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Power and Energy Potential of Mass-Scale Photovoltaic Noise Barrier Deployment: A Case Study for the U.S.

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Abstract

Solar photovoltaic (PV) systems have the greatest potential to meet the scale of sustainable energy demands, yet large surface areas beyond rooftop areas are required. One source of additional surface area that avoids conflict with food production while scaling with population density is noise barriers, which provide dual use of land area both as noise abatement and energy generation. This paper provides a method to quantify the potential of mass scale deployment of photovoltaic noise barrier (PVNB) systems in a country. Based on a feasibility analysis of the irradiation levels and noise barrier locations, the PV power potential and the energy output for the photovoltaic modules is calculated for specific locations using a tool chain of free software. This method, is then demonstrated with a case study for the state of California and the results are then extrapolated for the entire U.S. The U.S. is an ideal candidate country because noise abatement mandates fall well short of World Health Organizations guidelines and PVNB technology has not been implemented on a wide scale. Using conservative assumptions, the results show that the total PVNB power potential for the U.S. ranges from 7 to 9 GW using only existing noise barriers. According to findings of the paper the installed capacity of the large scale photovoltaic system deployed on noise barriers in a single state is comparable to the installed capacities of the largest solar farms in the U.S. and yet due to the unique mounting of PVNB, such systems provide better land utilization ratios for energy production than conventional solar PV farms.

Keywords: solar energy; photovoltaic; noise barriers; distributed generation; PVNB; photovoltaic noise barriers

1. Introduction

Worldwide the demand for energy is increasing and is expected to increase by 70% by the year 2040 [1]. The sun provides the most abundant source of energy available and capturing this energy with solar photovoltaic (PV) technology is a well-established path to a sustainable state [2]. However, PV power demands large surface areas. According to a study by the National Renewable Energy Laboratory [3] approximately 181m² of land area is required for PV per person to meet energy demands in the United States. In case of an urban areas land availability is a constraining issue [4,5]. Using large tracts of land for solar PV farms will increase competition for land in total [1] and for food production [6,7]. Demand for food and energy are both growing and vie for the limited land resources [6-8]. Significant effort has been focused on estimating the quantity of PV that can be deployed on rooftops of government, commercial and residential buildings in cities [9-17]. In some high population density cities there is not enough rooftop area available to meet all of electrical needs with PV so other surface areas are needed. One source of additional surface area that scales with city population is noise barriers, which can serve as an alternative potential partial solution as they provide dual use of land area both as noise abatement and energy generation.

Photovoltaic noise barrier (PVNB) systems are not a new technology, although there is a growing interest in the noise control engineering community [18]. There is no fundamental difference between PVNB and traditional PV systems. The small differences between PVNB and conventional PV is simply the mounting structure and limitations on optimal orientation due to a given noise barrier. There are several proven experimental methods to combine PV with noise barriers as shown in Figure 1. As can be seen in Figure 1, PV modules can be mounted on the top of the barrier (a), as shingles down the side of the barrier in addition to the top (b), covering the entire vertical surface (c) or as a bifacial surface (d), in a horizontal zigzag configuration (e) or similarly as cassettes (f). The first PVNB system was installed in Switzerland in 1989 [19]. After the success of that project many PVNB types of systems have been installed in Germany and Switzerland [19-23]. The majority of the PVNB systems have been installed in Europe, although the systems are also gaining popularity in Canada, China and Australia in addition to Europe [24-27].

Initially the majority of PVNB systems were retrofit designs where the PV modules were mounted on an existing noise barrier. The main retrofitting solution included the top (flush) mounting and shingles design, which offers a good sound absorption, but the PV yield is reduced from self-shading of the modules and soiling [20,27]. However, in the retrofitting solutions the PV modules do not offer substantial additional noise abatement than the noise protection solutions already in place. With improvement in the designs, integrated design solutions such as cassettes, bi-facial and zig zag arrays were developed (See Figure 1) [23,24]. These solutions provided better sound absorption and were highly integrated solutions although they entailed additional costs for the barrier design. The PV modules used in PVNB can be identical to those used for ground mounted or roof-top mounted systems and are thus functionality equivalent.

When PVNB are compared to conventional solar farms they may not be optimally oriented (azimuth or tilt angle) and both of these variables impact energy yield per year. In the case of cassette and zig zag designs, the PV module output is more due to favorable tilt angles that can be optimized for a given location. Advancements have also been made to replace the glass substrates of modules with ceramic substrates, which are comparatively heavy, but offer higher noise absorption without affecting the module output [38]. For retrofits, however, vertical flush mounts represent the least capital investment for existing noise barriers.

PVNB technology has not gained wide spread application in the U.S., although it may have considerable deployment potential because there are 41,942,457 miles of U.S. roads [29]. This paper provides a method to quantify the potential of mass scale deployment of the PVNB system in a country such as the U.S. Based on a feasibility analysis of the irradiation levels and noise barrier locations, the PV power potential and the energy output for the photovoltaic modules

was calculated for specific locations using a tool chain of free software. This method, is then demonstrated on a case study for the state of California and the results are then extrapolated for the entire U.S. The results are presented and discussed in the context of using this method to determine the potential for wide-scale PVNB deployment in any country.

2. Methods

2.1 Estimating PVNB Potential for a Country

Past studies limited analysis to noise barriers 500m or greater because of the historic economic feasibility [21]. However, the costs of PV modules has declined rapidly [30-35] enabling all sized noise barriers to be considered. An algorithm is defined that enables the potential of mass deployment of PVNB systems to be calculated in any country (summarized in Figure 2). First, the data of existing noise barriers locations and dimensions, which can be used to mount the PV modules, needs to be determined. The noise barrier locations are then marked on Google Earth (v 7.1.5.1557) [36] and are then converted into a shapefile by using the DNR Garmin software (v.5.4.1) [37] To estimate the PV yield, free and open source QGIS (v 2.14) [38] is used to calculate the global horizontal irradiation value at each of the locations and also to superimpose the noise barrier locations, roadmap and GHI data. As the noise barriers along the roads are oriented differently with respect to the azimuth angle and the PV energy output for each orientation will be different. To simplify the estimation, the noise barrier locations are categorized into N-S, E-W, NE-SW and NW-SE orientations by manually marking the location and finding the orientation using Street View option in Google Earth.

Performing the methodology described in Figure 2 for an entire country may be time and cost prohibitive for large countries. To expedite the calculations a subset area can be chosen and then extrapolated to the entire country. To demonstrate how to do this, here a case study area is taken of California, to calculate the potential for the entire U.S. A generic description of the calculations used is presented below.

In order to simplify the calculations the term coverage factor, C [percent], which is the ratio of the PV module area to the area of a typical precast noise barrier block is defined,

$$C = \frac{A_M}{A_{NB}} \quad (1)$$

Where, A_M is the area of the modules in m^2 and A_{NB} is the area of the noise barrier. It is assumed that the PV modules run the entire length of the noise barrier and are mounted flush to the side of the noise barrier. To be conservative it is assumed that PV is mounted from the top of the noise barrier leaving a small area at the bottom to avoid near object shading and damage during right of way maintenance (e.g. grass cutting). S is the power output per unit area of the PV module, which can be determined from the spec sheet of the module:

$$S = \frac{P}{A_m} \frac{[kW]}{[m^2]} \quad (2)$$

Now by using the categorized noise barrier data and the above defined constant term, the net area of PV modules in each orientation out of the total noise barrier area can be found as

$$A_{PV-k}(m^2) = \sum_{n=1}^T (A_{NB-k}) \times C \quad [m^2] \quad (3)$$

Where, A_{PV} is the net area of PV modules mounted on different orientations of roads k (N-S, E-W, NE-SW, NW-SE), which are summed from $n=1$ noise barrier to the total number of noise barriers, T . The above area is then used to estimate the power potential of the PV modules mounted on it

$$P_{PV-NS}(kW) = A_{PV-NS} \times S \quad (4)$$

$$P_{PV-EW}(kW) = A_{PV-EW} \times S \quad (5)$$

$$P_{PV-NW-SE}(kW) = A_{PV-NW-SE} \times S \quad (6)$$

$$P_{PV-NE-SW}(kW) = A_{PV-NE-SW} \times S \quad (7)$$

Where, P_{PV-k} is the power potential for array's mounted on different road orientations, k .

Using the above PV power potential as an input for the desired array size and corresponding azimuth angle for each road orientation (N-S, E-W, and NW/SE), the annual energy output for the PVNB system can be found out using SAM (v 6.3) [39].

The energy potential for other parts of the country can be found by multiplying the ratio of energy potential of a particular state to total road length in that state with the total highway length in other states [40]:

$$E_{PV} = \frac{E_C}{L_C} \times L_T \quad [GWh] \quad (8)$$

Where, E_{PV} is the PVNB energy potential in GWh for all regions states, E_C is the PVNB energy potential for a state, L_C is the length of roads in the same state, and L_T is the total length of roads in the other regions/states of study. Similarly the power potential, P_T , can be found using the power potential for a state, P_C , for other regions by:

$$P_T = \frac{P_C}{L_C} \times L_T \quad [\text{GW}] \quad (9)$$

2.2 Case Study: Estimating PVNB potential for the USA

2.2.1 Sub-Region California

The PV energy potential for PV modules deployed on noise barrier was carried out for the state of California because it has the highest number of noise barriers of any state in U.S. both in terms of number and miles [41]. The noise barrier locations along with its dimensions was obtained from the Federal Highway Administration website [41]. These locations were accurately marked and categorized into N-S, E-W, NE-SW and NW-SE orientation by using street view option in Google Earth and extracted and converted into a shapefile by using the open source DNR Garmin software. The noise barrier locations shapefile was then superimposed on the highway network shapefile [42] and the National Renewable Energy Lab 10km raster annual global horizontal index metadata file [43] with QGIS. The resulting map as shown in Figure 3 shows the potential PV yield for each noise barrier location.

For most of the analyzed locations noise barriers are located on both sides of the road. The photovoltaic modules are only considered to be mounted facing the road and on the side of the road which is more favorable in terms of capturing the solar incident irradiation. Thus, since all noise barrier locations are in the northern hemisphere, the PV are considered to be mounted on that face of the noise barrier which is facing the closest to south and towards the road. Thus only half of the length of the noise barriers at each location is considered to calculate the PV energy potential. This assumption leads to underestimates on the total PVNB for each location the total length of the noise barriers assumed to be equally distributed on either side of the road.

In this case study, it is assumed that in order to minimize racking costs that the modules are mounted vertically directly on the top 80% of the existing noise barriers as shown in Figure 4. This particular type of configuration helps to minimize the soiling losses, which can be anticipated to be greater than in a conventional solar farm when PV are located directly next to a roadway. Thin film PV technology was selected for the case study simulations because they possess superior temperature coefficients compared to the more widespread crystalline and polycrystalline silicon-based PV modules and mounting on a noise barrier reduces convective cooling [44]. This is because in noise barrier PV applications the back of the module ventilation is hindered, which leads to module temperatures reaching temperatures significantly beyond the standard temperature conditions (STC) and above normal PV operating temperatures. Previous work has shown in noise barrier applications the thin film technology is more applicable than crystalline silicon modules [26,45]. First Solar FS-4100 modules [46], with an area of 0.72 m² and a peak power output of 100Wdc, were used for the simulation in SAM.

The energy output study is carried out for five typical locations: Los Angeles, San Jose, San Diego, Fresno, Sacramento and Twenty-Nine Palms. These locations were chosen because the majority of the State's noise barriers are located in these regions or they have similar weather conditions. One of the major factors that reduces PV output in PVNB applications is soiling due to vehicular traffic on the roads. The soiling loss values are determined based on a study to estimate the soiling losses for photovoltaic systems within the state of California [47]. The soiling values summarized in Table 1 were used in the System Advisory Model for each of the selected metropolitan area.

Table.1 Annual Soiling loss in selected metropolitan cities of California

	Twenty-Nine Palms	San Jose	Sacramento	Los Angeles	Fresno	San Diego
Annual Soiling Loss (%)	4.2%	6%	6.2%	5.75%	4.75%	4.2%

The energy potential of the PVNB system for the other parts of USA is extrapolated using other states (Colorado, Georgia, Maryland, Minnesota, New Jersey, New York, Ohio and Michigan), which account for about 85% of the installed noise barriers [41].

Finally as a rough guide for estimating the loss in energy output as a function of tilt angle away from optimum and the azimuth angle away from optimum, and to quantify the trade off in the energy output, a sensitivity simulation was run using the First solar FS-4100 thin film PV module and irradiation data for Los Angeles for a 1kW system.

4. Results

4.1 Case Study: California

Based on the Federal Highway Administration statistical data, around 200 noise barrier locations were identified and marked in California and the total noise barrier length in each orientation for the above mentioned locations is summarized in Table 2.

Table 2. Length of noise barriers for each orientation in selected Californian regions

Orientation	Twenty-Nine Palms (miles)	San Jose (miles)	San Diego (miles)	Los Angeles (miles)	Fresno (miles)	Sacramento (miles)
N-S	0.93	44.66	5.31	46.56	2.73	14.21
E-W	-	27.64	3.38	103.52	-	25.93
NE-SW	-	20.65	4.21	14.92	-	5.29
NW-SE	-	57.65	5.21	81.64	8.06	8.18
Total	0.93	150.62	18.12	246	10.8	53.63

Using equation 3, the net PV area and the power potential in each orientation was found out. The power output per unit area for the First Solar FS-4100 module is 0.1388 kW/m^2 . The power output potential in each orientation was found out using equations 4-7. Table 3 shows the value of the net area available for PV modules in each orientation whereas Table 4 gives the power potential considering all of the area of Table 3 is used up for mounting the PV modules.

Table 3. Net area in square meters for potential PVNB for each orientation in six selected metropolitan areas in California.

	Twenty-Nine Palms	San Jose	San Diego	Los Angeles	Sacramento	Fresno
$A_{PV-NS} (m^2)$	2077	116,677	10,069	103,540	31,763	6,295
$A_{PV-EW} (m^2)$	-	69,762	6,128	233,810	65,427	-
$A_{PV-NW-SE} (m^2)$	-	149,587	10,947	192,427	17,386	18,925
$A_{PV-NE-SW} (m^2)$	-	52,396	7,238	37,728	12,731	-

Table 4. PV power potential in kW for each orientation in six selected metropolitan areas in California.

	Twenty-Nine Palms	San Jose	San Diego	Los Angeles	Sacramento	Fresno
$P_{PV-NS} (kW)$	289	16,205	1,398	14,381	4,412	874
$P_{PV-EW} (kW)$	-	9,689	851	32,474	9,087	-
$P_{PV-NW-SE} (kW)$	-	20,776	1,520	26,726	2,415	18,925
$P_{PV-NE-SW} (kW)$	-	7,277	1,005	5,240	1,768	-
Total (kW)	289	53,947	4,774	78,821	17,682	19,799
Total California (GW)	1.75					

The above results shows a 1.75 GW of total power potential for PV installed on noise barriers in California. Using the above power potential as the desired array size in SAM, the annual energy output for each orientation was calculated by changing the azimuth angle and is summarized in Table 5.

Table 5. Annual energy output for PVNB in each orientation in six selected metropolitan areas in California.

	Twenty-Nine Palms	San Jose	San Diego	Los Angeles	Sacramento	Fresno
$E_{PV-NS} (GWh)$	0.3	13.6	1.1	11.1	3.7	0.8
$E_{PV-EW} (GWh)$	-	10.1	0.9	33.9	9.0	-
$E_{PV-NW-SE} (GWh)$	-	22.8	1.6	28.4	2.5	2.8
$E_{PV-NE-SW} (GWh)$	-	7.4	1.0	5.1	1.7	-
Total (GWh)	0.3	53.9	4.6	78.5	16.9	3.6

From the above results, the total annual energy potential from photovoltaic modules mounted on all existing noise barriers in California is 157.8 GWh.

4.2 U.S. Potential

The energy and power potential of the PVNB system for the entire U.S. was found (shown in Table 6) by extrapolating the results obtained for California following equation 8 and 9. The total rural and urban highway length for the states of California, Colorado, Georgia, Maryland, Minnesota, New Jersey, New York, Ohio and Michigan was found out from the Federal Highway Administration data.

Table 6. Annual energy output for other states and California

Location	Total Roads (miles)	Power Potential (GW)	Annual Energy Generation (GWh)
California	225,531	1.75	157.8
85% Selected States*	786,002	6.1	550
U.S. Total	1,163,263	9.0	814

* Colorado, Georgia, Maryland, Minnesota, New Jersey, New York, Ohio and Michigan

The total estimate for energy production from PVNB system in U.S. was calculated by multiplying the ratio of the energy potential with the total highway length in California with the total highway length for the other states mentioned [29]. The results showed that the total power potential for the U.S. using the 85% selected state estimate is about 7GW and basing it on the total U.S. roadways is about 9 GW. Similarly, the energy potential from photovoltaic modules using the estimation based on those deployed on existing 85% of the noise barriers in U.S. is around 650 GWh/yr and the entire U.S. the total energy potential based on road miles is around 815 GWh/yr. There is some uncertainty due to such an extrapolation including the potential variance between road orientation in CA and other states, different soiling rates due to weather and road conditions, and different preferred types of NB; however, the impact on the overall PVNB potential would be small (on the order of a few percent). Overall the values presented here should be treated as conservative underestimates if it is assumed that the U.S. will in the future deploy NB in quantities sufficient to meet international health and safety norms the impact in potential PVNB deployment would be large, as will be discussed below.

The total GW of potential in the U.S. for PV system integration into NB in the selected states is 6.09 GW. These noise barriers could produce over 700 GWhs per year. This energy is sufficient enough to power more than 50,000 homes in the U.S. and result in an annual electricity cost saving of more than \$66 million [48,49]. These solar roadway farms would be substantial and comparable size at a state level to the largest existing solar farms. For example, in California a total noise barrier area of 1.14 km² can have an installed capacity of 1.75 GWp whereas the largest solar farm in the U.S. has an installed capacity of 550MWp spread over 13 km² [50]. Thus, because the PVNB systems investigated here are vertical in orientation and no area is devoted to avoiding inter-row shading the photovoltaic noise barrier system has a better land utilization ratio for energy production than conventional solar farms.

It is possible to install PVNB in non-optimum configurations. To provide decision makers with a rough rule of thumb the 1kW system simulated in Los Angeles with different azimuth angles and tilt angles are shown in Table 7.

Table 7. PV output in kWh as a function of orientation and tilt angle for a 1kW array in Los Angeles.

Orientation	Tilt Angle					
	0 deg	15 deg	30 deg	45 deg	60 deg	90 deg
N-S	1,378 kWh	1,330 kWh	1,237 kWh	1,119 kWh	987 kWh	711 kWh
E-W	1,378 kWh	1,520 kWh	1,573 kWh	1,538 kWh	1,416 kWh	953 kWh
NE-SW	1,378 kWh	1,454 kWh	1,455 kWh	1,389 kWh	1,264 kWh	890 kWh
NW-SE	1,378 kWh	1,492 kWh	1,525 kWh	1,480 kWh	1,365 kWh	973 kWh

As is well established the Table 7 shows that the 30° tilt position and the E-W oriented noise barrier having the PV facing southwards are ideal in terms of capturing solar irradiation. The 90° tilted PV array captures about 40% less energy compared to the ideal 30° tilted array. However, the annual energy output for the 30° tilted array is more affected by soiling along highways and additional costs are required to set up the PV mounting structure for the 30° tilt and most importantly in general there is less area available for PV in a 30° tilt so less total power would be deployed. The above mentioned problems are greatly reduced for the 90° tilt, which has been considered in this study. It should also be noted, that energy production penalties for non-optimal orientations are lower and can indicate the potential for large fractions of adoption for PVNB regardless of road orientation.

5. Discussion

The combination sound barrier and photovoltaic noise barrier technology has been implemented on a large scale in Europe [21] with detailed studies of individual countries (i.e. the Netherlands [51]). However, this technology is not nearly as mature in the U.S. market yet the results summarized in Table 5 indicate that the U.S. has an enormous potential to improve PV deployment using PVNB technology. These results should all be considered extremely conservative as both the number of PV installed vertically could be above the figures described above because of the assumptions due to orientation, but also because this study did not consider the potential from free standing PVNB road dividers with bifacial PV [52]. The energy output per installed unit power could also be significantly increased over the values found in Table 5. This can be done by using higher efficiency PV or using any of the more sophisticated PV system design topologies (e.g. cassette or zigzag [23]) that capture a greater percentage of the solar energy in a particular area.

Monitoring results from the already installed PVNB in Europe show that solar energy output is reduced by soiling, inverter malfunctioning, theft vandalism and shading losses [20,28]. Although soiling losses would be minimized with the vertical system design selected here, by using the cassette and zig zag configurations the soiling and shading losses can also still be minimized [23]. The integrated noise barrier system which use a ceramic substrates for the photovoltaic modules to absorb more sound are heavier and costly than conventional solar modules [28]. Also such solutions are costlier compared to traditional noise barrier solutions like berms, concrete walls and wooden walls [53]. This is one of the major reasons for most of the highway administration bodies failing to adopt the integrated photovoltaic noise barrier solution. However the

additional capital cost can be compensated by the energy generated by the photovoltaic noise barriers [53,54]. This electricity is a source of revenue for the noise barriers unlike conventional barriers that produce no revenue. Thus is important for PVNB to be treated as an investment, which provides a ROI (return on investment) over time [55]. As pointed out earlier because of substantial PV price declines the ROI is likely to be a positive attractive investment in much of the U.S. if results are extrapolated from commercial building PV economic studies [56]. Future work is needed to determine a more full understanding of PVNB economics in the U.S. given the unique attributes of distributed generation on roadways owned and operated by a range of entities (e.g. municipalities, states and federal highways).

In the United States, some of the primary impediments to the implementation of large scale photovoltaic systems like PVNB are lack of government policies supporting large scale use of solar photovoltaics seen in other countries [57-61], inadequate financing options [62-64], difficulty in overcoming established energy systems and a poor perception by people of photovoltaic system aesthetics [65].

In the case of PVNB systems, the main issues outside of policy and local logistics are the integration issues related to photovoltaic and acoustic properties [66]. Further work is needed in this area although it should be pointed out that there is no inherent tradeoff between the use of PVNB and noise reduction of sound barriers. Research is needed to determine the viability of the extreme case of using only PV as a noise barrier (and thus reducing the materials and associated costs needed in a standard noise barrier). The use of PVNB may in some cases decrease costs per installed unit power from a PV farm perspective because of being able to use existing noise barriers as part of the racking material. In general, when comparing PVNB to a traditional PV farm, the latter will have more optimal energy output because there are less restrictions on orientation and tilt angle. However, the overall benefit of PVNB is the use of PVNB allows for access to free surface area to increase total PV capacity for a region/country without encroaching on surface area needed for other applications (e.g. farming).

In addition, there are lack of adequate codes, standards, and interconnection guidelines for the photovoltaic noise barrier system, which is a primary concern of utilities and other administration bodies towards adopting this technology [67]. Land use and planning along highways is also a complex issue due to many considerations and parties involved [68]. The final reason that the U.S. is behind on PVNB is actually due to the lack of noise barriers. In the United States, the noise legislation calls for noise abatement measures to be used only when the equivalent noise level exceeds 67db for residential areas, schools, hospitals and recreational areas. This value is much higher than the World Health Organization specified value of 55db [69]. A recent review of effects of noise on health found that following the noise stress hypothesis chronic stress hormone dysregulations as well as increases of established endogenous risk factors of ischaemic heart diseases have been observed under long-term environmental noise exposure [80]. In summary, Americans exposed to highway noise below the current regulations would be expected to have an increased cardiovascular risk [70]. This strongly indicates that the U.S. should consider changing regulations to be more in line with the World Health Organization to increase the penetration of noise barriers to protect the health of the America public. Future work is needed to estimate the increase in NB deployment in the U.S. to reduce this public health problem. However, the results of this study also indicate that increased PVNB deployment will lead to a substantial deployment of PV, which also has a positive effect on health [71,72] as well as mortality [73] by offsetting pollution from conventional fossil-fuel electricity generation.

The study has outlined a general method to estimate the potential of the photovoltaic noise barrier systems in a country. However, future work could build upon this study to better assess the potential for PVNB. For accurate results and design of the system actual site surveys and site measured values of incident insolation should be used. In this study only existing noise barriers were considered thus for future work, the integrated photovoltaic noise barrier solutions can be considered for areas which suffer from noise pollution. In addition, this study did not consider any economic aspects for the photovoltaic noise barriers, so future work could assess economic potential for the deployment of large scale photovoltaic noise barrier systems.

6. Conclusions

In the United States of America, where the noise abatement mandates fall well short of the recommendations from the World Health Organizations, not only are noise barriers less dense than would be expected from the road system, PVNB technology has still not been implemented on a wide scale. This study provided a straightforward method for estimating the PVNB potential in any country using only free software. For the U.S. as a case study, the results showed that:

- The total power potential for PNB the U.S. ranges from 7 to 9 GW.
- Energy from U.S. national deployment of PVNB is sufficient enough to power more than 50,000 homes in the U.S.
- PVNB across the U.S. would provide more than \$66 million an annual electricity cost saving.

The study concludes that the installed capacity of the large scale photovoltaic system deployed on noise barriers in a single state in the U.S. is comparable to the installed capacities of the largest solar farms in the U.S. and yet due to the unique mounting of PVNB, such systems provide a better land utilization ratio for energy production than conventional solar PV farms.

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Figures

Figure 1. Types of PVNB shown in perspective and side view: a) PV modules can be mounted on the top of the barrier, b) as shingles down the side of the barrier in addition to the top, c) covering the entire vertical surface, d) a bifacial surface, e) in a horizontal zigzag configuration, and f) cassettes.

Figure 2. Methodology to estimate the PVNB potential for any country/state.

Figure 3. PV potential (kWh/sq.m/day) and noise barrier locations in California.

Figure 4. Detailed view of the vertical configuration of direct mount PV on road side sound barrier used in simulation.