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Influence of inclined photovoltaic panels on sound propagation and reflections from distributed infrastructure noise sources

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Abstract

Large-scale photovoltaic (PV) installations introduce extensive inclined planar surfaces that can act as screening elements but also as reflective structures. This can influence sound propagation from the source to the receiver. While PV plants are often assessed primarily as noise sources themselves, the role of PV panels as barriers and/or reflectors affecting sound from other noise sources is less commonly addressed. This contribution investigates the influence of PV panels on sound propagation and reflections for different types of noise sources commonly present. This can include road traffic, battery energy storage systems (BESS), distributed string inverters, central inverters and transformers, and wind turbines. The analysis focuses on geometric effects associated with panel inclination, relative source, panel and receiver positioning, and the interaction between screening and reflection mechanisms. By considering PV panels as part of the sound propagation environment rather than solely the PV plant, as noise-emitting equipment, the study highlights situations in which inclined panel layouts may alter sound paths and local sound level distributions in hybrid energy and transport infrastructure.

Keywords: *sound propagation, solar panel reflections, acoustic screening, hybrid energy infrastructure*

1. Introduction

Noise barriers are simple mitigation measures that are designed to reduce sound propagation by blocking direct transmission, although it does introduce diffraction over the barrier edges. Beyond purpose-built PV noise barriers, large-scale PV arrays themselves may influence sound propagation because they introduce repeated inclined surfaces into the propagation environment.

However, these two objectives impose conflicting geometric requirements. Noise barriers perform optimally when they are close to vertical, maximising diffraction and acoustic shadow zones. In contrast, PV panels require specific inclination angles relative to solar incidence to optimise energy yield.
This study proposes a simplified modelling framework to investigate how panel inclination, spacing, and source–receiver geometry affect the balance between acoustic screening and reflection.

1.1 Motivation

The deployment of utility-scale PV installations has increased substantially in recent years, leading to the widespread introduction of extensive arrays of inclined panels across the landscape. These developments can be co-located with other infrastructure, including transport corridors, substations, battery energy storage systems BESS and hybrid renewable energy projects.
Large PV fields introduce extensive artificial surfaces that may interact with sound propagation through both reflection and screening mechanisms. Consequently, PV installations should be considered not only as energy-generating assets, but also as physical elements capable of influencing the acoustic environment around industrial and transport infrastructure.
We further investigated the acoustic impact of large photovoltaic installations, including changes in ground conditions, reflections, and sound propagation [1]. The ground effect was evaluated for combined wind, photovoltaic, and storage developments across different layouts, locations, and conditions.

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The increasing deployment of photovoltaic (PV) arrays highlights the need to assess their influence on sound propagation, particularly given the limited evidence available for large-scale inclined structures and the uncertainty in existing prediction models.

1.2 PV Panels as Acoustic Elements and research gap

Utility-scale PV arrays can influence sound propagation through screening and reflection effects. Their acoustic performance depends on panel inclination, array geometry, and source–receiver configuration, requiring specific evaluation beyond conventional noise barrier assumptions.

While PV panels may act as physical obstacles that influence sound propagation through screening and reflection mechanisms, their geometry differs significantly from the vertical structures for which barrier attenuation models are typically applied. In particular, prediction methods such as ISO 9613-2 [2] do not explicitly address inclined and partially reflective barriers, creating uncertainty regarding the validity of representing PV arrays as equivalent acoustic barriers. This limitation is consistent with observations reported during the development of ISO 17534-1 [3]. It was recognized that the treatment of diffraction and barrier attenuation is not fully specified for arbitrary screening geometries. Consequently, additional guidance is required when prediction methods do not adequately represent situations occurring in typical environments.

There is therefore a need to assess the extent to which inclined PV panels can provide barrier-like acoustic performance and to identify the limitations and uncertainties associated with their representation within existing sound propagation models. Furthermore, the test cases included in ISO 17534-3 [4] for the verification of diffraction and barrier attenuation calculations are based on conventional vertical barrier geometries.

The absence of explicit guidance and validation examples for inclined barriers in both ISO 9613-2 and the ISO 17534 quality-assurance framework highlights a gap between current prediction methods and inclined photovoltaic structures as potential acoustic screening elements.

1.3 Objectives

The research aims to determine whether inclined PV arrays can be treated as conventional acoustic barriers and to clarify the limitations of applying existing ISO 9613-2-based prediction methods to these non-standard geometries.

The study evaluates the use of ISO 9613-2 for inclined PV barriers, identifying its assumptions and limitations rather than validating its applicability.

Controlled field measurements are required to validate modelling approaches and quantify their limitations. The present work is restricted to assessing the applicability of ISO 9613-2 as a reference modelling method for inclined PV barriers.

2. Background

Photovoltaic (PV) installations are generally not regarded as significant noise sources, primarily owing to their typically remote locations, large site dimensions, and the relatively low sound emissions associated with their principal noise-generating equipment, such as inverters and transformers.

The replacement of exposed ground with reflective panel surfaces can alter ground attenuation, potentially affecting noise levels from nearby sources. This effect may be particularly relevant in hybrid developments, such as PV plants combined with battery energy storage systems (BESS), where additional noise sources are present and this is the case study selected for the layout configuration.

2.1 ISO 9613-2 and Barrier Modelling

While ISO 9613-2 provides a framework for environmental noise prediction, it does not explicitly address the acoustic behaviour of inclined PV arrays. In particular, the effects of panel inclination, multiple-row interactions, and complex reflection patterns from tilted surfaces are not specifically covered by the standard. As a result, the predicted insertion loss (IL) may depend on the geometric representation adopted within the acoustic model. The present study therefore compares alternative modelling approaches to assess the sensitivity of the results to these assumptions.

The principal question is not whether ISO 9613-2 can be applied to PV installations, but rather how inclined PV geometries should be represented within an ISO 9613-2 framework. Different geometric and calculation assumptions may lead to different predictions of insertion loss.

PV rows are typically installed as elevated or “floating” panels, with an open gap between the lower edge of the panel and the ground surface. The size of this gap may vary depending on the PV design and terrain conditions, but it represents an important geometric parameter in the assessment of acoustic screening performance. The tilt angle from 15 to 30 degrees will change substantially the equivalent floating barrier as projected vertical surface..

The 3D reflector model accounts for the redirection of sound energy by inclined PV panels. Since higher-order reflections may influence the predicted acoustic effect, a sensitivity analysis was conducted considering reflection orders from 0 to 6.

A key limitation is that a reflector representation does not necessarily reproduce the screening behaviour assumed for conventional noise barriers. ISO 9613-2 barrier attenuation is based primarily on diffraction around obstacles that block the direct line of sight between source and receiver. When PV panels are represented only as reflective surfaces, the resulting insertion loss may not fully capture the diffraction-related attenuation associated with physical screening.

3. Methodology

3.1 Investigated Geometries

Common PV layouts include south-facing, east–west, and agrivoltaic systems. In the Northern Hemisphere, fixed-tilt south-facing arrays predominate, with latitude-dependent inclinations that may affect sound propagation differently from conventional vertical barriers.

A simplified hybrid PV-BESS model was developed considering a 10 MW battery energy storage system (BESS) with 20 MWh energy capacity located adjacent to a photovoltaic plant. The objective was to assess the acoustic screening effect provided by the PV installation on noise emissions from the BESS. The analysis evaluated the insertion loss as a function of the number of intervening PV rows between the noise source and the receiver, allowing the influence of increasing barrier depth and multiple-row effects on sound propagation to be investigated.

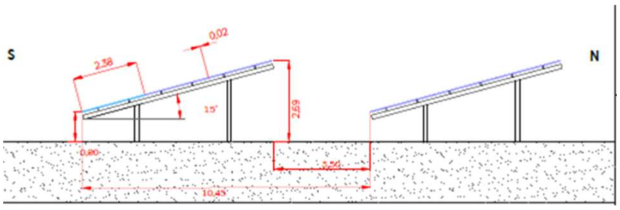

Figure 1. Side view of standard PV fixed-tilt south-facing row configuration

To avoid near-field effects and represent realistic project configurations, receptors were located at least 50 m beyond the last PV row. Acoustic performance was quantified as insertion loss, defined as the difference between source–receiver propagation with and without PV rows, for arrays comprising 1 to 10 rows keeping fixed locations for source and receivers.

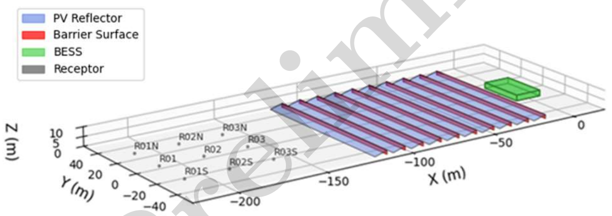

Figure 2. Representation of analysed layout with BESS as source 10 PV rows (15 degree tilt) and 9 receptor locations.

3.2 Source Types

The acoustic model considered the principal noise sources typically associated with hybrid PV-BESS facilities. For the BESS installation, the dominant sources were assumed to be the battery container cooling systems (chillers), in this case represented as fixed continuous point source, at 0.5 meter height, together with the associated inverter equipment, additional point source located at 3 meter height. The representative layout comprised six battery containers and three inverters. Other equipment, such as transformers, may also contribute to the total sound power level of the installation. Within the PV plant, distributed noise emissions may arise from electrical conversion equipment, including string inverters and central inverters. The present analysis focused primarily on the BESS-related noise sources, while acknowledging the potential contribution of ancillary equipment.

Hybrid renewable energy projects may include additional noise sources beyond PV and BESS equipment, such as wind turbines. Moreover, the presence of large PV panel surfaces may affect the propagation of environmental noise, including road traffic noise. Therefore, both source interactions and the acoustic influence of extensive PV arrays should be considered in comprehensive noise assessments. However, these aspects are outside the scope of the present study, which focuses exclusively on the insertion loss provided by PV arrays for BESS-related noise sources.

3.3 Modelling Approach

Calculations were performed using CadnaA (2026 MR1) commercial software and the ISO 9613-2 (2024) propagation method. Three geometrical representations of the PV array were investigated:

- Vertical floating barriers (0.8 m gap to ground)
- 3D reflectors (PV panel surface),
- A combined model incorporating both barrier and reflector characteristics.

These approaches were compared to evaluate their effect on the predicted insertion loss adding 0 to 6 reflection order in the calculations. For all simulations, the modelled barriers and reflector surfaces were assumed to be totally reflective.

3.4 Assessment Metrics

The screening effect was evaluated through the resulting insertion loss attributable to the PV array. Insertion loss was calculated as the reduction in sound pressure level at the receiver caused by the presence of the PV rows. Particular attention was given to the relationship between insertion loss and the number of intervening PV rows located between the source and the receptor.

The analysis also examined the influence of reflection paths introduced by the array geometry. The reflector and combined reflector–barrier models were used to assess whether the inclination of the panels alters the propagation path of reflected sound energy compared with conventional vertical barrier representations. The objective was to identify the contribution of reflections to the overall acoustic response rather than to quantify reflection effects independently.

The progressive activation of PV rows enables the incremental contribution of each additional row to be evaluated. This approach provides insight into whether insertion loss increases linearly, reaches a plateau, or exhibits diminishing returns as the number of PV rows increases. The analysis focuses on the relative behaviour of the different geometrical representations rather than establishing a unique prediction methodology.

4. Results

The results indicate three clearly different behaviours:

- Barrier models produce substantially larger insertion losses, at several receiver locations when multiple rows are included, indicating that diffraction-based screening is the dominant attenuation mechanism in the modelled scenarios.

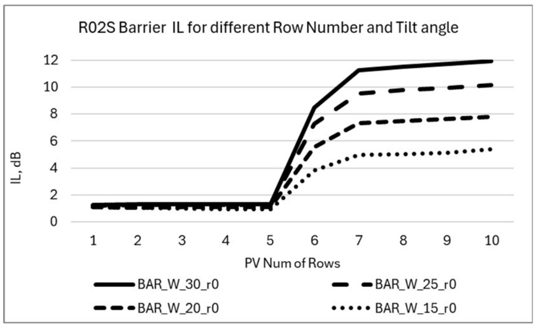

Figure 3. Insertion Loss for floating barrier and different tilt angle (15º to 30º)

- 3D reflector models generally produce relatively small insertion losses, typically below approximately 1 dB even with ten PV rows. Reflective modelling alone does not reproduce the screening effect observed in the barrier models.

  For reflection orders of two and above, negative insertion loss values are obtained, indicating an increase in the sound level at the receivers. The magnitude of this increase grows with increasing tilt angle. At higher reflection orders, the inclined surface creates additional reflected propagation paths that can redirect acoustic energy toward the receiver.

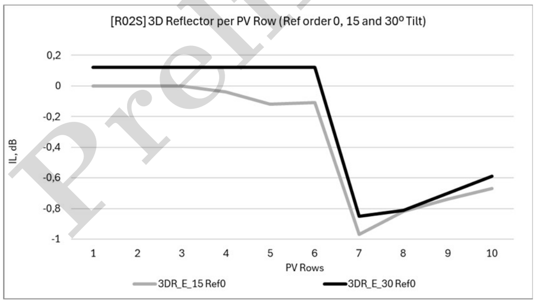

Figure 4. 3D reflector at 15 and 30 Tilt at 0 reflection order

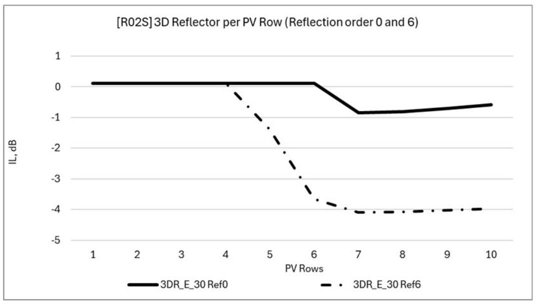

Figure 5. 3D reflector at 30 Tilt for 0 and 6 reflection order

- Combined Barrier plus 3D reflector models generally produce results similar to the barrier models, although local increases or reductions occur depending on receiver position, calculation reflection order and panel orientation, indicating that reflections may modify the acoustic field.

  For first-order reflections, the reflected contribution remains limited and the barrier attenuation dominates. However, when second-order and higher-order reflections are included, the cumulative reflected energy can exceed the attenuation provided by the barrier, resulting in negative insertion loss values.

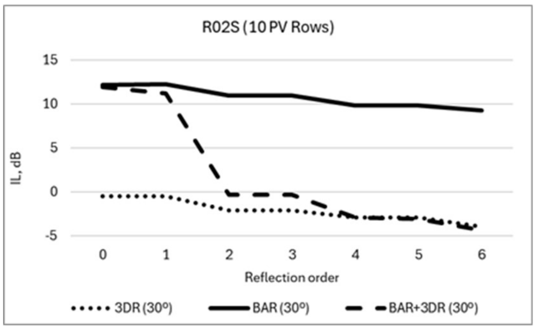

Figure 6. Barrier and 3D reflector combined effect on R02S receptor for 30 tilt and 10 PV rows configuration considering different reflection orders.

5. Discussion

The modelling results suggest that inclined PV arrays may provide acoustic attenuation under some conditions, but their behaviour differs from that of conventional noise barriers. Predicted insertion loss depends strongly on array geometry, panel orientation, source-receiver position, and the balance between screening and reflection effects.

High order reflections increases calculation times, because the number of rays grow exponentially with the reflection order. For conventional environmental-noise applications, first order of reflections are often considered sufficient. However, the simulations performed for arrays comprising one to ten inclined PV rows show a strong dependence on reflection order.

ISO 9613-2 does not explicitly address inclined, elevated, multi-row barrier structures. The representation of PV rows as barriers, reflectors, or a combination of both remains a modelling interpretation, and different assumptions can produce substantially different results. Consequently, the findings should be regarded as indicative rather than definitive.

While some configurations showed attenuation of several decibels, reflective effects may also reduce or locally reverse the benefit. Further validation through field measurements and more advanced acoustic modelling is therefore required before general conclusions can be drawn regarding the acoustic effectiveness of utility-scale PV installations.

6. Conclusions

The combined barrier and 3D Reflector configuration provides an instructive test of the interaction between conventional barrier diffraction and reflective 3D-object modelling. For no reflections, the results are identical to the conventional barrier calculation, indicating that the insertion loss is controlled by the wall-type screening mechanism when reflections are not included. A similar, although slightly reduced, behaviour is observed for first order reflection. However, from second order reflection onwards the calculated insertion loss decreases abruptly and becomes negative for many receiver positions, particularly for six to ten PV rows. This indicates that higher-order reflected propagation paths introduced by the 3D-reflector representation can offset, and in some cases exceed, the attenuation predicted by the conventional barrier component. The dominant modelling uncertainty is not inclination alone but the interaction between diffraction treatment, object representation and reflected propagation paths. Identical PV geometries can produce radically different insertion-loss predictions depending on modelling assumptions.

Experimental validation is therefore required as the next step to determine whether the predicted negative insertion loss values and reflection effects are representative of real installations. Future work should focus on field and laboratory measurements.

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