Environmental and Climate Technologies
2025, vol. 29, no. 1, pp. 540–551
https://doi.org/10.2478/rtuect-2025-0037
https://content.sciendo.com

Optimum Efficiency: Analysis of Bifacial Photovoltaic Railway Noise Barrier Configuration for Green Energy Generation

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Received 14.04.2025; accepted 24.08.2025

Abstract **– Sustainable energy is a crucial aspect of our urban development, with a rising demand for energy resources, having the ability to integrate sustainable energy generation technologies with the existing infrastructure represents a possible solution for the high energy demand in populated regions. The regulations in the European Union state the maximum allowable noise levels to be 55 dB(A) in residential areas during the day and 55 dB(A) during the night, with the rising demand for reliable means of transportation, railways are becoming an essential part of the urban infrastructure. Photovoltaic noise barriers (PVNBs) are expanding globally to meet those needs, and different studies are being conducted to evaluate the performance of this technology in various scenarios and configurations. This study focuses on the performance of the Photovoltaic integrated panels without affecting the overall efficiency of the noise reduction barrier. The primary results for energy generation evaluation show that the best results can be obtained from a horizontal bifacial PVNB, meaning that the Photovoltaic segment is in a horizontal configuration mounted on top of a railway noise barrier, where five different configurations for the PVNB were studied and based on the results it is clear that the horizontal bifacial PVNB outperforms the other configurations, with the highest value for annual AC energy generated being 292 kWh and the lowest being 153 kWh, a difference of 47.6 % in value. This study was conducted mainly by using PVWatt calculator, this tool was developed by the national laboratory of the US Department of Energy, Office of Energy Efficiency and Renewable Energy. Although it is optimal to use the vertical configuration to capture reflected indirect light, the horizontal configuration is the most efficient when it comes to energy generation. Noise mitigation efficiency is still an aspect to consider.**

Keywords **– Efficiency; photovoltaic noise barrier; PVNB; PVWatt calculator; PVSOL-Online; solar, sustainability.**

1. Introduction

Noise pollution is a major concern in urban development, affecting inhabitants of various land areas. For areas far from airports and industrial zones, the sources of pollution are mainly automotive and locomotive [1], and that justifies the need for using noise barriers of different configurations and shapes to minimize this form of physical pollution. The European Environmental Bureau [2] states that around 40 % of the population is exposed to a noise

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level due to traffic that exceeds 55 dB(A) and around 20 % are exposed to noise levels above 65 dB(A) in the daytime, and more than 30 % is exposed to levels exceeding 55 dB(A) at night. Also, the World Health Organization (WHO) Community Noise Guidelines specify that the background sound pressure should not exceed 50 dB(A) for more than 16 hours in outdoor living areas in the daytime and evening and that levels should not exceed 30 dB(A) for more than 8 hours outside bedrooms, making it essential to use various technologies for noise mitigation [3].

Climate change has significantly impacted global energy demand, with various studies exploring solar energy solutions [4], [5]. Remarkably, Europe contributed to an estimated 14.7 % of energy consumption globally in 2019. This figure has been decreasing in the last five decades. Moreover, it has been noted that in the European Union, the energy usage of structures is 40 %, which is the greatest proportional value among all industries [6], [7].

In 2024, coal's share of electricity generation in the EU fell to 10 %, while the solar contribution grew to 11 %, as shown in Fig. 1. This notable accomplishment in clean energy usage within the EU was made possible via the installation of solar PV systems among various other technologies. Nonetheless, the pace of this expansion was so rapid it created negative electricity prices, occurring when supply overcomes demand, and brought to light the urgent necessity for better energy generation and storage technologies as well [8].

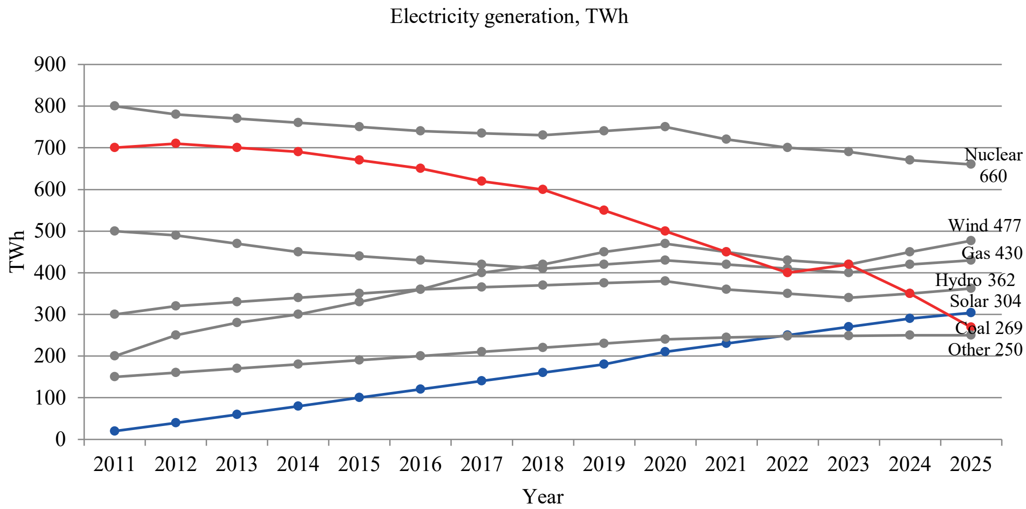

Fig. 1. Trends in energy generated per energy source in Terawatt's hours in the EU (2012–2024) [8].

The European Union's first Climate and Energy Strategy in 2008, which included specific goals for 2020:

- 20 % reduction of GHG emissions;
- 20 % share of renewable energy;
- 20 % improvement in energy efficiency.

Moving towards these goals justifies the rising share of solar and wind energy utilization – being major contributors to green energy – compared to coal and other fossil fuels in the last decade [9] as shown in the previous graph. In 2018, the European Union established a binding renewable energy target of 42.5 % for 2030, with an aspirational goal of reaching 45 % of total energy consumption from renewable sources [10] justifying the greater increase in solar energy share over coal and other fossil energy resources.

Integrating renewable energy technologies with existing infrastructure is a crucial strategy for achieving sustainability goals, reducing costs and time, and minimizing environmental impact.

Solar angles with respect to the ground and the sunbeam direction need to be understood clearly to be able to proceed with this study, most notably the slope (tilt)| angle β**,** the Azimuth angle φ of the barrier, and the solar zenith angle θ_z as illustrated in the following figure.

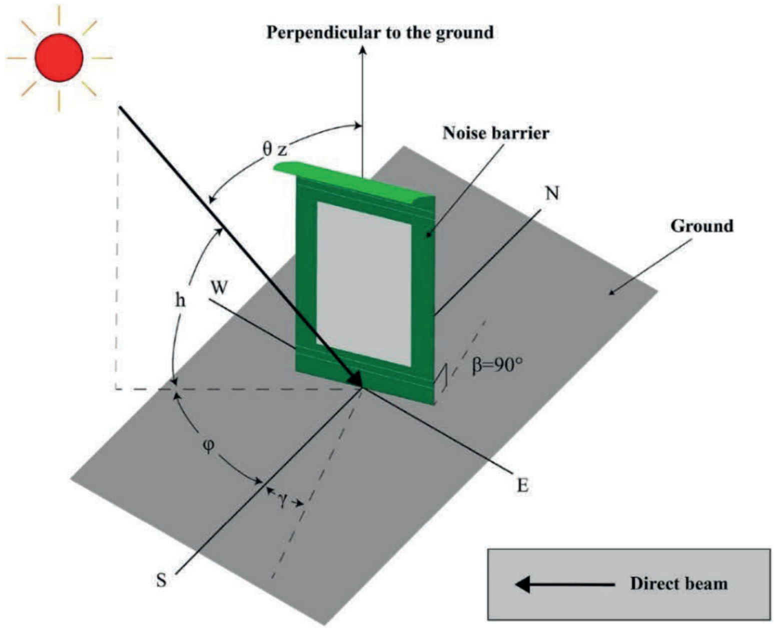

Fig. 2. Various solar angles, studying a system of solar panels relative to the sunbeam direction [11].

A study was conducted by Kai Zhang and other scientists assessing the energy generated (potential) by Photovoltaic noise barriers (PVNBs), specifically, Road Noise Barriers (RNBs), across 52 major Chinese cities, and the outcomes of that study showed that the orientation of the PV element – as part of the whole PVNB – represented by the barrier azimuth angle, plays a dominant role in the total energy yields as well as the nominal power output of the used PV segment, for it influences the incident angle for the studied solar panels [12], as shown in Fig. 3. The mentioned study considered the effect of diffuse and direct radiation on the studied photovoltaic noise barriers, with direct radiation being the major contributor to the resulting outcomes.

Another recent study conducted by Jixing Xie and others studied RNB performance in the city of Shenzhen in China, highlights that bifacial PV is more suitable to be integrated with vertical conventional noise barriers, resulting in an overall carbon reduction of 0.069 Tg/Km of the installed PVNB, making it a promising technology to substitute the conventional energy generation technologies [13].

A conclusion from a study by Soares & Wang stated that 'The top-mounted configurations have better payback time for energy, economic, and environmental impacts, while the built-on configurations have better performance on cumulative Net Present Value (NPV), Greenhouse Gasses (GHGs), and energy benefits' [14].

In this study, a designated design PVNB incorporating bifacial PV technology was utilized as a prototype to evaluate the PV power generation potential and economic benefits of a single-element railway PVNB in the city of Vilnius, Lithuania, focusing on the effect of changing the slope angle of the integrated bifacial solar panel element on energy yields around the year, the modelled system is of a single PVNB segment, to compare the specific energy output for various configurations, showing the structure of the photovoltaic noise barrier in a vertical configuration and the dimensions of the studied element as well. An existing project by the European company Solitek™ was observed as a pilot project regarding the specific annual energy yield; this project is a Photovoltaic noise barrier, a conventional Aluminium noise barrier segment with an integrated bifacial photovoltaic segment as mentioned previously, shown in Fig. 4.

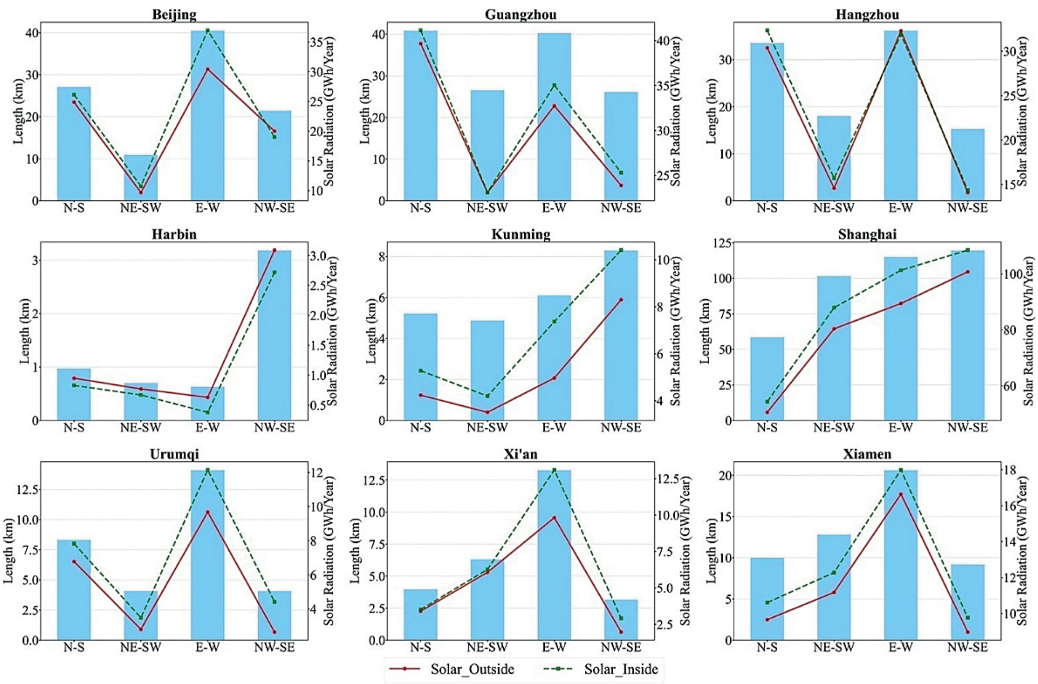

Fig. 3. Spatial distribution of the bifacial RNB's solar energy potential in 2021 for some major Chinese cities [12].

The Fig. 3 shows a direct relation between the orientation of the studied solar panel elements and the total energy harvested in GWh/year in various major Chinese cities. The reason for that is that the intensity and duration of the sunbeam exposure are maximized in the east-west orientation in most cases, with Northeast-Southwest and Northwest-Southeast coming in second place, justifying the possibility of harvesting more energy by the PV elements.

2. METHODOLOGY

In this study, different configurations of the PVNB were evaluated based on the specific energy output per segment of the barrier, as illustrated in Fig. 4. The proposed configuration considers five distinct scenarios, each defined by the tilt angle of the PV segment positioned on top of the railway noise barrier. This tilt angle is measured from the side facing the railway to the vertical direction [15], according to the following Table 1, the PVNB structure will be identical for all the studied scenarios with the tilt angle for the PV segment being the only difference to consider.

TABLE 1. TILT ANGLE ACCORDING TO DIFFERENT SCENARIOS

Scenario	Tilt angle β
Scenario I	0° (Horizontal)
Scenario II	36°
Scenario III	45°
Scenario IV	75°
Scenario V	90° (Vertical)

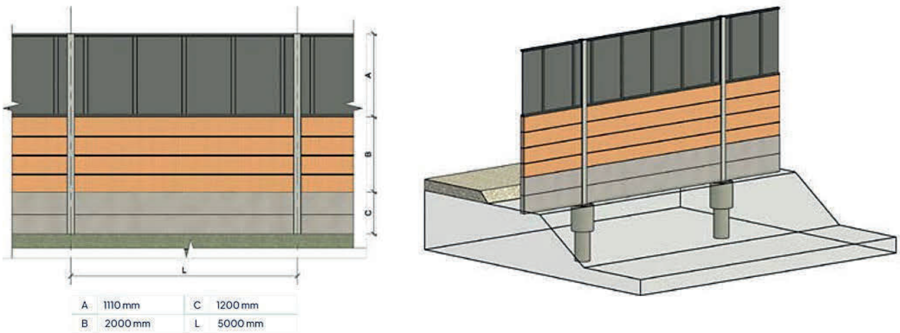

Fig. 4. Studied railway PVNB schematic view, showing scenario V as well [15].

3. LOCATION SELECTION

The studied location is in the area of Juodšiliai, south of Vilnius International Airport, the research area is centered around 54°34’50” N, 25°16’00” E, within an uncertainty of ±200 meters. This is where the Solitek™ pilot project of the Kyviškės–Vaičiūnai railway line is, as shown in the following map in Fig. 5.

As of 2025, Juodšiliai has a population of approximately 4760 residents. The village features a railway station – part of the studied railway line – and benefits from good connectivity to Vilnius, including city bus services [17]. The studied segment of the railway noise barrier is shown centred in the previous map with the noise barrier almost facing east-west direction, the Solar azimuth angle in this case is $\phi = 15°$, and the results shown in the following chapter will be for a single-element Photovoltaic noise barrier (PVNB).

Fig. 5. Juodšiliai, south of Vilnius International Airport, the original map is of a resolution 1 cm: 17.8 m [16].

The geographic location affects the value of Global Horizontal Irradiation (GHI), according to the following formula (1) [14]:

$$GHI = DHI + DNI \cdot \cos\theta_z\,, \tag{1}$$

where

GHI The Global Horizontal Irradiation;
DHI Diffuse Horizontal Irradiation;
DNI Direct Normal Irradiation;
θ_z solar zenith angle.

The global horizontal irradiation value is obtained using a specific simulation tool as it is explained below, also, the solar zenith angle depends on the weather data used for the selected location.

4. Tools Used

4.1. PVSOL-Online Tool

An open-source tool that is made accessible by the developers of the well-established PV simulation software PV*SOL, by Valentin Software Inc., the main outputs desired from this tool are the annual global irradiation in kWh/m² and the average temperature of the studied location in °C to understand the area solar energy potential and general climatic data, to be comparable with the energy output results for each studied scenario.

The required inputs in this case are only the Latitude and the longitude angles of the studied location, entered the "Search Address" cell. One beneficial feature in PVSOL-Online tool is the map view at the top of the webpage, followed by the Country, City, and Address data shown below the map for the entered location [18].

4.2. PVWATTS® Calculator

PVWATTS® Calculator has been developed by the National Renewable Energy Laboratory (NREL), a part of the national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Operated by the Alliance for Sustainable Energy, LLC.

Also, in this tool, the studied location is required to be identified, in terms of longitude and latitude, to be able to utilize the NREL weather data of temperature and global irradiance [19].

To determine the system losses, which represent the energy losses in relation to the optimal situation due to various factors, one can refer to Table 2.

TABLE 2. SYSTEM LOSSES CATEGORIES AND DEFAULT VALUES

Category	**Default Value, %**
Soiling	2
Shading	3
Snow	0
Mismatch	2
Wiring	2
Connections	0.5
Light-Induced Degradation	1.5
Nameplate Rating	1
Age	0
Availability	3

The system losses can be calculated according to the following Eq. (2):

System losses = 100 % × [1– (1 – Soiling) × (1 – Shading) × (1 – Snow) × (1 – Mismatch) × (1 – Wiring) × (1 – Connections) × (1– Light-induced Degradation) × (1 – Nameplate Rating) × (1– Age) × (1 – Availability)] = 14.08 %. (2)

The parameters in Table 2 are essential to calculate the energy output per solar panel segment, as shown in Table 3.

TABLE 3. INPUT PARAMETERS FOR PV WATTS CALCULATOR TOOL

Studied Parameter	**Explanation**	**Justification and formulas**	**Input value**
DC System Size (kW)	It represents the power rating of the photovoltaic array in kilowatts (kW) at standard test conditions (STC),	Size (kW) = Array Area (m²) × 1 kW/m² × Module Efficiency (%)	0.37 kW*
Module Type	The module type describes the photovoltaic modules in the array.	No given data about the module type, hence the standard type is selected	Standard*
Array Type	It describes whether the PV modules in the array are fixed, or whether they move to track the movement of the sun across the sky with one or two axes of rotation		Fixed*
System Losses (%)	The system losses account for performance losses you would expect in a real system that are not explicitly calculated by the PVWatts® model equations.	The default value for the system losses of 14.08 % is based on the categories in Table 2 and Eq. (2)	14.08 %
Tilt Angle (Deg.)	For a fixed array, the tilt angle is the angle from horizontal of the array where 0° = horizontal, and 90° = vertical	Values for different scenarios, from Table 1	0°; 36°; 45°; 75°; 90°.

Azimuth angle (Deg.)	For a fixed array, the azimuth angle is the angle clockwise from true north describing the direction that the array faces.	Measured on Google Earth® display map for the selected location	15°
DC to AC size ratio	The ratio of the array's DC rated size to the inverter's AC rated size	Given by the manufacturer, also the value can be standardized if not stated by the manufacturer	1.2
Inverter Efficiency	The inverter's rated AC power output divided by its rated DC power output	Given by the manufacturer.	99 %*
Ground Coverage Ratio	The ratio of module surface area to the area of the ground or roof occupied by the array.	For a single module, GCR can be considered almost = 1	0.99
Bifacial	A bifacial photovoltaic module is a type of module that converts solar irradiance incident on both the front and rear of the module into electricity.		Yes*

*Input values are from the project datasheet provided by Solitek™ if not stated otherwise [15].

Other parameters are required to be entered into the calculation tool; these parameters can be neglected or to use the default values, such as:

– Albedo effect: Obtained from weather data (geographic location entered).
– Monthly irradiance losses: account for the reduction in incident solar irradiance caused by dust or another soiling of the photovoltaic array surface that reduces the radiation incident on the array, this study aims to compare energy outputs for various scenarios, also, the PVNB is of bifacial vertical configuration, which minimizes losses due to dust or snow effect.

5. Results and Discussion

5.1. Global Horizontal Irradiation and Average Temperature

Numerical estimation of annual global irradiation and average temperature was obtained using the PVSOL-Online tool [18]. The results were 1028.8 kWh/m² and 7.2 °C, respectively. The following graph in Fig. 6 presents the monthly distribution of these values throughout the year, illustrating seasonal variations in solar irradiation and temperature.

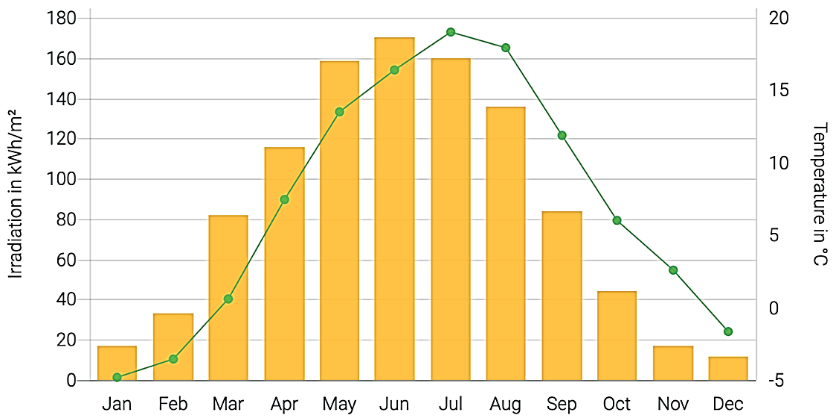

Fig. 6. Monthly distribution of GHI and average temperature for the studied geographic location, yellow bars representing GHI, and green line representing average temperature values [18].

5.2. AC Energy Output and Solar Radiation per Unit Area per Day

The following results, shown in Table 4, were obtained for four distinctive scenarios by using the values from Table 3.

The obtained results can be justified by the GHI and average temperature values in the previous graph, highlighting the higher GHI values between April and September, hence higher AC energy output values for the same period.

An observation from the following tables is that, irrespective of the GHI value, the tilt angle plays a major role in the amount of solar radiation captured by the PV segment, allowing some configurations to capture more solar radiation than others in specific periods. This can be seen when comparing the monthly performance for different scenarios in Fig. 6.

TABLE 4. SIMULATION RESULTS OF AC ENERGY OUTPUT AND SOLAR RADIATION

Parameter	**AC Energy, kWh**					**Solar Radiation, kWh/m²/day**				
Month	I	II	III	VI	V	I	II	III	VI	V
January	4	3	3	3	3	0.41	0.28	0.28	0.33	0.32
February	9	5	6	8	8	1.05	0.59	0.64	0.84	0.82
March	22	10	10	17	18	2.27	1.05	1.05	1.72	1.78
April	37	18	15	23	27	3.96	2.12	1.72	2.47	2.87
May	44	29	24	24	29	4.75	3.13	2.68	2.6	3
June	50	37	32	29	32	5.71	4.15	3.69	3.3	3.6
July	47	32	27	26	30	5.11	3.53	3.09	2.89	3.22
August	38	21	17	23	27	4.14	2.4	1.98	2.52	2.91
September	25	11	10	19	20	2.81	1.3	1.19	2	2.17
October	12	6	7	10	11	1.32	0.6	0.69	1.06	1.07
November	2	1	1	2	2	0.26	0.18	0.18	0.21	0.2
December	2	1	1	2	2	0.24	0.16	0.16	0.2	0.19
Total	292	174	153	186	208	2.67	1.62	1.45	1.68	1.85

An observation can be highlighted based on the results that the inclination (tilt) angle is not inversely proportional to the AC energy output all the time, for the scenario I, the tilt angle β is of the minimum value (0°), and the AC energy output is the highest in the studied scenarios with a value of 292 kWh, also, for the tilt angle β of the maximum value (90°), and the AC energy output is 208 kWh, the minimum value of AC energy output is for the scenario III – where the tilt angle β = 45° – and it is 153 kWh, these findings are partially supported by a similar study by Basak A. [20], which came up with various results, such as:

- Near-vertical bifacial modules generate less power but capture more reflected light;
- Balancing direct and reflected light is key to optimizing bifacial PV power generation.

The obtained results show that the tilt angle is related to the AC energy output and the solar radiation reaching the PV segment of the barrier, as shown in the following graph. The study by Basak A. [20], however, was conducted in a different location with different weather data, including a significantly different albedo impact on the results.

For illustration purposes, the obtained results are represented in Fig. 7; the value for AC energy generated is dependent on the amount of solar radiation captured by the PV segment, for instance, by comparing the results for scenario II and scenario V between April and May, the values for solar radiation are 2.12 kW/m^2/day and 2.87 kW/m^2/day for April, and 3.13 kW/m^2/day and 3.0 kW/m^2/day for May, resulting in 18 kWh and 29 kWh in April, and 27 kWh and 29 kWh in May.

Also, a study by Sahu P. K. concluded that bifacial modules boosted the energy yield by 4 % to 15 % depending on the module type and ground reflectivity with an average of 9 % [21], the studied System showed a performance ratio of 13 % for the SN orientation and 80 % for the EW vertical orientation, which supports choosing the near east-west orientation in such applications.

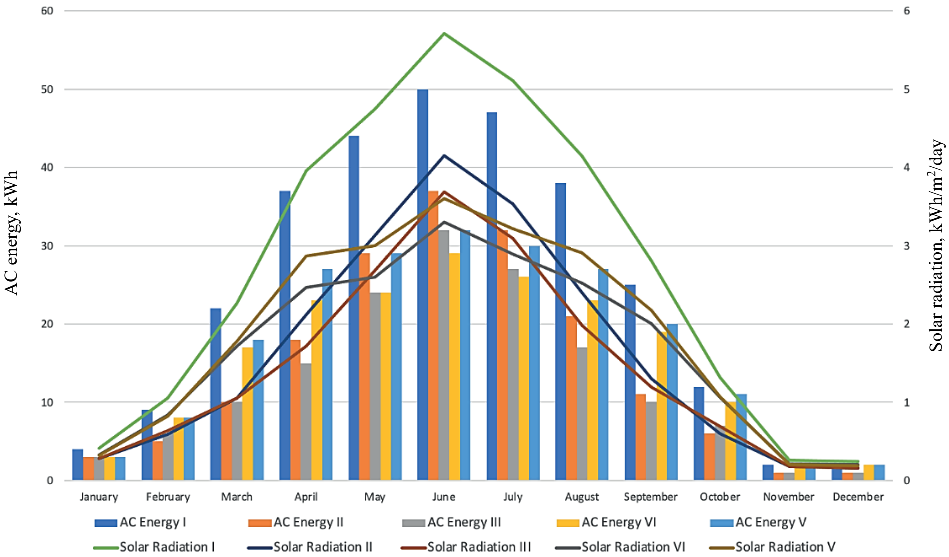

Fig. 7. Monthly values for solar radiation and AC energy (kWh).

6. Conclusion

This research analysed the energy production efficiency of a bifacial photovoltaic noise barrier (PVNB) in a railway context within Vilnius, Lithuania, through the study of five varying tilt angles of the PV segment. Simulation results using the PVWatts calculator showed that, of all the scenarios analysed, the horizontal configuration (0° tilt angle) produced the highest annual AC energy output. This result demonstrates that, at this particular site and configuration, a lower tilt angle is optimal for energy capture, which goes against the findings from other studies, which state that near-vertical bifacial modules are less effective than vertical ones for capturing reflected light. The energy output was found to be proportionally dependent on the local Global Horizontal Irradiation (GHI) and average temperature, demonstrating that greater energy generation occurred during periods when solar irradiation was higher.

Among the five configurations with different tilt angles studied for the bifacial Photovoltaic Noise Barrier (PVNB) system, Scenario I with 0° horizontal tilt yielded the maximum AC energy output in a year with 292 kWh; however, Scenario III with 45° tilt angle produced the minimum AC energy output in a year with 153 kWh. Scenario V, which had a vertical tilt of 90° was in the middle of this group with 208 kWh of annual AC energy output. From the evaluation of various AC energy outputs and tilt angles, the assumption that the angle of inclination and AC energy output would have a direct relation could not universally hold true.

The findings highlight the need for a site's site-specific investigation when designing PVNBs for maximum energy retrieval. This analysis proves energy generation from bifacial PVNBs is considerable, aiding in the integration of sustainable energy into existing systems, but also underscores the fact that the optimal tilt angle is contextually dependent and impacted by a variety of conditions such as geographical location and climatic conditions. Moreover, although this study was on energy generation, it is important to note that the efficiency of mitigation of noise remains the overriding purpose of railway noise barriers. This assessment can be extended by evaluating the balance between energy generation and noise attenuation for various configurations of PVNBs and analysing the economical and functional impacts of the installations in the long term. The use of bifacial technology, which is known to increase energy production, helps to further enhance the sustainability and value of railway infrastructure, which is a positive development.

References

[1] Sarpalius D., Grubliauskas R. Application of low height noise barriers to reduce railway noise. Vilnius Gediminas Technical University, Jul. 2022. https://doi.org/10.3846/aainz.2022.001

[2] European Environmental Bureau. Noise pollution in the European Union. [Online]. [Accessed 11.05.2025]. Available: https://eeb.org/work-areas/air-and-noise-pollution/noise-pollution/

[3] Clark C., Paunovic K. Who environmental noise guidelines for the European region: A systematic review on environmental noise and quality of life, wellbeing and mental health. *International Journal of Environmental Research and Public Health* 2018:15(11):2400. https://doi.org/10.3390/ijerph15112400

[4] Ju X., Xu C., Han X., Du X., Wei G., Yang Y. A review of the concentrated photovoltaic/thermal (CPVT) hybrid solar systems based on the spectral beam splitting technology. *Applied Energy* 2017:187:534–563. https://doi.org/10.1016/j.apenergy.2016.11.087

[5] Islam M. T., Huda N., Abdullah A. B., Saidur R. A comprehensive review of state-of-the-art concentrating solar power (CSP) technologies: Current status and research trends. *Renewable and Sustainable Energy Reviews* 2018:91:987–1018. https://doi.org/10.1016/j.rser.2018.04.097

[6] Hu W., Scholz Y., Yeligeti M., Deng Y., Jochem P. Future electricity demand for Europe: Unraveling the dynamics of the Temperature Response Function. *Appl Energy* 2024:368:123387. https://doi.org/10.1016/j.apenergy.2024.123387

[7] Komarova A. V., Filimonova I. V., Kartashevich A. A. Energy consumption of the countries in the context of economic development and energy transition. *Energy Reports* 2022:8(S9):683–690. https://doi.org/10.1016/j.egyr.2022.07.072

[8] Niranjan A. Rising star: EU made more electricity from solar than coal in 2024. The Guardian. [Online]. [Accessed 21.03.2025]. Available: https://www.theguardian.com/world/2025/jan/22/rising-star-europe-made-more-electricity-from-solar-than-coal-in-2024

[9] Verhaeghe G., Mauerhofer V. National progress towards supranational climate & energy goals due to policies & their mixes? Insights from Northern & Western Europe. *Journal of Environmental Management* 2023:348:119304. https://doi.org/10.1016/j.jenvman.2023.119304

[10] European Commission. Renewable energy targets. [Online]. [Accessed 24.03.2025]. Available: https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en?utm_source=chatgpt.com

[11] Zhong T. *et al.* Assessment of solar photovoltaic potentials on urban noise barriers using street-view imagery. *Renewable Energy* 2021:168:181–194. https://doi.org/10.1016/j.renene.2020.12.044

[12] Zhang K. *et al.* Power generation assessment of photovoltaic noise barriers across 52 major Chinese cities. *Applied Energy* 2024:361:122839. https://doi.org/10.1016/j.apenergy.2024.122839

[13] Xie J., Tang H., Lyu Y., Liu W., Tian X., Li C. Energy, environmental and economic performance of bi-facial photovoltaic noise barrier applied in city scale. *Renewable Energy* 2024:237:121599. https://doi.org/10.1016/j.renene.2024.121599

[14] Soares L., Wang H. Sustainability impact of photovoltaic noise barriers with different design configurations. *Transportation Research Part D: Transport and Environment* 2023:116:103624. https://doi.org/10.1016/j.trd.2023.103624

[15] Solitek EU. PVNB datasheet. [Online]. [Accessed 12.01.2025]. Available: https://www.solitek.eu/storage/app/media/atsisiuntimai/2023/EN/garso%20sieneliu%20datasheet_web.pdf
[16] Google Earth. Actual map of Juodšiliai. [Online]. [Accessed 14.01.2024]. Available: https://earth.google.com/earth/d/1DSeFXQ3DKJB87k_F28GknmGXHvvvkOR4?usp=sharing
[17] Vilnius District Municipality. Juodšiliai annual report. [Online]. [Accessed 21.03.2025]. Available: https://vrsa.lt/administracine-informacija/seniunijos/3/juodsiliu-5?utm_source=chatgpt.com
[18] Valentin Software. PVSOL-Online tool. [Online]. [Accessed 22.03.2025]. Available: https://pvsol-online.valentin-software.com/#/
[19] National laboratory of the U.S. Department of Energy, 'PVWATT Calculator', PVWatts®. [Online]. [Accessed 31.03.2025]. Available: https://pvwatts.nrel.gov/index.php
[20] Basak A., Chakraborty S., Behura A. K. Tilt angle optimization for bifacial PV module: Balancing direct and reflected irradiance on white painted ground surfaces. *Applied Energy* 2025:377(B):124525. https://doi.org/10.1016/j.apenergy.2024.124525
[21] Sahu P. K., Roy J. N., Chakraborty C., Sundaram S. A New Model for Estimation of Energy Extraction from Bifacial Photovoltaic Modules. *Energies* 2021:14(16)5089. https://doi.org/10.3390/en14165089