Renewable and Sustainable Energy Reviews 80 (2017) 125–132

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# Power and energy potential of mass-scale photovoltaic noise barrier deployment: A case study for the U.S

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ARTICLE INFO

*Keywords:*
Solar energy
Photovoltaic
Noise barriers
Distributed generation
PVNB
Photovoltaic noise barriers

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 GIS 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.

## 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 181 $m^2$ 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 Fig. 1. As can be seen in Fig. 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

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http://dx.doi.org/10.1016/j.rser.2017.05.223
Received 4 May 2016; Received in revised form 23 May 2017; Accepted 24 May 2017
1364-0321/ 

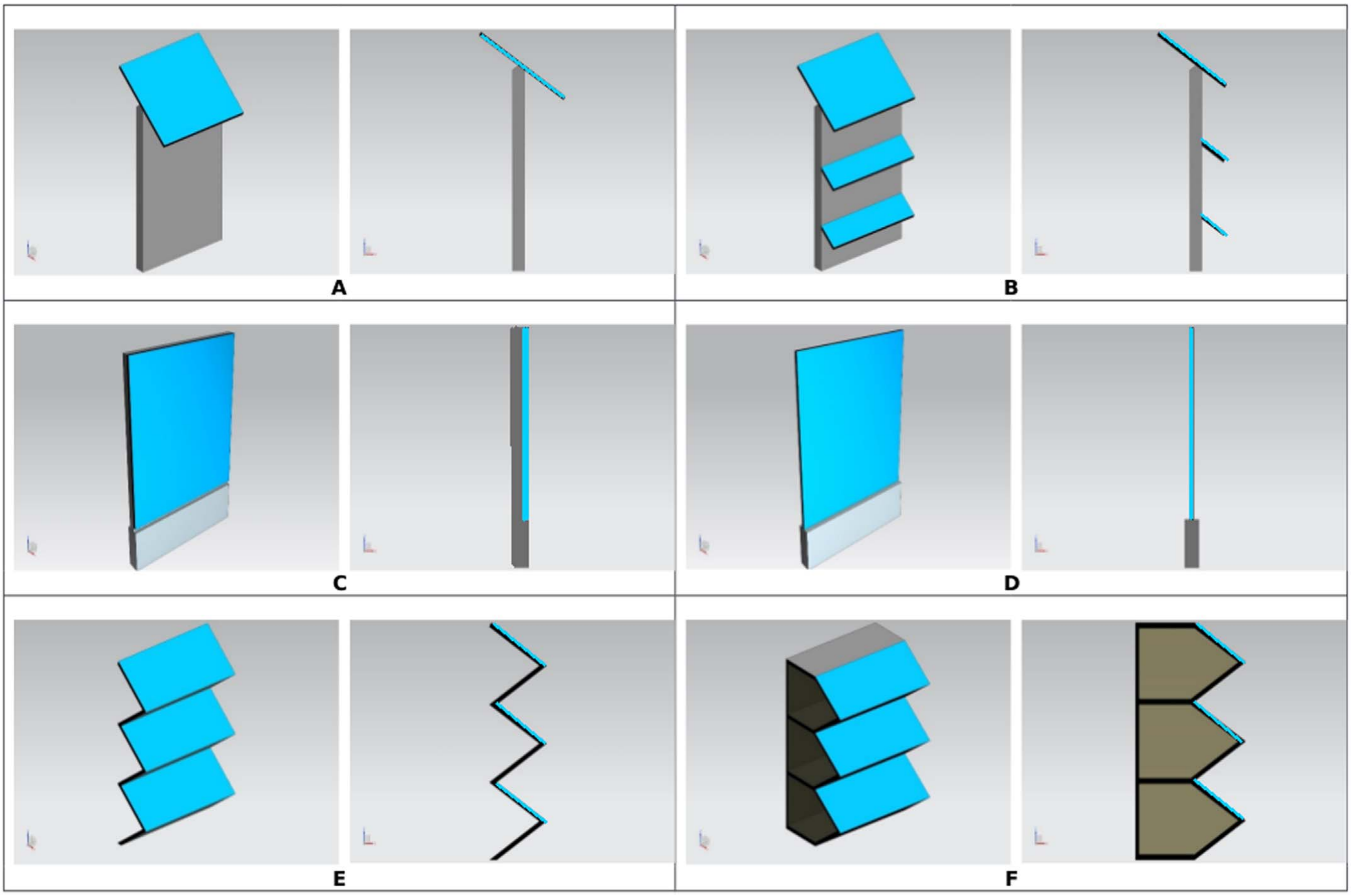


**Fig. 1.** Types of PVNB shown in perspective and side view: a) PV modules can be mounted on the top of the barrier, b) as shingles down the side of the barrier in addition to the top, c) covering the entire vertical surface, d) a bifacial surface, e) in a horizontal zigzag configuration, and f) cassettes.

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 Fig. 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 500 m 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 Fig. 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