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Towards glint and glare impact assessment best practice

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ABSTRACT

Developing photovoltaic (PV) powerplants close to airports, major roads and residential areas could pose potential challenges related to glint and glare. Glint and glare impact assessment (GGIA) has subsequently become an important tool for assessing potential impacts. This study analyses of a range of GGIAs, standards, and guidance to recognise and make recommendations for best practice. Twenty GGIAs are conducted by various consultants from diverse countries, and seven standards and guidance are critically reviewed with respect to practice for: methods; impact significance determination; mitigation; and stakeholder engagement. Key recommendations for best practice are made, albeit recognising that they reflect the best of existing practice which is not necessarily the best practice that might be aspired to. This study serves as a first step toward improving GGIA practice, with the ultimate objective of supporting the safe and sustainable development of solar PV projects.

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Environmental impact assessment; glint; glare; glint and glare impact assessment; best practice; solar photovoltaic

1. Introduction

In recent years, there have been numerous calls for countries to transition to renewable sources of energy (Dincer 2000; Lund 2007; Gielen et al. 2019), with solar and wind energy regarded to be the primary sources to consider (Moriarty and Honnery 2016). According to the 'Renewables 2023 Global Status Report' (2023), the use of solar photovoltaic (PV) systems, specifically, has increased from around 39 gigawatts in 2010 to close to 1,200 gigawatts in 2022. PV systems are used in various sectors in multiple ways, including small-scale generation for powering individual residential homes and industries, as well as large-scale generation on solar farms (Chapman et al. 2016; Rai et al. 2016; Setiawan and Yuliania 2018; Mousa and Taylor 2020). However, the integration of PV systems near airports, major roads, as well as residential areas, introduces the challenge of glint and glare. These phenomena, defined by Ho et al. (2011) as momentary flashes of light (glint) and continuous excessive brightness (glare), can pose significant risks to both road users and airport operations, but also discomfort residents in their homes. The potential hazards range from temporary distractions, like flash blindness, to more severe impacts such as permanent eye injury (Ho et al. 2009; Saraswat et al. 2020). In response, many governments now require that glint and glare impact assessments (GGIAs) be conducted for PV developments near airports or major roads (e.g. SVDELWP 2019; SACAA 2020; FAA 2021). A GGIA aims to predict the manner and extent to which glint and glare from a proposed PV system will impact receptors such as aircraft pilots, traffic control officers, and road users. However, despite these requirements from governments, GGIA remains a relatively new practice in many jurisdictions. While some countries have established at least some guidance forglint and glare impact assessments (Table 1), others have not yet initiated such processes or are still in the process.

This can lead to significant variations and lack of consistency in the quality of GGIAs across different regions and jurisdictions. To address this potential inconsistency, requires reflection on key considerations for best practice thereby addressing potential risks associated with glint and glare. In recent years, GGIAs have been conducted in many different countries, offering a potentially rich source of information and experience to learn from. This growing body of work presents an opportunity to identify best practices and establish a more uniform standard for future assessments. By reviewing a sample of existing standards and/or guidance documents (Table 1), as well examples of the assessments themselves, we can obtain valuable insights which will start to indicate key elements that need to be included in GGIAs as well as highlighting the emerging inconsistencies in practice. The aim of this study is to review a selection of GGIAs and associated guidance and/or standards as a first step towards recommendations for best practice.

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Table 1. Examples of standards, requirements, and guidance.

Standard/Guidance	Country
Federal Aviation Administration (FAA) Guidelines	United States of America
South African Civil Aviation Authority (SACAA), (2020)	South Africa
Transport Canada, 2013/14	Canada
Ministry for Environment Health and Consumer Protection, 2014	Germany
Zehndorfer Engineering Consulting, 2016	Austria
Civil Aviation Technical Service, (2013)	France
Stickelberger & Moll, 2016	Switzerland

The next section sets out the method used to evaluate a sample of existing practice. This is followed in section 3 by the results from the analysis of the existing guidance and/or standards and the case studies which sets out current practice. Section 4 sets out preliminary recommendations for moving towards best practice GGIAs, before concluding in section 5.

2. Methodology

A case study approach was used to review a selection of glint and glare impact assessments (GGIAs). The process of selecting cases and reviewing them is detailed below.

2.1. Case study selection

According to Eisenhardt's (2002) recommendation for case study research, a sample of 4 to 10 cases is typically required to provide sufficient depth in understanding of the concept being studied. For this research and to ensure a valid review sample, we included a total of 20 assessments. The GGIA cases were sourced online by entering the search phrases 'glint and glare', 'glint and glare assessment', and 'glint and glare impact assessment' into Google, and selecting cases based on the following criteria:

- As far as possible, each GGIA had been conducted by a different consultant to capture a variety of professional practices and approaches.
- As far as possible, the GGIAs had to be carried out in different countries to ensure geographical and contextual diversity.
- The cases had to be relatively recent, completed within the last 5 years, to guarantee relevance and currency.
- The GGIAs had to encompass a range of project types and scope, including small-, medium-, and large-scale PV installations.

The selected GGIAs are listed in Table 2 and can be accessed through the download links provided.[1]

2.2. Evaluation and analysis

Documentation for each of the twenty (20) GGIAs was sourced and evaluated against five main review areas:

–**Screening and scoping**: A review of how the need for and extent of the GGIA was determined.
–**Methods**: A review of the approaches and software tools used to determine potential glint and glare impacts.
–**Impact significance determination**: A review of how the significance of glint and glare impacts was determined.
–**Evaluation of mitigation measures**: A review of the approach that was followed to determine mitigation options.
–**Engagement with stakeholders**: A review of the stakeholder involvement process.

The five review areas are adapted from the established international best practice operating principles of EIA (IAIA 1999). We have assumed that GGIAs are typically

Table 2. Summary of selected GGIA case studies.

Case#	Country	Consultant	Project Type	Receptors	Year	Link
1	UK	A	Roofmounted PV	Roads, dwellings, railway and airport	2021	Download
2	South Africa	B	PV Plant	Airports	2023	Download
3	Australia	C	PV Plant	Roads, dwellings, railway and airport	2021	Download
4	Namibia	D	PV Plant	Aviation	2022	Download
5	Canada	E	PV Plant	Residential and Roads	2020	Download
6	New Zealand	F	PV Plant	Road and General Observation Points	2023	Download
7	Ireland	H	PV Plant	Aviation	2023	Download
8	Ireland	I	PV Plant	Residential, Roads and aviation	2024	Download
9	USA	J	PV Plant	Residential and Aviation	2018	Download
10	New Zealand	K	PV Plant	Residential and Roads	2023	Download
11	USA	L	PV Plant	General observation points	2020	Link10
12	Australia	M	PV Plant	Residential and Roads	2020	Link11
13	Australia	N	PV Plant	Residential and airport	2021	Link12
14	UK	O	PV Plant	Residential, Roads, Railways and Airports	2021	Link13
15	USA	P	PV Plant	General observation points	2020	Link14
16	USA	P	PV Plant	Residential and Roads	2021	Link15
17	UK	Q	PV Plant	Residential, Roads and aviation	2022	Link16
18	UK	R	PV Plant	Residential, Roads and aviation	2021	Link17
19	South Africa	S	PV Plant	Aviation	2022	Link down
20	Ireland	T	Roof mounted PV	Aviation	2022	Link18

The consultant column codes different consultants using different letters and serves to illustrate that there are only two cases where the same consultant was used (consultant P), albeit based in different offices.

going to be incorporated into EIAs and so the preparation of EIA reports, review, and decision-making, as well as the follow-up process, falls outside the scope of this review as this is part of the overall EIA process. As a single impact category, we take screening and scoping together, as a determination that a GGIA is needed essentially scopes in glint as glare to an EIA. In cases where an EIA is not required, the GGIA can still stand-alone as a separate assessment. That is, screening for a self-standing GGIA, or scoping for GGIA to be included in an EIA, are essentially the same. That is, screening for a stand-alone GGIA, or scoping for GGIA to be included in an EIA, essentially leads to similar glint and glare assessment requirements. Screening generally refers to the decision of whether the project requires an assessment to be conducted. However, in the case of glint and glare it can also refer to measures that are taken (such as planting hedges or erecting walls), to obstruct the line of sight between a glare source and a receptor, which can mitigate glint and glare impacts. Strong methodologies are important for accurate impact assessments and identification. Assessing significance involves prioritising issues deemed to be critical, and also evaluating the importance and acceptability of residual impacts. Effective mitigation measures are essential for reducing adverse effects posed by glint and glare, aligning with the goal of avoiding or minimising predicted impacts. Finally, stakeholder engagement is a standard part of any EIA process and in our evaluation, we focus on the need to recognise that stakeholders may hold different views.

3. Review results for selected GGIAs

The following sections discuss the review results for the five review areas.

3.1. Screening and scoping

Screening and/or scoping are essential steps in the assessment process, helping to determine both the need for and the scope of the assessment. The analysis of the cases reveals a range of approaches and regulatory standards applied for screening and scoping. Despite this variability, recurring patterns were observed, offering insights into best practices.

The screening process determines the need for a GGIA while scoping integrates it into an EIA. The analysis revealed that the proximity of PV developments to sensitive receptors, such as commercial airports, airfields, air force bases, and major roads, often triggers the requirement for an assessment, regardless of whether an EIA is required. It was found that specific distance thresholds, such as a defined radius around an aerodrome or a specified distance along the extended centerline of a runway, often guide this process. These threshold distances did, however, show variation across cases. For example, one case required a GGIA for PV systems developed within 3 km of an aerodrome, while in another case, the threshold was set at 15 km for developments near an airbase. Observed differences in the existing guidance – such as different distance thresholds – suggests a need for standardisation. Where available, screening requirements were outlined by national aviation authorities (4 cases) or through planning policies (4 cases). The absence of such requirements in other regions (12 of the cases) suggests a need for clearer, more uniform screening criteria to ensure thorough assessments and more consistent practice. In some cases, the GGIA was preceded by a visual impact assessment (VIA) in which viewshed analysis was used to first assess the general visibility of the proposed PV development. This helped to determine the extent to which the PV development would be visible to key receptors and subsequently affected the GGIA scope, especially for roads and residential receptors. The duration of the assessments varied depending on the scale and location of the project, i.e. larger PV developments, or those affecting more sensitive receptors such as airports, generally required more detailed assessments.

3.2. Methods

Methodology is key to any assessment, especially those based on information obtained through computer modelling and analysis. Four key themes were identified through the review: the availability and variability of technical guidance, the predominant use of specific analysis tools, the consideration of screening effects, and the consideration of alternative configurations.

3.2.1. Technical guidance for glint and glare assessment

The availability of technical guidance for conducting GGIAs varied widely across different jurisdictions. From the review, it is apparent that many national governments lack formal technical guidance (12 cases representing seven countries). In the absence of local guidelines, many assessments reference the United States Federal Aviation Authority's (FAA) Technical Guidance (7 Cases) for Evaluating Selected Solar Technologies on Airports, suggesting that it is currently viewed by many as a 'best practice guideline' even though it is primarily focused on aviation safety. Additionally, some reports made reference to guidance from the private sector such as Page Power's 'Solar Photovoltaic Glint and Glare Guidance'. Several reports did, however, mention conformity with interim policies or technical guidance from aviation authorities, suggesting that work is being done to improve on this lack of guidance (8 Cases).

3.2.2. Analysis approach

The GlareGauge toolset (see www.Forgesolar.com) was used to model glint and glare in 18 of the 20 GGIA cases. Of the remaining two cases, one mentioned the use of an alternative, but less documented approach, while the remaining case did not mention any specific software used for modelling. Nonetheless, the existence of alternative models suggest the potential for diverse modelling approaches, provided they are well-documented. These models typically predict the glint and glare that can be expected at specified receptor points (e.g. along an aircraft landing approach or on a road segment) over the course of a year. Therefore, they are critical to any GGIA, and exploring alternative modelling approaches is important to ensure the best available methods are used.

In terms of model parameters, a significant observation is the consistent use of the software's default parameters across all the cases that employed GlareGauge. These parameters include viewing angles,direct normal irradiance (DNI), slope error, analysis time interval, and glide angles, among others. While the consistent use of default settings suggests a standardised approach, it also raises questions regarding the customisation and adaptability of the assessments to site-specific conditions.

For receptor identification, airport receptors were commonly identified based on the location of the air traffic control tower and specific points along approach lines calculated at 3° glider slopes. However, the methods for selecting other receptors, such as residential areas and roads, varied widely, from using viewshed analysis (6 cases) and proximity-based criteria (3 cases), to seemingly random selection (11 cases). The review suggests that while there is some consistency in the use of tools, there is currently no way of knowing whether these results reflect a lack of proven alternatives. There is scope for GGIA practitioners to collectively consider what is needed and what works best as experience develops.

3.2.3. Consideration of screening effects

The screening effects of barriers, such as vegetation and existing structures, were rarely considered in the modelling process (only 5 cases). Although more applicable to ground-level receptors, such as roads and residences, these barriers can be important in determining whether they affect the line of sight between the source and the receptor. Of the 15 cases that did not consider these barriers, 13 included ground-based receptors as part of the assessment.

3.2.4. Consideration of alternative configurations

Alternative configurations were considered in only six of the cases. These cases modelled alternative configuration to determine the extent to which they would reduce glint and glare impacts. They tested different orientations, backtracking strategies, tilt angles, module surface types, and the effects of anti-reflective coatings.

3.3. Impact significance determination

Considering the impact significance in GGIAs is crucial for understanding the relative acceptability of predicted glint and glare effects. The review revealed three themes to be discussed: the variability in defining significance, the methods used to assess impact significance, and the consideration of cumulative effects.

3.3.1. Defining significance

As with EIA, the concept of significance is fundamental in any GGIA as it aids in understanding the importance of potential glint and glare effects. However, there was variability in how significance was defined and applied across different cases. The majority of reports (12 cases) did not mention or define the concept of significance. This indicates a weakness in the methodological rigor of these assessments within the context of EIA. Some reports (4 cases) provided basic definitions, while others (4 cases) did not define significance but did evaluate it during the impact assessment phase.

3.3.2. Determining significance of impact

In terms of impact assessment, the review found considerable variation in how impact was assessed and how significance was considered. In four of the cases glint and glare effects were noted but their impacts not assessed in any meaningful way, highlighting a weakness in translating modelled effects into meaningful impact assessment results. In eight of the cases an ocular impact scale was used to determine impact. However, in most of these cases, the duration and time of day of the predicted glare were not considered, leading to an oversimplified impact assessment where glare duration is treated uniformly, potentially resulting in inaccurate conclusions. Four of the assessments did, however, categorise impacts using predefined categories based on the duration and frequency of glare, along with previously cited ocular impacts, resulting in a more structured approach to evaluating impact significance. Nevertheless, the analysis reveals a lack of consistency and rigor in assessing impact significance across GGIAs. Many reports stop at modelling potential effects without fully evaluating their impact significance. In terms of best practice, two cases stand out. Case 19 employed a detailed risk assessment considering extent, duration, magnitude, significance, and probability was used to evaluate impacts. Meanwhile, Case 17 assessed significance based on the magnitude of impact against receptor sensitivity, demonstrating a more nuanced approach. These cases highlight the value of detailed risk assessment and sensitivity analyses, suggesting that more rigorous and standardised methods – which are already available – are needed to accurately determine the significance of glint and glare.

3.3.3. Consideration of cumulative effects

Only one GGIA report (see Table 2, Case 17) addressed cumulative impacts by considering the combined effects of a nearby existing solar facility. The concept was absent from the other 19 assessments. Considering cumulative effects is important, as they influence the understanding and interpretation of overall impact on receptors in an area.

3.4. Mitigation measures

The review revealed different approaches for dealing with mitigation measures in GGIAs, although some reports (9 cases) did not mention any mitigation measures at all. Potential mitigation methods such as textured glass and Anti-Reflective Coatings (ARC) were noted in three of the assessments but lacked detailed information on their application or testing of their effectiveness. This highlights a general lack of thorough evaluation of mitigation measures. Only a few studies (6 cases) explored mitigation through alternative configurations or screening mechanisms and tested their effectiveness through modelling. These more comprehensive approaches not only propose solutions but also validate their effectiveness, ensuring that the recommended measures are likely to reduce impacts. Common mitigation measures to address glint and glare concerns include adjusting the angle of solar panels, utilising ARCs, planting hedges, or installing barriers as obstructions, and reorienting solar arrays to minimise reflection towards affected areas.

3.5. Engagement with stakeholders

Stakeholder engagement details were often scant, but where mentioned, consultations with relevant authorities were noted, e.g. aviation authorities for airports and local authorities for roads. Engagement with aviation authorities was mentioned in 10 of the cases, while local planning authorities were reported as being consulted in only eight of the cases. Engagement with the public was limited with only four of the cases reporting any form of engagement; however, this might have been dealt with in the broader EIA process. Finally, engagement with relevant authorities are essential as it ensures that specific conditions, contexts, or requirements are understood as well as potential impacts considered and measures for mitigation included. Moreover, transparency and trust in the assessment process is thereby facilitated between the developer and authorities.

4. Recommendations for best practice

Some variability in current practices are revealed through the review of GGIA cases. However, several best practices are also highlighted that, if adopted, can potentially improve GGIA practice. This section presents recommendations for best practices based on results from the reviewed GGIA reports.

4.1. Screening and scoping

The variability in screening requirements and scoping processes highlights the need to identify key aspects that should form the foundation of effective screening and scoping practice. The following recommendations are made:

- **Establish clear distance thresholds for airport receptors**: The distance thresholds used to determine the necessity of a GGIA near airports must be clearly specified. Existing thresholds seem to vary between 3 km and 15 km. Adopting a higher threshold may be more sensible to ensure that potential impacts are not overlooked, following a precautionary approach, but could also result in unnecessary assessments. The most appropriate distance can be determined through the application of the concept of atmospheric attenuation, which suggests that around 80% of radiation is likely to be lost at approximately 15 km.
- **Incorporate viewshed analysis for other receptors**: Screening GGIA against road and residential receptors would be more accurate and pragmatic if based on the outputs from a simple viewshed analysis. This approach will highlight the extent to which these receptors might be affected and better inform the subsequent need for a GGIA.
- **Contextualise screening/scoping criteria**: Since aviation-related receptors and receptors such as roads and residential areas differ significantly in their sensitivity to glint and glare, the screening criteria should reflect these differences. The criteria should be contextualised to address the specific sensitivities of each type of receptor.

4.2. Methods

The use of established guidelines and specialised software tools is common, which guarantees a basic level of thoroughness and consistency. There are, however, key considerations that underpin effective assessment methodologies as reflected in the following recommendations:

- **Review of available software**: A critical review of available software should be undertaken by the

GGIA practitioner community with a view to specifying a design brief for future software versions.

- **Consider default parameters**: Default parameters of software tools should not be used without careful consideration of the specific characteristics of the site. Properly adjusting these parameters ensures a more realistic and accurate assessment.
- **Systematically identified receptors**: Given that GGIA relies heavily on computer modelling, careful consideration should be given to the selection of receptors. For example, glide angles vary significantly between passenger airplanes and military aircraft, which will influence the placement of receptor points. For ground-level receptors, viewshed analysis should be employed to ensure that all relevant receptors are accurately identified and included in the assessment.
- **Incorporate screening effects**: The screening effect of existing landscape features, such as buildings and vegetation, must be considered in the assessment (especially for ground-level receptors), as these elements can significantly influence the results of the glint and glare analysis.
- **Consider alternatives**: Given that the impact assessment process relies on computer modelling, alternatives can be tested with relative ease. Various configurations, orientations, backtracking strategies, tilt angles, module surface types, and more could be tested to ensure that scenarios with the lowest impact are identified and proposed. This approach facilitates and justifies the selection of the most preferred alternative.

4.3. Determining significance of impacts

The variation in approaches used to assess glint and glare impacts and to deal with significance highlights the need for clarity in the process. The following recommendations can be made:

- **Define and consider significance in the context of glint and glare**: The concept of significance should be understood as the probability and severity of predicted glint and glare impacts on specific receptors. Impacts should be assessed with this understanding in mind.
- **Enhance the impact assessment process**: Glint and glare modelling results should be interpreted and evaluated in terms of their significance to ensure a comprehensive impact assessment. Key considerations that must form part of this process include the sensitivity and risk to the receptor, the extent of the impact, the expected duration of the impact, the expected magnitude of the impact, and the probability of the impact. This standardised approach ensures that the significance of predicted impacts is accurately assessed.
- **Consider cumulative impacts**: The concept of cumulative impacts must be acknowledged and considered in glint and glare impact assessment. This is because increasing the footprint of PV facilities around possible receptors adds to the overall glint and glare risk that will be experienced, effectively resulting in a cumulative effect.

4.4. Mitigation

Mitigation measures were generally not adequately dealt with. The following recommendations are made:

- **Contextualise mitigation measures**: Receptor types differ in terms of sensitivity to glint and glare effects, e.g. an air traffic control tower is more sensitive than a residential dwelling. Mitigation measures should, therefore, be considered within the context of the receptors for which they are being proposed.
- **Evaluate mitigation measures**: Proposed mitigation measures should be evaluated through further modelling, such as, including screening features and different surface types (smooth glass vs. textured glass) in model runs. This is to ensure that appropriate mitigation measures are proposed and to ensure their effectiveness.

4.5. Stakeholder involvement

Stakeholder involvement is an important component of any impact assessment process. Given the potential effect of glint and glare on communities, it is essential to engage key stakeholders during the GGIA process. The learning from the reviewed cases is that there is a lack of stakeholder involvement and so the following recommendation is made:

- **GGIA practitioners should establish a list of key stakeholder groups**: It is possible to identify stakeholder groups that are important for GGIA depending on the project type. For example, aviation authorities should be engaged for projects near airports, road transport, and automobile associations for projects near roads, and housing associations and residents for projects adjacent to residential developments. The list of key stakeholders should form the basis for stakeholder engagement.

5. Conclusion

The transition towards renewable energy sources, specifically large-scale photovoltaic (PV) systems, is a global priority. Consequently, the increase in such developments will lead to more frequent glint and glare impacts on sensitive receptors such as roads and airports. As glint and glare impacts are increasingly being assessed, this study reviewed 20 GGIA cases to serve as an initial step towards developing best practices for GGIA. Applying the recommendations outlined can contribute to improved practice and more effective GGIAs, opening the dialogue for further enhancements in the field.

A limitation of this approach is that recommendations are largely derived from existing practice. So, whilst we can identify what stands out as being the best example of current practice, it is not necessarily the same as being the best way of conducting GGIAs, that is, it might not represent an aspiration for a thorough and credible assessment that is fit for purpose. As suggested in some of the recommendations, existing practitioners are perhaps best placed to take the lead on pushing forward expectation for GGIA practice by opening dialogue and sharing experiences with each other and key stakeholders.

Note

1. All links were active at the time of submission but may stop working depending on the service providers.

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