of PV systems alongside roads, in the form of noise barriers, on roads, in the form of pavements, and above roads, in the form of tunnels and roofs. The possibilities of using the same land area for transport and to generate power with photovoltaics is investigated. Different solutions for the same problem have already been tested, some of which are only in an early project stage. This work aims to highlight the possibilities to use land areas in more thoughtful ways, that sometimes include more innovative ways of thinking. One important factor when producing environmentally friendly energy is to see where it shall be implemented and what the consequences are. It also requires land area to function and produce energy. With an ever-increasing population, the world sees more pressure on the earth's resources, and an increased demand for energy. Sustainable energy sources must be designed in a way that their competition for land with other important uses such as food production is eliminated. The idea of engineering a combined solution that solves multiple challenges is becoming more popular in a time where big shifts in energy production and living quality are present. The aim is to provide an overview of the state of development in this area while critically examining the issues of economics and sustainability.

When examining and assessing the various alternatives, special attention will be paid to ensuring that the main purpose of roads is still met. The safety of road transport must not be compromised. Furthermore, complexity of installation, repair/maintenance and costs are discussed in this paper. The study focuses on Europe as an area of implementation. Reference is therefore made mainly to European Standards, especially when assessing the different approaches, theories and implementations.

2. METHOD

This research follows a qualitative approach and is based merely on literature. Searches on database engines like Oria and Science direct are carried out to find relevant literature. Journals, official documents, and publications from governmental agencies (like EU), as well as press releases from stakeholders are the main sources for qualitative data. The main keywords used to find literature relevant to the research topic are photovoltaic, noise barriers, road infrastructure, road networks and solar roads. These keywords are searched for in various combinations and with additional other keywords. In addition, the reference lists of the literature found using the keywords are searched for further relevant literature.

This topic has grown in popularity and system improvements are often made in this area. Therefore, particular attention is paid to recently published work. In particular, literature searches in recently published work by other researchers can provide valuable information on pioneering research studies and innovative ideas [15].

Although the study focuses on Europe as a geographic area, the literature on which the study is based is not limited to these boundaries. When examining and comparing implementations of photovoltaic systems for road networks, European cases are chosen. To get a holistic view of the topic, other studies outside EU needs to be considered provided they are relevant to the objective of the study. However, the discussion should take into consideration that projects may not be fully transferable to Europe.

3. REVIEW

In the following, the information obtained from the literature search is presented. The Literature review is structured according to the different fields of applications of PV systems for road networks. This is presented in sections: PV on roads, PV next to roads and PV above roads.

3.1 PV on the road

Solar cells on roads have aroused great interest in recent decades and many projects have been completed. The idea is to change the pavement to specially designed photovoltaic modules that can withstand the high compression forces of passing vehicles. How they are structured depends on each project, but in general each solar module consists of a protective layer (light transmissive as tempered glass), a PV layer to generate power and a base that acts as a connection to the ground and the PV layer [14]. Because of its structure the power generation efficiency of the such type of PVs is lower than the conventional ones. For instance, the world’s first solar bicycle lane in the Netherlands has an overall annual efficiency of 8.6%, that is much lower than other commercially available solar panels used in solar plants [16]. When solar panels are placed in real-life conditions, many factors can play a role in the conversion efficiency of solar energy. When used in solar pavement applications, the panels are fixed horizontally to the ground, creating a less optimal angle for capturing solar radiation energy and reducing the power generated. Solar roads, like conventional roads, are exposed to snow, dust, dirt, leaves, and other particles or elements that can cover or shade the road surface. In addition to the examples given, vehicles obstruct the sun's waves to reach the PV cells, resulting in little to no electricity being generated. Reduced power generation is also a result of the high operating temperatures that require heat extraction to cool the solar cells [17, 18].

Solar panels on roads can reduce the UHI (Urban Heat Island) effect compared to paved roads by converting some of the radiant energy into electricity. Although it has a positive impact on the environment, the efficiency of power generation is discussed. Xiang et al. claim that the energy consumption efficiency for solar roads is too low, and to improve this they proposed a solar cell thermal road [19].

3.1.1 Photovoltaic cells and thermal energy capturing

While some of the sun's radiant energy is converted into electricity, the PV units will still experience a heat surge when exposed to sunlight. By combining photovoltaic roads with solar thermal collector options, part of the thermal energy can be recovered and reused. The efficiency can actually be up to 3.95 times higher when thermal and photovoltaic technologies are combined, compared to just a photovoltaic road solution according to the study in [19]. While this seems to improve the capturing capabilities of photovoltaic by controlling operating temperatures and reducing some of the UHI effect by diverting some of the heat to a specific purpose. However, the complications involved in implementing solar cells in real-world environments do not take into account its ability to withstand real-world usage and weather conditions. The collection of thermal energy can be done through an Asphalt Solar Collector (ASC), which transports the heat by installing pipes on the street and using liquid or air. The heat can be removed to reduce the UHI effect in summer [20]. Thermoelectric Generator (TEG) uses the temperature difference within the road structure to generate electricity. Since temperature gradients in roads are small, the power generation of TEG is low [14]. Both concepts can be used to reduce the UHI effect and improve the operating temperature of solar cells, but further research on durability, efficiency optimization, maintenance and cost should be done.

Although, multiple projects have been implemented, little information is provided on efficiency performance, economics, maintenance, service life and potential risks associated to the projects [14].

3.1.2 Road safety

Roads are subject to stringent requirements for the skid resistance of pavemnets, and studies on roads show that mechanical wear resistance is important to maintain a high level of safety [21].PV devices must be protected from the environment as the technology can be described as fragile in itself. There are several ways to design a system around a solar panel. When used in solar road applications, the panels are covered in transparent tempered glass designed to withstand the forces exerted by passing cars. The use of materials such as glass is necessary to give solar radiation free access to solar panels. While this creates a solution for a free road for solar radiation, it creates challenges for a sufficient skid resistance for road safety. This can be solved by creating a non-slip coating on the tempered glass. In some cases, this coating has become delaminated due to long exposure to the sun and temperature differences [22].

The solar panels will still experience a rise in temperature when exposed to sunlight if they are not supplemented with heat energy solutions. This can cause reduced efficiency and ultimately damage the components [23].

Tempered glass has high compressive strength and in a laboratory test a PV floor unit can withstand a maximum load of 15-16 MPa, far greater force than a passenger car in normal condition [22]. Nevertheless, some solar projects have experienced damage to the solar modules due to high external power from passing vehicles in combination with other environmental factor [24].

3.1.3 Maintenance, cost and durability

The costs for solar roads are significantly more expensive than for conventional roads. There is also the challenge of replacing damaged modules due to their high weight [22].

There is on the other hand significant advantage of solar roads in terms of avoiding traditional road repairs like fixing potholes which in this case can be completely eliminated with solar roads [25]. Furthermore, this will not only save cost for road maintenance but reduce the inconvenience of repairs for drivers and wear or damage to vehicles.

Solar roads must be kept clean to ensure proper power production due to sun blocking effects of particles and settlements [18]. In some cases, the existing road cleaning schedule can potentially be maintained, and it may increase in some locations. Although in some cases there is a need for more cleaning, they are considered easier to clean than pavement roads [26].

When it comes to cost of solar roads, there are some indicative figures from pilot projects such as the ones in Normandy, France and Jinan, China [14]. The 1-kilometre solar road “Wattway” was installed in the Normandy, France in 2016, and is considered to be the world’s first solar road. The total area of the solar panels is around 2800 m^2 and its cost was 5,000,000 Euros [14]. In 2017 the first solar highway was to be built in Jinan, China with a length of 1080 m. Its cost was approximately 5,300,000 Euros [14]. From a cost perspective, these pilot solar road projects are expensive and not able to compete with traditional roads when comparing only the investment cost.

3.2 PV next to roads

In 2019 the Fraunhofer Institute for Solar Energy Systems published a press release on solar building components. This press release mentions numerous functions of building-integrated PV solar modules, one of which is the function of a noise barrier [27]. Noise barriers are parts of road construction that shield places near roads and are required by law in many areas. The first photovoltaic noise barrier (PVNB) was built in Switzerland in 1989 [28]. [28] present in a contribution on the state of the art of noise barriers numerous examples of documented PVNB systems in Europe, most of them in

Switzerland and Germany. The authors state that the use of existing noise barriers as substructures for photovoltaic modules, or the integration of photovoltaic modules into new noise barriers, has many advantages. Dual use of land resources is important, which is beneficial especially in densely populated areas. In addition, the integration of solar cells in or on sound barriers facilitates access to construction and maintenance, as transport routes are already there and so are vehicles for general road maintenance [28].

3.2.1 Examples of implementations

In Germany alone, there is an area of about 10 million m^2 of noise protection wall. And the Federal Ministry of Transport, Building and Urban Development (BMVBS), which is responsible for the construction of motorways, has set itself the objective of promoting the use of photovoltaics, particularly for noise reduction in motorway construction [29]. A report in the magazine “Die Bautechnik” [29] describes the project "Photovoltaik plus Lärmschutz A 10". The aim of the project is to equip the 8-lane expansion of the A 10 on the Berliner Ring with solar noise protection walls. The route has an east-west orientation, for which an optimum angle of inclination of 70 degrees has been determined, considering the electricity yield and noise protection effect. Since the inclination slightly reduces the sound insulation effect, the total height has been increased to 10m throughout [29]. On the south side of the walls, the PV modules with a total of 35.000 m^2 start at a height of 4 m, as below this height the efficiency of the modules decreases due to the shading. In principle, even with standard glass walls, the lower 2 m of the walls are always made of concrete for technical reasons. The PV modules must be connected in an airtight and soundproof manner to ensure an insulating effect. It is also stated in the report [29] that possible impairments of the functionality in the traffic area are glare of the drivers, electric shock or fire of the modules. However, these aspects have been excluded for this project. A similar project was realized in 2009 on the A 22 Brenner motorway in the Italian municipality of Isera. Here, 3,944 photovoltaic modules were installed on a noise barrier which is 1,067 meters long and up to 5.6 meters high. The annual average electricity output generated by this solar noise barrier installation amounts to approximately 750,000 kWh. The barrier has proven to reduce the noise from traffic by up to 10 decibels (dB) [30]. In Neuötting, Germany, a new noise barrier was needed due to a new development area. The noise level in the newly built area exceeded the permitted level by up to 8 dB. The design of the noise barrier facilitates quick assembly and onsite installation. This modular and standardised construction has the benefit that elements can be used in other projects in the future. A prefabricated system with integrated photovoltaics is unique in this size range [31]. The system has a nominal output of 65 kW. The noise barrier is inclined by 5 degrees to the north. Compared to a vertical orientation, this should increase the annual output of the PV system by around 5% [32].

3.2.2 Construction, maintenance and safety

A study conducted by [33] examined how PVNB should be shaped in order to optimise the acoustic and energy properties. The authors tested scenarios for 5 different shapes of noise barriers: A straight wall with a top element at a 60° angle, a T-shaped barrier, a completely straight wall and two semi-circular ones. They found that the T-shaped barrier and the one with the 60° diffractor performed best in terms of acoustics. When it comes to the electricity yield the barrier with the 60° diffractor attained the best results.

The authors also note that the latter is valid for all road orientations except north-south orientation [33]. Furthermore, the authors [34] state that electrical and acoustic functionality are not the only quality features of PVNB. In their view, safety, easy maintenance, and visual impact are also important. Another important aspect here is that it must be ensured that contact with the PVNB during operation, installation and maintenance, or after accidents is not dangerous. One safety risk is panel damage caused by the impact of cars, trucks, parts, or stones on the barrier. This situation put special demands on the PVNB structure in general and the glass or plexiglass plates of the PV modules. Solutions must also be found to manage the risk of fire from internal faults or external causes. Furthermore, the geometry of the barrier needs to be designed to prevent light being reflected from the structures towards the road surface. This is important to prevent drivers from being dazzled [34]. But the barrier geometry is also important to achieve the desired acoustic function. According to [28] the glass surface of a PV module can only be used for sound reflection. To achieve sound absorption, a cassette or zigzag construction must be applied. With regard to the construction of the installations, the authors also point out that the performance of the modules can be affected by vehicle pollution if the modules are mounted too low or too close to the road surface. The authors in [34] also address this issue and state that cleaning of the PV modules is a costly procedure, even if it is carried out by semi-automatic machines.

3.2.3 Costs

The fear of additional costs, a higher effort in construction and maintenance with the electrical system are often obstacles for PVNB projects in Germany [32]. The construction of a PVNB such as the one in Neuötting is only 15 % more expensive than a conventional noise barrier without photovoltaics. However, this does not include the investment costs for the photovoltaic system [31]. A case study from Belgium [35] investigated the profitability of PVNB in the hypothetical case of an implementation along the highway E313 near Tuilt in Belgium. The authors included CO_2 reduction benefits as well as Belgian governmental subsidies called green current certificates (GCC) in their cost-benefit analysis (CBA). The result of the CBA states that the profitability of the PVNB in the case study is highly dependent on the GCCs. The authors state that government subsidies are of high importance [35]. Based on the results from this study, the probability that such investment will be profitable varies between 54 to 98 % considering that the subsidies vary. The authors conclude, that PVNBs have the potential to be beneficial for government, private investors, and residents. They also proposed flexible government policies on investment conditions for PV noise barriers as one possible way to promote PVNBs.

3.3 PV above the road

Another way of application of PV in combination with roads, is to elevate the solar panels above the roads surface and passing vehicles. Two main concepts are presented in the following: solar road tunnels and solar roof for roads.

3.3.1 PV on road tunnels

Tunnels are used in road networks that encounter obstacles such as mountainous terrain or where the road must be protected from natural phenomena such as avalanches. These infrastructures are usually located inside or next to elevated landscapes, where they partly extend into their surroundings Another purpose of tunnels is to protect the environment from roads and railways. A railway tunnel in Antwerp, Belgium, was constructed to protect wildlife, people, and trees and reduce noise pollution from high speed trains [36]. 16,000 solar panels were installed on the top tunnels roof, providing the railway infrastructure with an estimated annual electricity of 3.3 MWh [37]. Higher efficiency solar panels can be used compared to solar roads as there are no restriction in solar design and road regulative standards to follow. Another advantage is that the panels can be mounted at a more optimal angle to the sun due to the flexibility of roof mounting.

The Solar tunnel was not originally designed with the installation of solar cells in mind but designed with the intention to solve other challenges such as protection and noise reduction. From the renewable energy perspective, it may be difficult to transfer this project to other similar applications. However, this project can definitely serve as an inspiration by showing how several challenges can be solved with one solution. The problem of wear and tear is also addressed in this solution. Factors such as rain and sunlight will not be able to degrade the pavement surface as it is protected under the tunnel roof. Therefore, a prolonged lifespan of the road can be expected in this case.

3.3.2 Solar roof for roads

Although there are so many cars registered in Europe that statistically one car is available for every other inhabitant [38], it is common for sites that do not require tunnels to be built as a noise reduction measure [39]. Therefore, interest is shown in a roof over roads with the main purpose of generating electricity. In general, roofs over streets are not a new idea, but with the idea of photovoltaic cells on the roof, a real benefit is more concrete than ever. This thought is driven by many of the same benefits behind a more traditional concept of solar roads. Multipurpose use of existing captured areas and reduction of the UHI effect are some of the main similarities. While the solar cells are positioned on the roof, traditional and less expensive pavement compared to solar road modules can be used when constructing the road. A roof will furthermore protect the pavement against, rain, snow, and solar radiation that would have reduced its durability and lifespan. The UHI effect will also be reduced when the pavement is protected from direct sunlight. Unlike solar tunnels that have been implemented, solar roofs only exist in an early design phase. Roof-like structures for solar application can be seen for example in parking lot applications, or at petrol stations for cars, but they are not implemented for large scale road applications. An ongoing project between research organisations in Germany and Austria investigates many of the aspects surrounding such a system in a large scale. The aim is to construct a functional PV system that will be tested on roads [40].

Such construction requires solid columns along the road to carry the weight of the PV system, be able to withstand the natural conditions such as wind and snow and withstand collisions. While this is feasible in terms of construction, it constitutes a set of considerations that need to be addressed. Cost, traffic safety, maintenance, visibility is the subject of further research in this project.

Shaded solar cells act as an obstacle in the circuit of solar cells. This barrier may result in overheating of the cells and can cause the damage of cells. To avoid this countermeasures are taken by either using bypass diodes or blocking diodes [41]. Due to the design of solar roofs, the electricity generation is not affected by shades created by cars, or debris on the road. Still, there are chances of partly covering of leaves and dust but is seen as lower due to its elevation compared to the surroundings. Unmanned solar cell cleaners can potentially clean the solar cells regularly to attain a high level of efficiency. When considered from the design phase, this cleaning process can occur automatically and without disturbing traffic below.

4. DISCUSSION AND CONCLUSIONS

The EU strives to become carbon neutral by 2050 as a key contributor to halting climate change. In addition, guidelines for "no net market" have been proposed, resulting in a land area requiring renewable energy, such as solar PVs, to find new implementation areas. Europe's extensive road network is considered by some to be a potential multifunctional area where electricity can be produced with solar PV systems. In this paper, several concepts such as implementing solar cells on the road surface, next to the road, as a roof above roads have been presented. Each concept shows potential benefits in theory and pilot projects, although more research is needed to fully understand its feasibility.

The proposed solar cell systems for roads are, from an investment perspective, significantly more expensive than traditional pavements, tunnels or noise barriers. However, a cost / benefit analysis for the entire life cycle is difficult to carry out due to uncertainty and lack of scientific data. It is shown that both solar panels on and above roads can reduce the urban heat island effect and reduce the surrounding temperature. Unlike solar roads, solar tunnels do not change the road surface. In this case, an ordinary, cheap road surface can be used. The frequency of replacing and repairing of the road surface will decrease, which is especially true for heavily trafficked motorways with high wear, as the road surface is better protected from the environment. Of all the options discussed in this article, photovoltaic noise barrier is probably the least intrusive in existing road networks, especially if the panels are installed on existing walls. However, when installed on existing walls, the possibilities of adjusting them to achieve high efficiency are very limited. Inefficient solar power plants are uneconomical and consequently the possibility of refinancing the construction of PVNB through electricity production is eliminated. New PVNB structures, just like new PV tunnels and roofs, can be designed to achieve maximum possible effect. This is more expensive, but the investment can be much more profitable in the long run than converting existing structures.

Adding more complexity to roads by embedding photovoltaic systems can create new challenges, but given the stricter rules on land use, carbon neutral targets for the EU and the constant reduction in the cost of photovoltaic technology, the interest in finding solutions and engaging in new projects. can be expected to rise.

At present, Europe is continuing to use its land in a way that harms the biodiversity and is not on track regarding the goal of achieving no net land take by 2050 [7]. This implies a need for an urgent need for measures where environmental goals must be prioritized in new projects. An attempt to achieve these goals should not lead to the implementation of uneconomical installations of renewable energy production facilities, but instead pave the way and allow new thinking and innovation along this line. PV in the road network is still linked with a lot of uncertainty, and as previously mentioned, the authorities often fear invisible costs, but these barriers can be removed if more investments are made in research and further projects. The above-mentioned research project from the Austrian Institute of Technology [40] is currently a good example and gives hope that change is imminent.

In conclusion, this work shows that solar panels in road networks have great potential to be advantageous on many levels and from several perspectives. Although more research and targeted policy measures are needed, the presented and other similar projects indicate potential benefits in terms of energy, climate and sustainability.

CONFLICT OF INTEREST

The authors confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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