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TNO-rapport

Radio and visual hindrance caused by solar parks next to waterways

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Samenvatting

Because this is a translation from the original Dutch report https://puc.overheid.nl/rijkswaterstaat/doc/PUC_702009_31/ the Dutch summary has been deleted from this document and can be found in the original.

Summary

Due to the transition to renewable energy, Rijkswaterstaat (in short: RWS; part of the Ministry of Infrastructure and Water Management) receives an increasing amount of permit requests to build solar parks near highways, waterways and other locations managed by RWS. These permit requests should, among other things, be judged on whether the solar park is a hindrance to nearby traffic.

In the past, The Dutch organization for applied scientific research (TNO) has calculated the hindrance to nearby traffic caused by individual solar parks. In this report a wider perspective is adopted. To keep up with the increasing number of permit requests a generic guideline or assessment method has been developed in the current project. This guideline or assessment method should end the necessity to start an entire research project for each individual (proposed) solar park.

TNO focusses on waterways and shipping in the current report. We investigate guidelines for both electromagnetic and visual hindrance. By “electromagnetic hindrance” we mean the hindrance in parts of the electromagnetic spectrum used for communication, information transfer and navigation (Radio, AIS, GPS, 4G, etc.). By “visual hindrance” we mean the hindrance a skipper or relevant personnel ashore experiences due to reflection of sunlight (dazzle). In short, electromagnetic hindrance affects the transfer of information and visual hindrance affects the perception of information.

Both forms of hindrance are complex phenomena in which many different parameters are involved. For electromagnetic hindrance think for example of the equipment properties of both interfering system and receiver, but also the distance and relative position of the two. Calculating the electromagnetic hindrance is done using an advanced model to simulate the electromagnetic propagation of the signals.

With regard to the electromagnetic hindrance, it is noted that the CE label on PV installations does not warrant the absence of interference on nautical communication. Without additional measures, the impact of high-frequent emissions can be significant. To warrant the quality of communication in those cases mitigating measures to the infrastructure would be needed (additional locations with relay stations, directional antennas, etc…) with substantial financial consequences. Although the Radiocommunications Agency Netherlands (AT) observes that -in particular- professional PV installations mostly do conform to the emission standards, this does not warrant that (future) PV systems won’t cause interference or disturbances. The risk of network degradation is most prominent for C2000 followed by AIS/Radiotelephone Service and GNSS systems. A maximum increase in system noise by 3dB should be tolerated.
Beyond that, the minimal audio (SINAD) and data quality (AIS) cannot be warranted resulting in reduced coverage than desired or required.

The increasing number of PV installations and electronic devices with switched power supplies must not jeopardize wireless communication. Our recommendation states that the Directive 2014/30/EU of the European Parliament and of the Council

of 26 February 2014 on the harmonization of the laws of the Member States relating to electromagnetic compatibility be tightened up.

For the visual hindrance the complexity is mostly geometric in nature. The orientation of the solar panels, the skipper and the position of the sun all play a major part. The calculations for the visual hindrance are done using a modified version of the Solar Glare Hazard Analysis Tool. This is a propagation model for reflections which accounts for human observers to determine whether a reflection is obstructive. We find that, like in previous research, most solar panel configurations do not result in significant hindrance in terms of hours per year.
The “worst-case” configuration however can result in a very high amount and duration of hindrance. Identifying these scenario’s is important for safety.

Because of the complexity it is not possible to develop a one-size-fits-all guideline. Every situation and proposed solar park has many different factors that need to be taken into account. To make sense of this complex problem and to start assessing solar parks, this report provides many graphs and tables that can be used to lookup the amount of hindrance caused by placing a solar park in a certain situation. These results are presented for both electromagnetic and visual hindrance. The examples provided should help RWS to apply the results in practice. For the visual hindrance a “tool” is provided where someone can easily input three values and retrieve the exact calculated hindrance for that situation. Using these values a rough estimation of the risk is made based on the calculations and thresholds set in this report. This risk estimate is context dependent and it is up to RWS to decide to what extent a specific risk estimate is acceptable or not. This may depend on specific infrastructural characteristics of the situation. TNO has no influence on how these results will be implemented by RWS.

The current research set up(and the tool), does not allow for assessment of moving solar panels that follow the sun with their energy generating surface. Such solar panels do exist and are actively used, albeit less than static panels at the moment. It is reasonable to assume that moving solar panels could cause more hindrance than static ones. In future research this could be investigated extending the methods developed here..

Contents

Annexes

1 Introduction

The energy transition requires investment in alternative energy sources, such as wind turbines and solar parks. On a large scale, private individuals and entrepreneurs install solar panels on the roofs of houses and buildings. Solar parks are rising on former agricultural land, but also along and in waterways, lakes and in coastal waters.

As a result of these developments, the number of applications regarding the construction of solar parks that arrive at Rijkswaterstaat is increasing. Although Rijkswaterstaat would like to allow solar parks to be built, its task is also to guarantee the safety of shipping traffic. Solar parks can endanger this safety by blinding skippers with the reflection of the sun or by emitting electromagnetic radiation that disrupts radio communication (such as VHF Radio).

Currently, Rijkswaterstaat has no framework to assess the hindrance caused by the installation of solar panels next to waterways. In order to be able to process the increasing number of applications efficiently, there is a need for guidelines. Rijkswaterstaat is asking the Netherlands Organization for Applied Scientific Research (TNO) for help in drawing up this. This report will focus on the hindrance caused by solar parks on shipping traffic. The two themes that will come back are visual hindrance (glare) and electromagnetic hindrance (disturbance radio, 4G, etc.).

This report starts with a literature review to map out what is already known about hindrance caused by solar panels along waterways. For radio hindrance, the focus will be on existing high-frequency emission standards with regard to photovoltaic (PV) installations and the consequences on all safety and communication equipment on ships and shore stations. For visual hindrance, existing models and studies regarding hindrance caused by solar panels along highways and airports will be looked at in particular. These existing forecasts and models are then extended for application to shipping traffic.

2 Theoretical background and literature study

This chapter covers the theoretical background of both electromagnetic interference and visual hindrance.

With regard to electromagnetic interference, the emphasis here is on the electrical components that cause the interference and on the regulations that the equipment must already comply with. We then discuss the effect of these regulations in practice. We pay special attention to any additional measures.

For visual hindrance, we look at the properties of the panels that determine how much light is reflected by them. We briefly discuss a number of mitigating measures to limit this reflection, after which we discuss various models that have been developed over the years to predict how much hindrance one experiences from certain reflections.

2.1 Radio communications and the influence of (electromagnetic) sources of interference

Radio communication can be disturbed by all kinds of electromagnetic radiation. In this report we only discuss human-made sources of interference (man-made noise), in particular by parts of solar fields or PV installations.

To prevent this type of disruption, electrical equipment must comply with the EU Directive (EMCD) which refers to European harmonized standards[1] as agreed by manufacturers and users of the spectrum. They are valid within Europe and also for equipment that is imported into the European Union. The normative part of the directive is objectively defined in terms of maximum emission in dB microvolts/m. This directive is further explained in the next chapter.

2.1.1 Background Electromagnetic Interference

The efficiency of conversion of light to electricity by a solar panel is between 20 and 24% at the current state of the art. In order to limit further losses, the generated electricity must then be converted as efficiently as possible from direct to alternating voltage that can be offered to the electricity grid. So-called inverters provide this conversion with an efficiency that is between 95 and 99%[2].

The exchange of electrical energy between a DC and AC alternating voltage can only be carried out effectively by switching quickly. That is, the DC voltage is, as it were, chopped into pieces, after which it can be transformed and modulated into an alternating voltage that can be offered to the national electricity network, for example. The faster it can be switched, the smaller the energy losses in the system. A side effect of switching quickly is that very large currents run for a short time, creating electromagnetic radiation. If this radiation escapes from the inverter, it is experienced as electromagnetic noise, which can reduce the sensitivity of nearby receivers. This effect is commonly referred to as EMI and EMC ("Electro Magnetic Interference" and "Electro Magnetic Compatibility").

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[1] NEN-EN 55011:2016/A1:2017, pag. 4, EN61000-6-4/A1, pag. 7, 8
[2] Solar Inverter Efficiency - What is the Most Efficient Solar Inverter? - Understand Solar

Without additional measures, a switching converter will emit this energy over a large part of the high-frequency part of the radio spectrum. In practice from a few kHz to the GHz area. So from medium wave, short wave, FM broadcasting, VHF, DAB+, IMT2020, C2000, GNDS, GMDSS to radar. Satellite communication is less sensitive to disturbance because directional antennas are used to look away from the earth, and thus away from possible sources of interference. The intensity of the appearance of switching equipment decreases with increasing frequency.

A well thought-out inverter design, supplemented with filters and shielding around the switching parts of the converter, can minimize EMI effects. However, the extent to which these measures have been implemented varies greatly between the different manufacturers. In particular, some suppliers from China are performing very poorly.

The appearance of a converter is not only decisive for disturbing effects. In fact, the EMC problem consists of 2 parts: the direct radiation through the converter, and what is usually more important: the high-frequency noise current that is injected by the inverter into the cabling to the solar panels. The interplay of these two factors determines the disturbance that is experienced at some distance.

2.1.2 *Signal-noise ratio*

The *signal-to-noise ratio* (SNR) indicates the ratio between the desired information (in the case of VHF: speech) and the background noise on a logarithmic scale. The higher the SNR, the better the speech can be distinguished from the background. The concept of signal-to-noise ratio applies to the reception of radio signals mainly in two areas: at the input of a receiver and after demodulation (for example on the loudspeaker). For the user, the SNR is important after demodulation, because it determines how the audio is experienced or how well digital data is processed. However, the relationship between the SNR at the entrance of a receiver and after demodulation is not one to one. With amplitude modulation (AM) as used in aviation, the relationship is almost one to one. Frequency modulation (FM), on the other hand, has a so-called *improvement factor* due to the larger bandwidth that is occupied than with AM. As a result, for example, an SNR of 10 dB at the receiver input is translated into a 16 dB audio SNR on the speaker.

The audio SNR is sometimes expressed as SINAD (SIgnal Noise And Distortion), where the degree of audio distortion in the chain counts when determining the ratio between signal and noise. In practice, the difference between the measured audio SNR and SINAD at low values (≈ 20 dB) is small. SINAD uses the VHF radio standard when determining the audio quality, which is why reference is made to this in this document

2.1.3 *Communication and navigation levels around airports*

The International Civil Aviation Organization (ICAO) is part of the United Nations and sets standards and requirements for safety for civil air traffic. Requirements for radio communication and navigation are described by the ICAO in various documents[3] which also refer to the International Telecommunication Union (ITU).

SM.1009-1[4] describes interference aspects that can occur between FM broadcasting and aviation communication and navigation.

However, the above documents do not reveal any hard definitions that set a limit for the absolute value of environmental noise or its increase as a result of human activities. However, definitions and guidelines are indicated to prevent the quality of speech and navigation systems from falling below specified limits. For example, in aeronautical communication, the quality of the audio, due to intermodulation by FM broadcasting stations, may not be degraded below a signal-to-noise ratio of 6 dB.[5] A value of 6 dB means that the audio is 4x as strong as the noise or interference produced by FM broadcast transmitters. The degree of interference and the situations in which it occurs means that the ICAO does not always use the same values of minimum audio SNRs. In this[6] ICAO document, a minimum interference ratio of 14 dB is used for mutual interference (e.g. between aircraft using the same channel but communicating with other airports). Noise or interference are generally considered to be the same interference quantity. Signal-to-Noise or Signal-to-Interference are therefore usually indicated by the abbreviation SNR.
There are rules for aviation that guarantee a minimum quality, but no absolute restrictions on ambient noise. Only for communication between satellites and aircraft (AES) there is a specified limit to the increase in ambient noise, namely 25%[7]. *For airports, no specific rules apply with regard to the ambient noise other than previously reported.*[8]

2.1.4 *Principles interference sources and radio equipment*

Electrical and electronic equipment shall meet radiation requirements expressed as a noise-field strength determined at a defined distance from the object. The noise-field strength that the object emits can reach a receiver and thus increase the existing noise floor. The stronger the disturbing noise, the worse the reception of the desired signal. The field strength is expressed in dBμV/m and decreases linearly with distance in clear vision.

Electrical equipment is divided into various classes, such as medical, industrial and consumer, and into power groups. This report will always be based on industrial systems in which the power classes ≤ 20 kVA and > 20 kVA will be used for small and large PV installations respectively.

[3] ICAO-Annex-10-Volume-1-Radio-Navigation-Aids; ICAO-Annex-10-Volume-2-Communication-Procedures; ICAO-Annex-10-Volume-3-Communication-Systems; ICAO-Annex-10-Volume-4-Surveillance-and-Collision- Avoidance
[4] ITU-R SM.1009-1, Compatibility between the sound broadcasting service in the band of about 87-108 MHz and the aeronautical services in the band 108-137 MHz
[5] ICAO-Annex-10-Volume-3, 1.3.1
[6] ICAO-Annex-10-Volume-5-Radio-Frequency-Spectrum-Utilization, 4.1.5.1
[7] ICAO-Annex-10-Volume-3, 4.3.3
[8] Source: Luchtvaart Nederland

For class A equipment (industrial, business or commercial) the following standards apply. The stated measuring distance of 10 m is a reference value and has nothing to do with restrictions on the presence of equipment or safety.

Table 1 Class A group 1 emission limits[9].

Frequency range [MHz]	**Open Area Test Site (OATS) @ 10 m**	
	≤ 20 kVA	**> 20 kVA**
	Quasi Peak dBµV/m	**Quasi Peak dBµV/m**
0.4 - 30	*)	*)
30 – 230	40[10]	50
230 – 1000	47	50
1000[11] - 3000	46	*)
3000 - 6000	50	*)

*) Not specified by NEN EN55011 below 30 MHz and above 1 GHz.

For the waterways, radar, VHF radio, AIS but also C2000 (river police) are of great importance for the safety of shipping traffic.

2.1.5 *Interference scenarios*

The Ministry of Economic Affairs and Climate Policy is responsible for radio communication throughout the Kingdom of the Netherlands, the implementation of which is deposited with the Telecom Agency. The responsibility for safety on the Dutch waterways lies with the Ministry of Infrastructure and Water management (I&W), whereby the implementation is entrusted to the competent authority, namely Rijkswaterstaat or another waterway manager. Communication in shipping has been legally determined by IMO, EU and CCNR, whereby VHF radio is still the most important means of communication on the waterways. Companies, provinces and municipalities are planning fixed or floating PV installations in the immediate vicinity of waterways, so that the risk of serious disruption of radio communication is real.

In this study, we approach the interference problem in two ways, with the field strength values of Table1 as a starting point:

1. Based on an installation that exactly meets the required radiation standards, we can say something about the distance where it should be able to be placed without the need for mitigating measures;
2. Based on an installation that must be placed at a certain distance, we can (taking into account the emission limits) set requirements for the electrical components of the PV installation.

The difference between the approaches is that in the first case a minimum distance to the waterway will have to be maintained, while if stricter requirements can be met (second approach), no minimum distance will apply. In many cases, equipment will be better than the standards require, but that will have to be demonstrated. The standard EMC (CE marking) declaration of conformity is then *not* sufficient

[9] Group 2 equipment mainly includes specific medical equipment, such as MRI and hyperthermic equipment and has significantly higher permitted radiation values.
[10] NEN-EN 55011, Industrial, scientific and medical equipment – radio-frequency disturbance characteristics – limits and methods of measurement (CISPR11:2015,MOD)
[11] Voor frequenties > 1 GHz zal “average” worden gebruikt. Zie NEN-EN-IEC 61000-6-4/A1, Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments

2.1.5.1 *Floating PV-installations*

Floating PV installations[12] offer options to expand the surface area of solar panels. Both on lakes and offshore at sea, projects for the generation of electricity are or are being developed. The differences with PV installations on land are small, the mounting heights will usually be slightly lower because the water surface is the reference, not the land. There are no consequences for the calculations and simulations, as long as the actual heights are maintained.

2.1.5.2 *Approach 1: Examples of installations that meet EMC standards*

The example in Figure 1 shows the areas where the norm of 3 dB ambient noise degradation can be exceeded in imaginary installations. This does not necessarily mean that communication is no longer possible, but the risk of poor or no communication increases. The same applies to the reception of AIS signals, although weak signals will usually mean that the ship in question is still quite far away and an increase in ambient noise is not yet directly relevant. is.

Figure 1 Example of possible interference areas that can have a negative impact on communication on a river, where the maximum emission values according to Table 1 have been adhered to. The circles each have a radius of 500 m, assuming one source of interference (inverter) per location.

In the scenario where no additional measures or requirements are imposed on a PV installation, and interference on the waterway must be prevented, these installations will have to be placed at least 500 m from the waterway in the example scenario of Figure 1 to prevent disruptions.

There are also PV installations with multiple inverters. Often these are the larger PV installations. Figure 1 shows an example of the failure area of such a PV installation. The yellow circle is an installation with more than one inverter, and therefore a joint appearance that is higher at a great distance..

[12] Nationaal Consortium Zon op Water | TNO, Locatie drijvend zonnepark Krammersluizen | Rijkswaterstaat, Drijvend zonnepark Tynaarlo - unieke innovatie (groenleven.nl)

Figure 2 Example where the PV installations have shifted. The purple circles represent locations at a distance of 500 m, the yellow circle the position of an (imaginary) PV installation with more than 1 inverter, and therefore more radiation, where a distance of 880 m must be maintained to stay within the emission standards.

2.1.5.3 *Approach 2: Limit the emission*

Based on the maximum permissible degradation of a VHF connection, the situation can also be reversed: What is the maximum interference field strength that may be generated by a PV installation to stay within it? The path that is then followed is therefore: "a PV installation is planned at distance x of a waterway”. The installation in question shall then not produce more than (for example) 13 dB microvolts/m measured at a distance of 10 m of interference field strength. This is a lot stricter than the standard that says that it (if it concerns a > 20 kVA installation), must remain below 50 dBµV /m in terms of power. A situation like this can occur, for example, when the PV installation is very close to a waterway or close to a traffic post.

The difference between the standard of 50 and 13 dBµV/m in this example seems very large, but some of the current equipment probably already meets this requirement. However, measurement data is usually not made available; suppliers only indicate that they are "certified" and therefore meet the standard.

2.2 Reflections and visual annoyance

Reflections always occur when light falls on a solar panel. Both sunlight and artificial light can therefore create visible reflections for an observer. The main question is not so much how much light is reflected, but where the light is reflected to. In this report we will therefore disregard artificial light since an artificial light source can be placed in any place and can therefore almost always be a hindrance for an observer, provided that the artificial light is sufficiently bright. The orbit of the sun, on the other hand, is fixed and therefore we can determine on the basis of this in which viewing directions there is hindrance caused by light reflections. Although we will not go into it further due to the highly situation-dependent nature of artificial light, very bright artificial light sources are therefore a factor to take into account.

For sunlight reflections, in contrast to the situation for radio communication, there are no generally accepted (international) standards regarding reflections and when they are still acceptable. In this section we first discuss the background of reflections, after which we look at anti-reflection measures. Then we briefly list different models for hindrance. In these models, man and the human eye play an important role.

2.2.1 Background Visual annoyance

Solar panels aim to capture as much sunlight as possible and convert it into electricity. Although modern solar panels are very good at this, reflections always occur when light falls on a smooth surface. The light from the sun that falls on the smooth front of a solar panel will be partially reflected. Solar panels are often aimed in such a way that they capture as much light as possible and will therefore often reflect light.

Solar panels reflect light in the same way as an everyday mirror. Sun reflections therefore also occur when the sun, panels and the driver are positioned in such a way that the panel can serve as a mirror in which the sun is visible to the waterway user. Solar panels therefore reflect very focused light. As with billiards, where a billiard ball bounces against the edge of the table, the same applies to sunlight that the angle of incidence is equal to the angle of dropout. As with billiards, a small change in the angle determines whether or not the ball falls into the pocket, so for a driver a small change in angle or position also determines whether the reflection of the sun is visible in the solar panels.

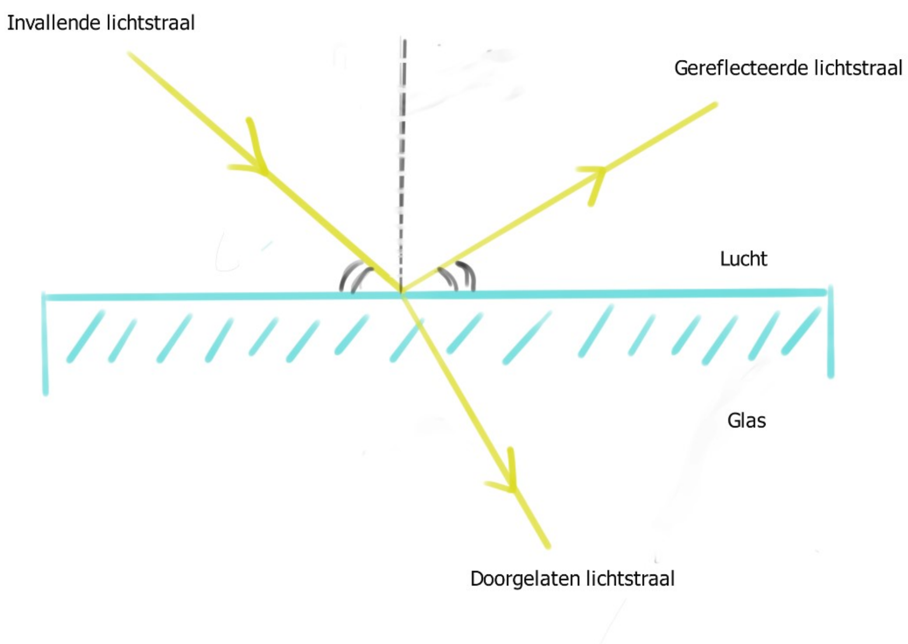

Figure 3. Schematic representation of the reflection process.

Because small changes have a big effect, hardly any generic guidelines have been drawn up for visual hindrance caused by solar parks. What is more common is that one specific situation or set-up is simulated and it is determined on a case-by-case basis whether the hindrance is permissible.

In addition to the (relative) position of the sun, panels and driver, human factors are also important to determine whether the sun reflection is experienced as a hindrance. Factors such as age and eye colour, but also of the viewing direction and reaction time of the observer[13] play a role. It is customary to first calculate on the basis of physical principles whether and how brightly a reflection is visible to an observer. Then, based on the characteristics of the human being and the eye, it is determined whether the reflection is a hindrance.

[13] The "observer" in this research is always a human being. A camera with the same field of view and the same viewing direction will detect the same reflections, however, it depends on the camera specifications whether these are annoying.

2.2.2 *Theoretical background reflections*

The physical principles that determine whether a reflection is visible and how bright the reflection is are known and well described. One clear description can be found in (Zangwill, 2013) and the description below in this report is based on that.

2.2.2.1 *When does reflection occurs*

Reflection of light always occurs when a beam of light leaves one medium and enters another medium. The relevant transition in this report is of course the one where a ray of sunlight first passes through normal outside air and then enters a glass plate. Exactly how much reflection occurs depends on how the two materials differ from each other..

Each material has a certain "optical density". This density determines how difficult it is for light to travel through the material. How difficult it is for light to travel through a material is indicated by the refractive index of the material. In principle, each material has one specific value for the refractive index. It is a material property just like density (for weight) and conductivity (for current). As mentioned earlier, light is reflected on the border of two different materials. For a beam of light, two materials are different if their refractive index differs. The more the refractive index differs, the more light will reflect. If the refractive index of the materials does not differ, no reflection will occur.

An example of this can be found in the video of (Physics Lens, 2020). In it, transparent balls with almost the same refractive index as water are placed in a glass of water. Because the refractive index of the water and the balls is the same, no reflection occurs when a beam of light hits a ball. This makes the balls seem almost invisible. Air has a very different refractive index than water. In air, the balls are therefore easily visible.

2.2.2.2 *Reflection strength*

How strong the reflection is therefore depends on how much difference there is between the refractive index of the two materials. The refractive index of air is 1.0. The refractive index of normal glass is 1.5. Based on this property, the Fresnel equations can be used to calculate how much of the incident light is reflected, given a certain angle of incidence of the light.

To give an idea of the amount of reflection, we give an example here where a beam of light from the outside air falls perpendicular to a glass plate. The amount of reflected light as a percentage of the incident light is then:

$$Reflected\ light\ (\%) = 100\% \cdot \left|\frac{n_{air} - n_{glass}}{n_{air} + n_{glass}}\right|^2 = 100\% \cdot \left|\frac{1{,}0 - 1{,}5}{1{,}0 + 1{,}5}\right|^2 = 100\% \cdot \left|\frac{-0{,}5}{2{,}5}\right|^2 = 4\%$$

That is, if one were to look directly into the reflection of the sun whose rays fall perpendicular to the solar panel, then the reflection is 4% of the strength of the sun. At first glance, this is not so bad, but the reflection increases sharply if the light falls at an angle on the glass plate. Figure 4 plots that dependency. At an angle of incidence of 0°, it can be seen that 4% of the light is reflected. Note that for large angles, the reflection becomes many times stronger.

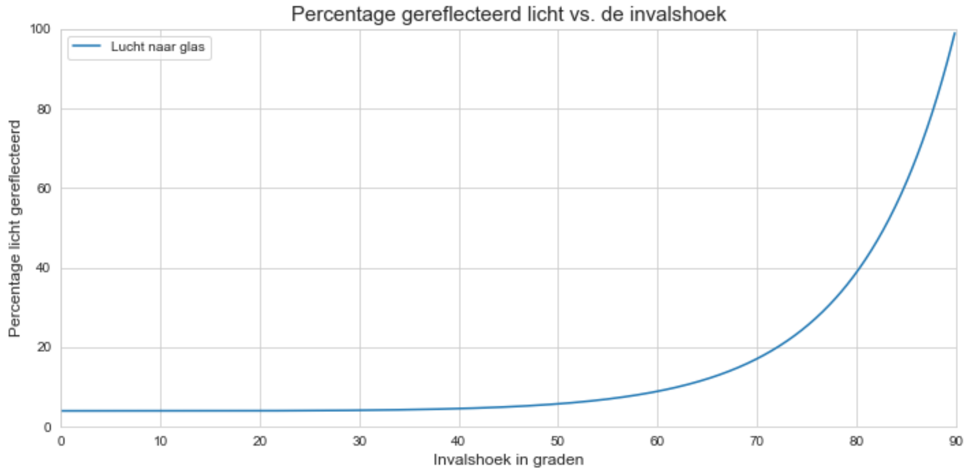

Figure 4 Percentage reflected light at the transition from air to glass and the dependence on the angle of incidence.

2.2.2.3 *Weaken of the reflection*

There are ways to reduce the amount of reflection from solar panels by using anti-reflection coatings. These coatings work because they have a refractive index between that of air and glass. Light that falls on the panel then first goes from air to the anti-reflection layer and then from the anti-reflection layer to glass. The light should then, as it were, not once over a large bump (from air to glass) with a lot of reflection as a result, but two small bumps with twice a little bit of reflection.

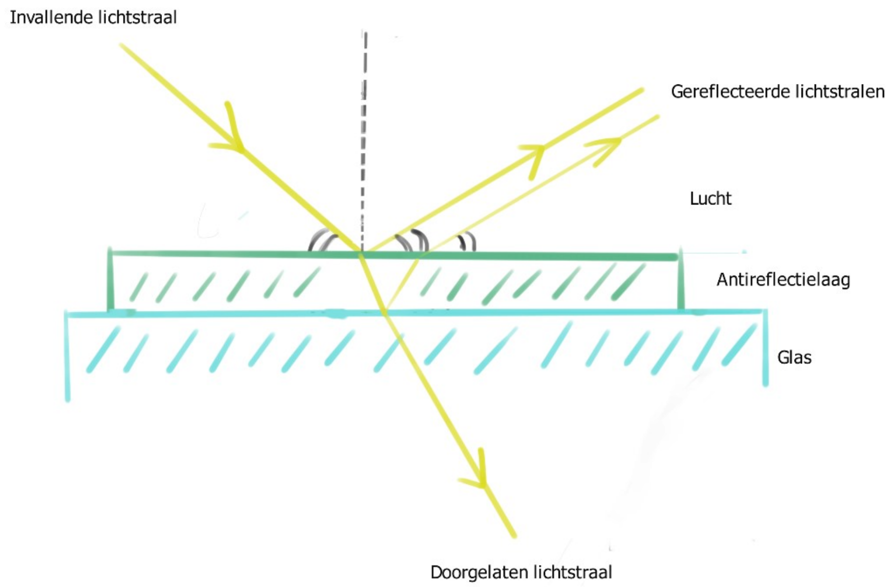

Figure 5. The reflection process when a single anti-reflective layer is applied.

The optimal refractive index of such an anti-reflective coating is 1.23, this would reduce the reflection of perpendicular incidence (the earlier example) from 4% to 1%. For large angles of incidence (where most reflection occurs) adding one anti-reflection layer has less effect, see Figure 4.

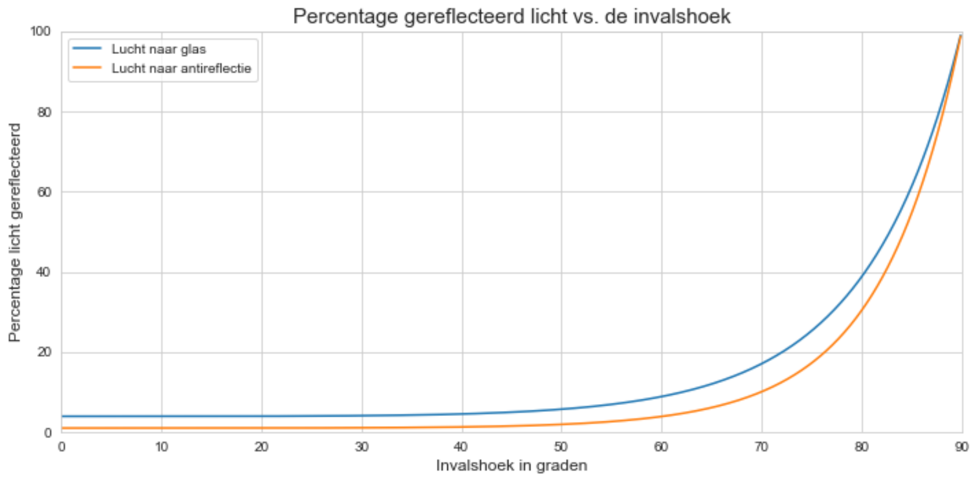

Figure 6 Comparison percentage of reflected light with and without anti-reflective coating

Currently, there are no suitable coating materials with a refractive index of around 1.23. Materials currently used are usually around 1.3-1.4 (Kim & Park, 2013).

In theory, it is possible to use multiple anti-reflective layers so that the transition between the materials always results in a very small difference in refractive index and therefore also very little reflection. Such coatings are currently being developed, but are still at an early stage and therefore quite expensive. Other anti-reflective solutions currently seem better as an alternative.

By making a coating very thin, it is also possible to enhance the anti-reflective effect of the refractive index. This is possible for both single layer coating and multi-layer coatings. The amplifying effect depends on the wavelength of the incident light. Usually, a coating is chosen that most weakens the reflection around 600 nanometres (nm) wavelength, since sunlight radiates the most energy around this wavelength. With multiple coating layers, reflections for multiple wavelengths can be suppressed.

A second way to reduce the reflection does not rest on reducing the reflection itself at all. Reflections in solar panels can be annoying because they are reflective reflections. That is, light that falls on the glass has the same angle of failure as angle of incidence. The direction of the light is retained and therefore objects, such as the sun but also your own face, are visible in the glass. Compare this with wire glass, where the glass is slightly textured. On this glass, the angle of incidence is still equal to the angle of failure, but because the glass has a rough surface, incident light is spread over a much larger dropout angle, since at the microscopic level the angle of incidence is always different. This method of reflection reduction is even less developed than the anti-reflective coatings, but in theory can achieve better results. A perfectly textured panel would look almost matte and therefore hardly be able to cause any hindrance. To get an idea of how much a textured panel suppresses the reflection, we refer to Figure 7, taken from (Ho, Ghanbari, & Diver, 2011).

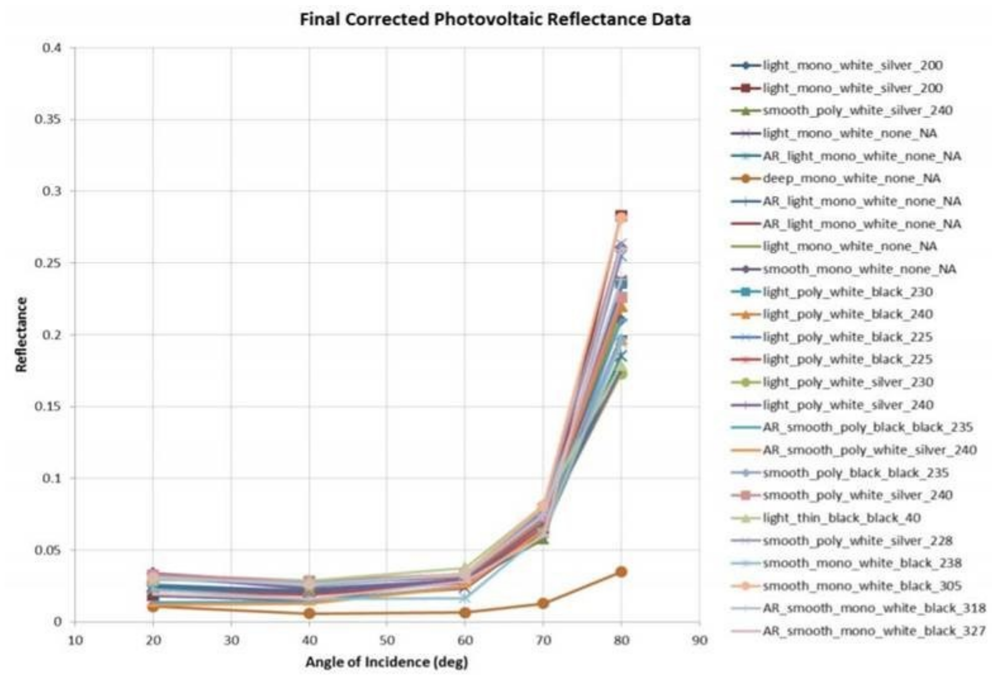

Figure 7 Reflection of different types of solar panels. The lower curve concerns "deeply textured" panels. Source: (Ho, Ghanbari, & Diver, 2011)

2.2.2.4 *Other influences on reflection*

Due to natural conditions, it can happen that the glass plate does not reflect as the theory predicts, for example because it is dusty or wet. It is difficult to quantify these situations properly as they are chaotic by nature.
It is likely that in almost all cases the panels will reflect less than clean panels with a smooth glass plate as the front. Dusty panels absorb a larger part of the incoming light and will therefore look matte. The dust suppresses the reflection. Panels with raindrops on them are expected to reflect the light in more different directions as the raindrops will be spherical. In addition, water (1.33) and ice (1.31) have a lower refractive index than glass (1.5). Even if there is a smooth water layer or ice layer on the panel, it is expected that it reflects less. Only snow could possibly increase the hindrance as snow reflects substantially more visible light.

2.2.3 *The human aspect of annoyance*

In contrast to the physical theory of reflections, the literature is less clear about which light intensities are bothersome to people. There are many reasons for this. First, every human being is different, both in terms of vision and in terms of ability to ignore visual distractions. In addition, hindrance is also context dependent, which means that the same light can be a hindrance in one situation and not in another.

We cover multiple ways to define annoying reflections in the following sections.

2.2.3.1.1 *Discomfort Glare*

The first definition of hindrance is based on the point when it becomes uncomfortable to perceive a certain (reflected) light source. This can be expressed in many ways, but common reactions are a tendency to turn the head away from the light source or hold the hand above the eyes or in front of the light source. De Boer (De Boer, 1967) has developed a scale that, in words, gives a measure of how annoying a (reflected) light source is. The scale was initially developed as a subjective measure to standardize hindrance caused by a light source and thus to be able to perform statistical analyses.

Score	Benaming
9	Niet noemenswaardig
8	-
7	Acceptabel
6	-
5	Nèt toelaatbaar
4	-
3	Storend
2	-
1	Ondraaglijk

Figure 8. The scale of De Boer.

In previous research (Alferdinck, Lichthinder geluidschermen A35, 2008) the limit was that a score of 5: "just permissible" is too low and scores 1 to 5 are therefore considered as light sources that cause uncomfortable glare. This scale can be used for experiments with test subjects, but since these types of experiments are very labour-intensive and time-consuming, an analytical model has been developed that can give an outcome on the De Boer scale based on measurements or calculations. For night and twilight situations one can start from the formula of (Schmidt-Clausen & Bindels, 1974).

In addition, (Alferdinck, Lichthinder van geluidschermen, Fase 1: Literatuurstudie , 2006) has also found an analytical formula that applies to a single light source.

The score on the De Boer scale is mainly determined by the illuminance and the position in the visual field of the observer. This applies to both the Schmidt-Clausen and Alferdinck methods. The brightness of the background and the size of the light source itself also play a role, but to a lesser extent.

2.2.3.1.2 *After images and glare (SGHAT)*

A second way to define hindrance is to rely on the process that takes place in the eye. The Solar Glare Hazard Analysis Tool (SGHAT) from Sandia National Laboratories in the US is based on this (Ho, Ghanbari, & Diver, 2011). This tool calculates, using the laws of physics described earlier, the amount of light that falls on the retina. The angular size of the light source in the visual field of the observer is also calculated. Based on these two measures, it is then calculated how much light falls on the retina and how large the light source is depicted on the retina. A strong light source that seems very large is less annoying than a slightly weaker light source that is focused entirely on one point on the retina.

Given the amount of light per unit area that falls on the retina, it can be determined whether the reflected light source is a hindrance. Experimental research has identified the different areas shown in Figure 9.

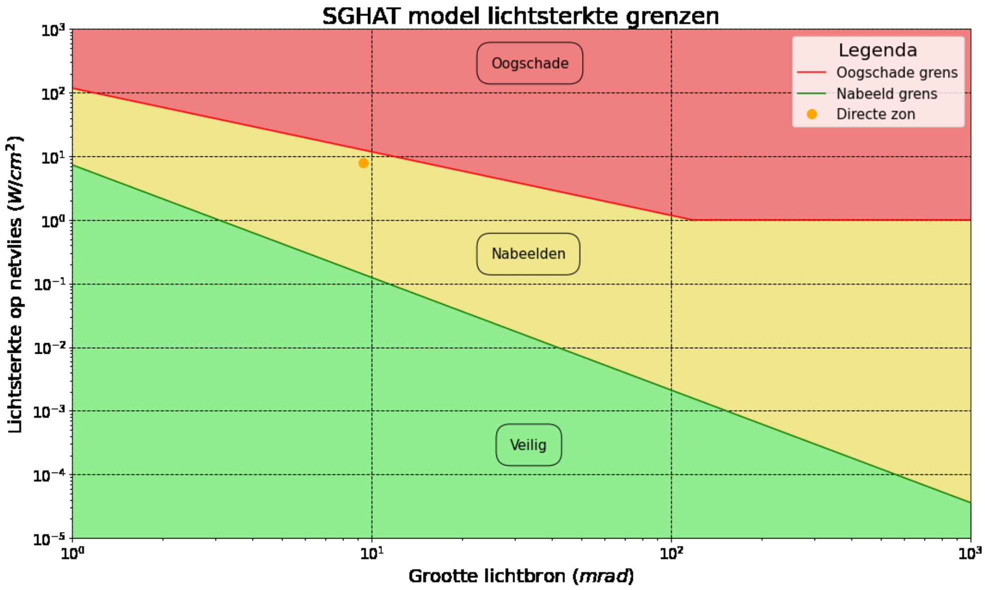

Figure 9. Effect of amount of radiation on the eye. In the green area there are no negative effects, in the yellow area there are afterimages and in the red area there is a chance of eye damage.

The green area is the area in which, in principle, no problems occur. The brightness is relatively low or is spread over a large area on the retina. In the yellow area, the brightness is higher and/or the same brightness is more focused on the retina. This can create afterimages in which the observer continues to see the sun even though it has already disappeared from the field of view. The red area is about extremely high brightness's or luminous strengths that are very much focused on one point on the retina. These light intensities can cause eye damage. The data is about an exposure time of 0.15 seconds, the normal time for a flashing reaction.

With this information, it can therefore be determined on the basis of the brightness that falls on the eye and the size of the light source whether the reflection is permissible (green area), annoying (yellow area) or dangerous (red area).

2.2.3.1.3 Disability Glare

Where the "discomfort glare" is based on the (subjective) reaction or experience of the observer, the "disability glare" is based on the observer's ability to distinguish an object from its surroundings.

Again with the help of the laws of physics described earlier, it is possible to calculate the contrast between objects for an observer. If the contrast is too low, an observer cannot reliably distinguish between the object and the background. As a result, there is a good chance that the observer does not see the object correctly or not at all. If an observer cannot distinguish an essential object, the reflection is a hindrance. For research on motorways, the limit has been that the driver must be able to distinguish the road markings at all times.

The road marking is ideally suited as a criterion because it is standardized on Dutch roads and is essential for performing the driving task.

A second aspect that is explicitly taken into account in this model concerns the characteristics of the observer himself, such as age, eye colour, reaction time, etc. People with lighter eye colour and older people are more likely to be bothered by reflections. In the "disability glare" model, these properties are explicitly included where in the other models they are hidden behind a formula ("discomfort glare") or a graph (SGHAT).

2.2.4 *Influence of sun reflections on traffic*

In the past, all these models have been used for research into hindrance caused by reflective surfaces in traffic situations. However, waterways have never been specifically looked at. Instead, research has often been done on motorways and airports. Since a large part of the models are not context-specific, some of these studies are described below.

2.2.4.1 *TNO research into disruption caused by solar panels*

TNO has done a lot of research in the past into hindrance caused by solar panels and reflective noise barriers along highways. Although there are some differences with waterways and boat traffic, there are also many similarities. The solar panels obviously reflect in the same way, the drivers are similar people in both situations and in both cases the driver is focused on a similar driving task. The differences in the two situations are mainly in the speed and manoeuvrability of the vehicle and the relative position of the driver in relation to the panels. For example, there will be more variation in height among skippers than among motorists. In addition, there will also be more variation in the lateral distance between the ship and the quay/solar panels than the lateral distance between lanes and the verge. With these differences in mind, it is useful to look at previous research into light pollution from solar panels along highways.

2.2.4.1.1 *Specific situations*

TNO has calculated many specific situations to see whether proposed solar parks would be acceptable for transiting traffic.

a) In the (Alferdinck, Analyse van reflectie zonnepanelen langs de A15, 2015) investigated how much hindrance occurs from a solar park with solar panels on the south and south-east-south that lie fairly flat on the ground (an angle of inclination of 18°). The road along which the panels would be located is towards the southwest and northeast. There is a reasonable lateral distance (tens of meters) between the motorists and the solar panels. It turned out that for 20 hours during the year there were reflections that were visible to the driver. For 14 of these hours, the norm as calculated by the discomfort glare model is exceeded. That is, the reflection has a calculated score of 3 or less on the De Boer scale;
b) In the (Alferdinck & Kooi, Lichthinder geluidsschermen A28 bij Zeist, 2013) looked at the hindrance in a residential area adjacent to a highway with a noise barrier. The residents looked straight at the noise barrier from the south, which was approximately in the direction of east-west. It was calculated that the residents could observe reflections for about 20 hours a year. This research has not been able to identify any hindrance because residents can easily avert their gaze from the reflection and therefore the known models do not give a consistent outcome as they all depend on viewing direction.

c) For the research into light pollution caused by noise barriers near Amersfoort (Alferdinck & Kooi, Lichthinder geluidsschermen A28 bij Amersfoort, 2013) it has been calculated how many reflections are visible to road users. In addition, the discomfort glare model has calculated how often the reflections are annoying (score 3 or lower). The road runs roughly towards south-north, with the noise barrier placed on the east side. The drivers do not experience much inconvenience. Most locations experience zero hours of disruption per year. Some locations receive nearly 15 hours of reflections per year, some of which are bothersome.
d) Also within (Alferdinck & Hogervorst, Analyse lichthinder toekomstige geluidsschermen A4 bij Steenbergen, 2014) it was determined on the basis of the discomfort model how much hindrance future noise barriers would cause. The road situation here is more complicated than in previous studies. For this location, it turned out that in some cases reflections would be visible for up to 90 hours a year, which were also a hindrance for about 20 hours a year. In the study, some mitigating measures have been proposed that can limit the hindrance. The focus is mainly on reducing the reflecting.

2.2.4.1.2 TNO comparison models

In the development of the disability glare model (Alferdinck, Goede, & Buuren, Lichthinder zonreflectie voor weggebruikers – ontwikkeling beoordelingsmethode op basis van disability glare, 2016) is the differences of that model with the TNO discomfort glare model and the SGHAT were strongly discussed. The different strengths and weaknesses of each model were examined in response to simulated situations.

One of the simulated situations concerns a solar park with a size of 400x400 meters that is placed 9 meters from the road. The solar park is oriented to the south and the adjacent road is an east-west road. An anti-reflective layer has been applied to the panels in the simulated solar park. This study has shown that the TNO discomfort model and the SGHAT model predict approximately equal values for the amount of hindrance defined as uncomfortable reflections or reflections that cause afterimages. It is TNO disability glare model predicts less hindrance, but defines hindrance as reflections that ensure that the road markings can no longer be observed. In a way. It is TNO disability glare model is slightly easier than the TNO discomfort glare model and the SGHAT.

Another simulated situation concerns a noise barrier that reflects next to the road. A difference has been found between the discomfort model and the SGHAT. The SGHAT predicts a chance of afterimages much more often than the discomfort model predicts an uncomfortable reflection. The disability model then predicts inability even less often than uncomfortable situations.

If we look at all simulated situations, it has been found that the discomfort model predicts about 1.67 times as much hindrance as the disability model. The SGHAT predicts about 2x as much hindrance as the discomfort model (3.34x as much as the disability model). The SGHAT therefore seems to be the most strict option to determine hindrance. That the SGHAT is the strictest is not surprising. The SGHAT takes the least account of the context, as it is purely based on brightness. The disability model, on the other hand, specializes for use on highways. As a result, the disability model can "approve" reflections that may generate some afterimages, but do not have a strong influence on driving behaviour, for example because they are too short, easy to block from the visual field, are not bright enough to hide essential objects in traffic, etc.

2.2.4.1.3 TNO study guidelines for highways

TNO recently conducted a study into drawing up rules of thumb for annoying reflections by solar panels along highways (van Emmerik, van der Sanden, & Alferdinck, 2021). The purpose of these rules of thumb was to give an immediate answer to the question of whether this is safe for some of the situations where Rijkswaterstaat sees opportunities to build solar parks, without having to calculate specific situations as in previous reports. At its core, the goal was to divide the situations into three categories: "Safe", "To investigate further" and "Unsafe". The first and the last category therefore no longer have to be calculated in detail.

This research emphasizes how complicated it can be to draw up a single rule of thumb or guideline that sets a limit to reflection. The reason for this is that mirrored reflections are a very focused phenomenon. As described in 2.2.1, the angle of incidence is equal to the angle of failure and a small change in direction can therefore have major consequences. Nevertheless, it is possible to calculate the average amount of hindrance for certain groups of situations and thus give an estimate of how much influence changing specific factors has. Not all factors are equally relevant for the research of waterways, but we highlight some interesting factors here:

1) By far the strongest influence on the amount of hindrance is given by the combination of viewing/driving direction and the orientation of the panels. This combination directly determines whether reflections are visible at all and also largely determines to what extent these can be a hindrance.
2) Looking directly at the panels is much less likely to cause hindrance than looking past the panels. Due to the larger angle of incidence, the reflection through the panels is much stronger.
3) An almost optimal anti-reflective coating (refractive index 1.25) has relatively little influence on the amount of hindrance generated. The amount of hindrance decreased by an average of 11% in this study.
4) The lateral distance to the solar panels (i.e. how far left or right in the visual field the panels are) had a very strong effect on the amount of hindrance generated. A solar park at a lateral distance of 30 meters generated only (about) 19% of the hindrance that the same solar park generates at a lateral distance of 3.8 meters.
5) The height difference between the panels and the driver plays a particularly important role when the panels are raised. This is not an unusual situation as panels are often raised to maximize power output.
6) Panels to the left and right of the driver's viewing direction reflect at completely different times of the day and year. It is therefore worth looking at these separately. Although this has not been further investigated in the report, the interaction between viewing direction and panel orientation does give rise to this.

2.2.4.2 *Sandia National Laboratories research*

Sandia National Laboratories is the developer of the SGHAT. They have developed this tool mainly to prevent annoying reflections around airports, but since there are no context-specific properties in the model, this can also be used for other purposes. Sandia National Laboratories has also put the model into practice. There are not many reports known about the use of this tool as it was initially released as free-to-use. It is therefore not known how many projects have used the tool. Nowadays, the tool is no longer free to use because Sandia falls under new cybersecurity rules.

2.2.4.2.1 *Soscol Ferry Solar Facility*

One example of an analysis done on the basis of the SGHAT software is the analysis of a very large solar park in America (Thomas Cleveland, 2019). This involved looking at hindrance caused by the solar panels for a nearby airport, several nearby highways and viewing points from certain buildings and offices in the area. In this particular study, it was found that the proposed solar park will not generate significant disruption to any of the observation points. Based on the findings in the report on rules of thumb (van Emmerik, van der Sanden, & Alferdinck, 2021) the finding in this report is not surprising since all observation points are at a great distance from the solar park. In some cases it is possible to see some afterimages through reflections of this solar park, but that does not happen often during the year.

3 EMC directive 2014/30/EU of the European Parliament and of the council

When determining possible disruption caused by solar panels and inverters, the European Directive that deals with this must always be taken into account. This chapter examines the interpretation of this Directive, which applies to almost all electrical and electronic equipment in Europe.

3.1 European free trade and EMC-policy

In the eighties and nineties of the last century, the European Union drew up an EMC directive to facilitate the free movement of goods within the European Union. Free trade between Member States is covered for electromagnetic compatibility by the EMC Directive 2014/30/EU (EMCD) and a set of harmonised standards covered by this Directive has been published in the Official Journal of the European Union. The EMCD prescribes limitation of the electromagnetic radiation to ensure the immunity of the device to a certain level of electromagnetic field strength. An example of the latter aspect is the interference that 3G phones in particular caused in audio installations. In TV recordings, it was, and is, invariably asked to turn off phones (or at least on airplane mode), because as soon as a call arrives at a phone, the phone will answer it with a transmission signal. When the audio installation in a studio is not sufficiently shielded from electromagnetic signals, the transmitting telephone causes an audible rattle in the TV recording..

On the emission side, the EMCD maximizes the intensity of electromagnetic radiation that may be emitted by an electrical or electronic device. This refers to radio signals that are (unintentionally) transmitted over large parts of the frequency spectrum. The harmonised standards set a field strength limit value, as a magnetic or electric field strength, which shall not be exceeded at a defined distance. These unintentional radio signals often have high-frequency rattle, pulsed noise or white noise characteristics that can make them similar to normal radio ambient noise. The effect of these emissions may be to increase ambient noise near a receiver, which may limit its operation. Most equipment produced and imported into Europe must comply with EMCD.

3.2 EMC-standard and effects on wireless communication

When drawing up the EMCD and the associated EMC standards in the eighties and nineties of the last century, individual (relatively small) systems were used. PV installations hardly existed or barely existed and were small in size. Neither the size nor the large number of PV installations was taken into account in the original drafting of the Directive. In addition, a deluge of cheap electronic equipment has appeared on the market that draws its energy from switched power supplies. The large number of these electronic devices contributes to the increase in man-made noise, especially in the built environment. In order to prevent disruptions to radio communication as a result of the increase in ambient noise from increasing further, stricter radiation standards should be drawn up. This would mean that other, costly, measures such as the installation of additional base stations, support transmitters or repeaters for VHF radio, AIS, IMT-2020, C2000, DAB+, etc.) can be avoided.

However, the major changes in the amount of electrical and electronic equipment in society do not yet lead to a tightening of EMC standards[14], despite pressure from various parties, including the IARU.[15]

3.3 Essential requirements

The EMCD obliges manufacturers to design that meets the essential requirements. The EMCD sets out the essential requirements as Annex 1 as follows:

1. ***General requirements:***

Equipment must be designed and manufactured, taking into account the state of the art, in such a way as to ensure that:

a) ***the electromagnetic disturbances generated do not exceed the level above which radio and telecommunications equipment and other equipment can no longer function in accordance with their intended purpose;"***

Manufacturers can test the essential requirements against harmonized standards. If a manufacturer complies with the limit values set out in the relevant harmonized standards, there is a presumption of conformity for apparatus which satisfies the essential requirements[16]

The harmonized standards for the amount of radiation have been drawn up on the assumption that this does not lead to an unacceptable deterioration in the functioning of radio equipment. This means that the reception of, for example, FM broadcasting and DAB+ must not deteriorate to such an extent that the coverage of the existing transmitters is no longer sufficient. The same applies to means of communication such as VHF radio, C2000 and IMT2020: the effects of radio noise due to a device must not lead to unacceptable degradation. With IMT2020 (mobile telephony), the signal margins are often very high, because they are "interference-limited" networks, which means that human environmental noise is less likely to be affected. The planning of broadcasting networks takes into account a built environment, indoor coverage and electronic equipment, and therefore there is slightly more margin for radio interference from PV installations. This does not apply to, for example, the C2000 network and VHF radio.

The ITU makes contributions by identifying natural and human contributions to environmental noise, in so-called "ITU-Recommendations[17]". Based on this, boundaries can be set for the specific environment in which communication takes place.

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[14] André Canrinus, chair of the EMC-EMF committee of the VERON and delegate of the NEC-EMC and NEC-EMF meetings in The Netherlands
[15] IARU: International Amateur Radio Union
[16] Regulation (EU) No 1025/2012 of the European Parliament and of the Council of 25 October 2012 on standardization.

The general requirements set out in Annex I to the EMCD may be interpreted as a specific protection if a communication or navigation system can no longer function according to its corresponding destination. This seems to be independent of the fact that the source of interference in question complies with the harmonized (product) standard. The general requirement for manufacturers is also underlined again in Article 7 of the Directive:

Obligations of manufacturers
1. When placing their apparatus on the market, manufacturers shall ensure that it has been designed and manufactured in accordance with the essential requirements set out in Annex I.

Annex I is an essential part of the EMCD and is a top priority. Experience[18] shows that even if a device complies with the harmonized EMC standards, disruption of the affected radio service can be expected (or experienced) in such a way that sometimes a contradiction arises with the essential requirements listed in Annex I. In such cases, it can therefore be demonstrated that the previously indicated presumption of conformity is incorrect and that the affected radio and telecommunications equipment can no longer function in accordance with their intended purpose. The EMCD does not offer a solution for these situations. Article 5 allows individual States to derogate from the harmonized standards in specific situations:

Free movement of equipment

[...]

2. The requirements of this Directive shall not prevent the application in a Member State of the following special measures concerning the putting into service or use of equipment:

a) measures to remedy an existing or foreseeable electromagnetic compatibility problem at a given location;

b) measures taken for security reasons to protect public telecommunications networks or transmitting or receiving stations, if they are used for security purposes in clearly defined spectrum situations.

Without prejudice to Directive 98/34/EC of the European Parliament and of the Council of 22 June 1998 laying down a procedure for the provision of information in the field of technical standards and regulations (1), Member States shall inform the Commission and the other Member States of these special measures

The special measures adopted shall be published by the Commission in the Official Journal of the European Union.

It is up to the Dutch authorities to determine whether nautical communication and navigation systems fall under point (b) of Article 5 of the EMCD.

[18] Voorkom storingen door zonnepanelen | Tips voor veilig gebruik van apparaten | Agentschap Telecom; Zonepanelen storen als een gek op radio - Kassa (bnnvara.nl); storingen-veroorzaakt-door-pv-2-0-1.pdf (hollandsolar.nl)

3.4 Who is responsible?

The EU's interpretation of the essential requirements is worded as follows [19]:"….Harmonised standards […] provide a recognised methodology to **demonstrate compliance with the essential requirements** and are usually the preferred way to demonstrate compliance. The manufacturer may ask a third party to perform the EMC assessment for him or help him with part of it, but the manufacturer is and remains fully responsible for the compliance of his apparatus with the provisions of the Directive…..". If the individual parts of a system do, but the whole (for example because wiring has been added) does not comply with the EMCD, then the manufacturer is responsible for taking measures

The EMCD seems to assume that "If there is a suspicion of EMC compliance, no disruption will occur". There is no mention of situations where unacceptable disruption occurs, despite compliance with EMC standards.

The conclusion to be drawn on the basis of this analysis is that a PV system that complies with the standards will, as a rule, be allowed to be placed (other objections aside). If in practice hindrance is caused by the receiving installation, the essential requirements do not provide a legal framework to require adjustments. Only in exceptional cases (national security) can the government enforce concrete measures. As a rule, a solution is usually sought in consultation. Further research into case law in this area falls outside the scope of this investigation.

In summary: In the previous description of the EMCD, the essential requirements play a crucial role: They describe that wireless equipment must not experience unacceptable malfunctions in the functioning of other electrical and electronic equipment. To make this measurable, reference is made to EMC norms and standards. If the device in question meets the radiation standard, a *presumption* is established that the device also meets the essential requirements, after which the product receives a CE mark with regard to EMC. This *presumption* is no longer tested for a specific situation, i.e. if the radiation standard is below the "standard limit", then the device is approved on the EMC aspect.

[19] Guide for the EMCD (Directive 2014/30/EU, DocsRoom - European Commission (europa.eu)

4 Methodology

4.1 Electromagnetic disturbance

Increasing ambient noise at a ship or shore receiver is the crucial factor on which the calculations are based when determining the effects of PV installations. An increase in ambient noise implies that the initial situation may have changed and that it must first be determined to determine the effects of external noise influences. Literature from the ITU and NTIA (National Telecommunications and Information Administration) will be used for this purpose. In Appendix A, the considerations and calculations that lead to the determination of the reference background noise have been carried out. The curve resulting from the calculations will be used in this document to determine the acceptable interference and the associated distances from PV installations to receivers.

Antenna heights on ships and shore stations, together with the installation heights of PV installations, determine to a large extent the distance at which the effects of radiation can be observed. As soon as the view is blocked, for example by a dike, the noise emission effects will also decrease sharply. This report will always assume a flat earth without obstacles, which is a worst-case scenario. The two-beam model is used to calculate the effects of PV installation on shore and ship antennas with the height as a variable.

In summary we want to determine and calculate the following:

a. The reference background noise over the entire operational spectrum;
b. What is the acceptable increase in ambient noise (= interference from the PV installations);
c. Antenna heights on shore and on ships;
d. Installation heights of PV installations;
e. Based on the EMCD minimum distances from PV installations to receivers;
f. Based on the acceptable increase in background noise, for a given position of a PV installation, the maximum emission field strength.

The problem of noise interference is approached in two ways:

1. Starting from the EMCD, as defined in Table , for installations of ≤ 20 kVA and > 20 kVA.
2. The *receiving* side sets the standard, i.e. ship or shore station situation is decisive. The result will be that a PV installation may generate a maximum defined fault at a specified distance to the receiver, expressed in a field strength.

Ad.1 In the calculations for electromagnetic hindrance, the existing "high-frequency emission standards with regard to PV installations" are the starting point. In order to determine the consequences on all safety and communication equipment on ships and shore stations, the following steps are taken:

1. Choosing a range of input data with regard to antenna heights on shore and on ships as well as the installation heights of PV installations.
2. Calculating distances at which the interferences are acceptable. What is and is not considered "acceptable" will be explained.
3. Visualizing the relationship between input values and distances.
4. Results are presented in graphs, text and/or formulas.

Ad.2 Based on the receiving location and a *given position* of a PV installation, calculate the maximum high-frequency emissions. For this we draw up a maximum acceptable degradation of communication, safety and navigation systems, based on the principle of among other things, the standards as used around airports will be looked at when determining the acceptable degree of degradation. The step-by-step plan is comparable to the hindrance determination based on the appearance according to the standards, whereby only step 2 is reasoned from 'the other side':

1. Choosing a range of input data with regard to antenna heights on shore and on ships as well as the installation heights of PV installations.
2. Calculating the maximum field strength in relation to the expected (acceptable) degree of degradation.
3. Visualizing the relationship between input values and distances
4. Results are presented in graphs, text and/or formulas.

The result will be broken down by the effects for different frequency bands so that they can be translated to the different types of communication equipment.

4.2 Visual disturbance

In the research into guidelines for solar parks along highways (van Emmerik, van der Sanden, & Alferdinck, 2021) TNO has found that the most important factor is the orientation of the solar panels. The position of the sun and the direction of travel or departure are fixed for almost all situations. Other factors often only have a mitigating impact, such as the decrease in reflections due to an anti-reflective coating. Therefore, the guidelines (for visual hindrance) drawn up in this report will relate to the orientation of the solar panels in combination with the viewing direction of the observer.

We will calculate the visual hindrance using the same method as the SGHAT. We elaborate on this in section 4.2.1. Although this is a method that, compared to the TNO disability model, is quite strict, it is also a generic approach that does not require any further adjustments. The TNO disability model is based on measured values of objects that will occur in the specific context (in this case shipping). To date, there is no conclusion about an object within shipping that can be used as such a measure. That is why it is not possible to use the TNO disability model within shipping. The TNO discomfort model is based on a certain background luminance. Although different standard values are available for this, it has been decided to go for the purely biological measure of the SGHAT in order to keep the results as generic as possible in order to make the guidelines widely applicable.

The guidelines will be determined in the same way as in the report for highways (van Emmerik, van der Sanden, & Alferdinck, 2021). Since it is very difficult to predict how the hindrance between two situations (for example with differently oriented panels) relates, it was decided to sample the entire space by means of simulations. This means that for the SGHAT method all input parameters are determined. It is then determined whether each parameter can be standardized. If this can be standardized by, for example, maintaining a worst-case scenario, then that is done. If the parameter cannot be standardized, it will be varied over all possible (realistic) values.

In this study, it was decided to focus only on the relative positions and orientations of the driver and the solar panels. The direction of travel of the driver, azimuth of the solar panel and the angle of inclination of the solar panel will therefore be varied. Also, roughly speaking, the location of the solar panels in the visual field (left or right of the driver) will be taken into account. The viewing/sailing direction will be sampled at every 10° (compass angle). The orientation of the solar panels will be sampled every 5°.

As a result of these simulations, we will calculate for almost fifty thousand combinations of sailing direction and panel orientation how many annoying reflections occur during the year. We then summarize these results in an Excel sheet and various tables and graphs. As far as possible, we will also convert these results into guidelines without references to the underlying data, but due to the focused nature of the reflections, this may not be possible for all situations..

4.2.1 *Technical terms*

Since geometric concepts such as azimuth, angle of inclination, (viewing) direction and orientation constantly recur in the analysis of visual hindrance, we define them explicitly here.

Solar panels are precisely defined by the combination of azimuth and angle of inclination. The **azimuth** of the solar panels is the compass direction in which the reflective plane of the solar panels is oriented. In everyday language, the compass rose is only used with the help of wind directions (eastern, south-western, etc.), but these names do not give enough precision for this research. In this report, the compass directions are therefore named using a number of degrees, where 0° is the north and the compass rose is rounded clockwise. A visualization can be found in Figure 10. If a solar panel has an azimuth of 90°, this means that the front of the solar panel is oriented to the east. An illustration of this example can be found in Figure 11

Figure 10. A compass rose where the number of degrees is indicated along the outer edge. The four wind directions are North (0°), East (90°), South (180°) and West (270°).

Figure 11. Solar panels with their front facing east. These panels have an azimuth of 90°.[20]

The azimuth of the solar panels only indicates in which compass direction the panels are located. However, the panel can lie almost against the ground or stand upright, this is indicated by the **angle of inclination** of the solar panels. The angle

[20] The solar panel icon is coming from flaticon.com

of inclination is the angle that the solar panel makes with the (horizontal) ground. If the panel is completely horizontal on the ground, the angle of inclination is therefore 0° and if the panel is completely upright, the angle of inclination is 90°. An angle of inclination of more than 90° is not possible in our definition. This would mean that the energy-generating surface is directed downwards. In practice, this never happens because it is unfavourable for the yield of the panels. Figure 12 shows an illustration for an intermediate angle of inclination. Note that the angle of inclination is determined in relation to a horizontal. Normally this is the ground, however, if the panels are placed on an embankment, sloping quay or another ascending or descending surface, the angle of the subsoil must be settled in the angle of inclination.

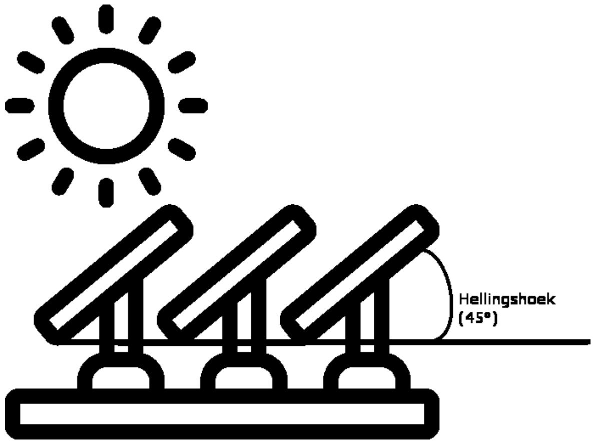

Figure 12. An illustration of the angle of inclination. The more upright the panels are, the greater the angle of inclination and the flatter they are, the smaller the angle of inclination.[17]

The angle of inclination and the azimuth of the solar panels together determine a unique orientation of the solar panels. When we talk about the **orientation** of solar panels, we mean the unique combination of azimuth and angle of inclination with which the solar panel is defined.

The **viewing direction** of the observer is defined in the same way as the azimuth of the solar panels. Using an angle, a unique compass direction is called in which the observer looks. There is no equivalent of the angle of inclination for the viewing direction as it is assumed that the observer is looking at the horizon (an angle of inclination of 0°).

4.2.2 SGHAT Simulation method

The complete (adapted) SGHAT model that TNO uses to calculate the hindrance has the following structure:

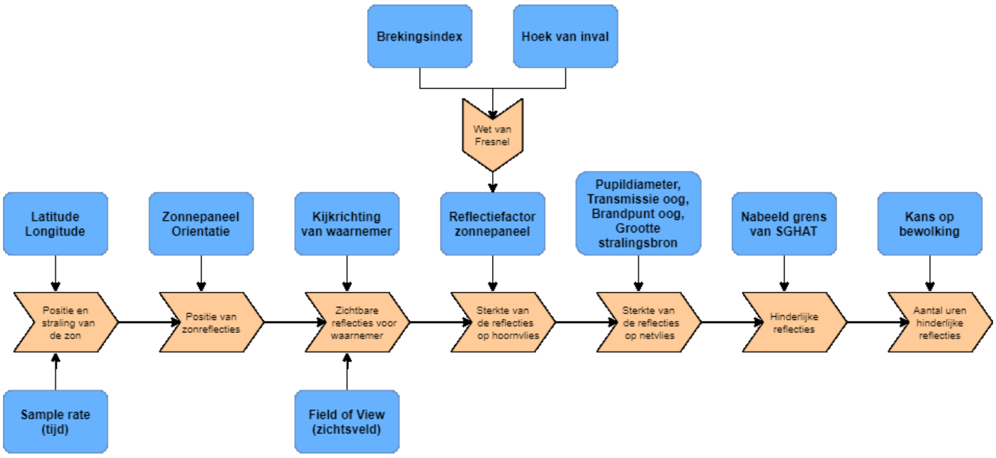

Figure 11. Process that the SGHAT model goes through to determine how many hours of hindrance per year an observer experiences. In blue, parameters that must be filled in in the model and in orange are the calculations that the model performs.

The model has a number of parameters that need to be varied, but a large part of the parameters can also remain the same. The choice of parameters can be found in Table 2.

Table 2 Different parameters and their values in the SGHAT model.

Parameter	Value
Latitude	52°
Longitude	5°
Sample rate (time)	1 minute
Solar Panel orientation	*Varies*
Viewing direction	*Varies*
Line of sight horizontal	120°
Line of sight vertical	40°
Breaking index	1,5
Angle of inclination	*Varies*
Pupil diameter	0,002 meter
Transmission coefficient eye	0,5
Focal length eye	0,017 meter
Size radiation source	0,0094 radial
Afterimage boundary	0,139 W/cm^2
Chance of clouds	66,67%

The parameters where it is indicated that these are varied are parameters that are filled in with a certain range and on which the final result will therefore depend.

We go through each calculation step and parameter choice in this section of the report.

SGHAT was primarily developed for assessing the sun reflection of solar panels and mirror installations. Based on the position and the location of the solar panels, it can be calculated whether the reflection can be annoying or harmful. Based on the irradiance (W/cm2) on the eye and the size of the radiation source (visual angle in radians), the glare situation is classified into one of the following categories:

- Low risk of afterimage
- Risk of afterimage;
- Risk of eye damage (burning of the retina).

Figure 9 shows a graph showing three different categories including associated irradiance and visual angle. The lines in the figure indicate the boundary between two categories. An exposure duration of 0.15 seconds (average flashing reaction time) is assumed. Finally, it is indicated where the sun would be on this graph (yellow dot).

The SGHAT model takes into account the size of the radiation source. An object that does not reflect exactly like a mirror, but (partially) sends the light in other directions can take up a larger visual angle. The SGHAT model can take this into account. In addition, it is also possible to model hollow or convex mirrors with the SGHAT model. However, this study is based on completely flat solar panels. Flat panels reflect like a mirror and therefore do not distort the size of the reflection. The reflections will therefore, like the sun itself, cover a visual angle of 9.4 mrad. However, the reflections will have different irradiances, since the sun is not always perceived as brightly (by the day and over the year). The formula used to calculate retinal irradiance is as follows:

$$I_{retina} = I_{cornea} \cdot \tau \cdot \left(\frac{d_p}{f\omega}\right)^2,$$

where I_{retina} is the irradiance on the retina, I_{cornea} is the irradiance on the cornea (just outside the eye), τ the transmission coefficient of the eye, d_p the diameter of the pupil, f the focal length of the eye and ω the size of the radiation source. For transmission coefficient, pupil diameter, focal length and source size are default values for daylight conditions chosen, as shown in Table 2.

If the default values from Table 2 are entered in the formula for irradiance on the retina, we find that: $I_{retina} = 78{,}3 \cdot I_{cornea}$. It may be clear that the eye strongly focuses the irradiance on the cornea on the retina since the "power" per square meter increases by 78.3 times.

The limit for afterimages of a radiation source with a size of 9.4 mrad is 0.139 W/cm^2 in the SGHAT model. The limit for eye damage (for a radiation source with a size of 9.4 mrad) is 12.6 W/cm^2. The limit for eye damage is slightly higher than the irradiance that one receives by looking directly at the sun. Since a mirror image (in a flat mirror) can never be brighter than the light source itself, the reflections in this report will never exceed the limit of eye damage..

4.2.3 *Additions to the SGHAT model*

The SGHAT model does not take into account two factors that, as shown in previous research (van Emmerik, van der Sanden, & Alferdinck, 2021), play an important role in determining the amount of hindrance: the viewing direction of the observer and the angle of incidence of light on the panels. The driver's viewing direction is important because it excludes a large part of the reflections (reflections in the back are not included). The angle of incidence of light on the panels is important because it determines how much light is reflected by the panels (according to Figure 4).

The irradiance of the sun is further weakened because a large part of the light that falls on the solar panels is let through to be converted into electricity. Only part of the light that falls on the panels is reflected. In the original SGHAT model, this is taken into account by using one constant reflection factor. In this report, this factor is replaced by the Fresnel reflection coefficient that depends on the angle of incidence.

The viewing direction is included in this report as described earlier. An observer looks one particular way and only reflections that are visible in his field of view are included. The field of vision of a normal observer is taken as 120° (i.e. both 60° to the left and right of the viewing direction) and 40° from top to bottom. This is a common field of view for a person where the distant periphery is not taken into account (the area from 60° to 110° to the left or right of the viewing direction). Also, very high and very low viewing angles are not taken into account.

The vertical angle is chosen in such a way that a driver does not have solar panels in his field of vision within a circle whose radius is as large as the driver's eye level in relation to the water surface. In other words, if the driver is 10 meters above the water, no panels are simulated that are less than 10 meters away from the driver. Reflections in the far periphery are believed to be rarely bothersome.

By choosing the field of view in this way, we do not have to make statements about the exact distance, position or amount of solar panels. If, given the orientation of the solar panels and the field of view of the observer, a reflection occurs in the field of view, it will be seen. For this, it must also be reflected. In fact, we simulate that *wherever solar panels can be placed, there are also solar panels*. In the results, we then split up the field of view so that for a permit application it can be assessed whether the proposed panels are in the part of the field of view where the hindrance comes from.

4.2.4 *Floating and moving solar parks*

Based on the above method, TNO generally does not expect large differences in the amount of visual hindrance between floating solar panels and panels that are placed on land. Floating solar parks will therefore not be explicitly modelled here.

The biggest difference between floating solar parks and solar parks on the mainland is that floating solar parks will (slightly) vary in their orientation over time, because they move with the water. This will affect the direction in which they reflect. However, simulations (Golroodbari & Sark, 2020) show that solar panels on the North Sea (floating on a pontoon) usually deviate only 3° or less from their original orientation. On days with strong winds this can be up to 10° and sporadically up to 20°.

Most days, the orientation of the solar panels varies less than the 'discretization' that we use for the azimuth and inclination (5°). For this reason, we do not expect a major effect on the visual hindrance for most days and inland waterways.

For situations where:
- • often restless water is expected (for example, a narrowing or a natural wind tunnel);), or
- • the solar panels are less well anchored than with a pontoon as described in (Golroodbari & Sark, 2020), or
- ships sail relatively close to the solar panels, so the stern wave does the solar panels strongly oscillate.

it will have to be evaluated whether the variation in orientation is small enough. If not, we recommend looking at multiple "mainland" orientations. For a panel with an angle of inclination of 45°, for example, you can also look at angles of inclination 40° and 50° in order to take into account the variation in orientation. However, it is expected that in most cases this is not necessary.

5 Acceptable levels of degradation

This chapter establishes spectrum usage and the acceptable noise increase on ships and maritime shore sites used for communication and navigation. Based on this, calculations are carried out in Chapter 6 on the distances from PV installations to waterways and shore stations, whereby the noise increase remains below acceptable limits.

5.1.1 *Spectrum use*

By shipping, frequencies are used between a few hundred kilohertz in the medium wave and 10 GHz in the SHF part of the frequency spectrum. Some of the systems as applied to ships and shore are shown in Table 3. Plotted on a logarithmic frequency scale, Figure 14 is created. Almost the entire radio spectrum is used for safety, communication and navigation applications and disruptions to reception will have to be kept to a minimum to ensure safety and continuity.

Table 3 System specifications of systems with reception capabilities

System	Freq. band [MHz]
GMDSS	0,49 / 0,518 / 2,1875 / 4,2095 / 6,215 / 8,25 / 12,290 / 16,420 / 18,795 / 22,060 / 25,097
VDES (= VDE, AIS, ASM)[21]	156 – 164
VHF radio	156 - 164
C2000	380 – 400
IMT2020	800, 900, 1500, 1800, 2100, 2600, 3500
GNSS[22]	Various links between 1164 and 1616
RADAR	3000 & 10000

In Figure 14 a spectral picture is shown with the maritime frequency bands used for emergency, navigation and communication. The red lines show the bands for inland navigation, the blue lines are specific emergency frequencies for maritime shipping.

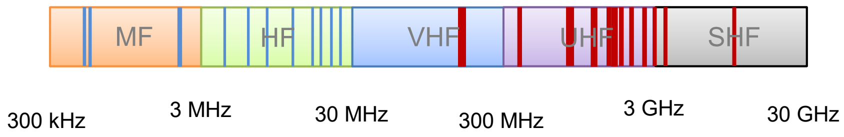

Figure 14 Maritime spectrum use by shipping and shore stations

WiFi and Bluetooth are widely used for wireless applications. They operate license-free at 2.4 and 5.4 GHz in the so-called Industrial Scientific and Medical bands (ISM). Users of these bands must accept interference and cannot be protected. For this reason, these applications are not included in the maritime frequency overview.

[21] Technical characteristics for a VHF data exchange system in the VHF maritime mobile band (itu.int)
[22] Global positioning system - Wikipedia

5.1.2 5.1.2 *Reference ambient noise*

The environmental background noise is easy to define on the basis of measurement data from the literature (ITU, NTIA), whereby assumptions for human activity in the environment give a correction to the ideal ambient noise. In Appendix A, a reference ambient noise curve has been calculated on the basis of these principles, which will be used for the calculations of the distances between receiving antennas and PV systems. The choice for "rural/ rural" versus "quiet rural / without man-made noise" is explained there. See Figure 15.

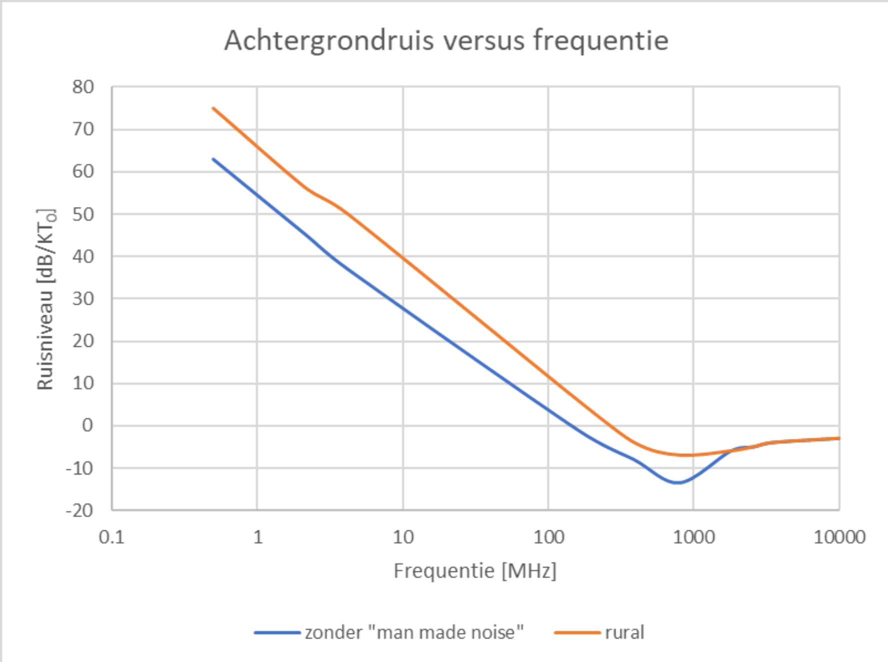

Figure 15 Ambient noise in order to interference calculations

The effects of "man-made" noise on ambient noise have been established up to 1 GHz. Above that, the effects were negligible, hence the blue and orange curves coincide for high frequencies. Due to technological developments, this situation may change in the future.
The blue line represents an ideal situation without any disturbance of the ambient noise due to human influences (read: complete lack of electronic and electrical equipment). In practice, this situation is almost non-existent, even on ships there is a lot of electronic and electrical equipment that contributes to the background noise. A rural background noise (orange curve), which is still classified as "silent", is a realistic value for a lock/bridge and waterway environment.

5.1.2.1 *System sensitivity*

The sensitivity of a system is determined by the noise number of the receiver plus the ambient noise. Together they form a noise floor where the desired signal must come out with a certain margin so that it can be decoded or understood. If the noise number of a system is high, then the influence of the ambient noise is relatively small, the receiver is then the predominant factor that determines the minimum sensitivity. With a low noise number, the ambient noise will be the determining factor. In the latter case, the sensitivity of the complete system (receiver + antenna + ambient noise) will be much better than in the situation of a high receiver noise number, but the effects of changing the ambient noise are much greater. When determining the effects of the increase in ambient noise, the increase in system noise will be taken into account: *receiver noise + external noise summed*. The receiver noise is derived from the standards that apply to the respective system..

5.1.3 *Acceptable incensement of ambient noise*

Every communication system or reception system, such as public and commercial broadcasting, has specific operational requirements. A generic approach to the acceptable noise increase for all wireless systems is therefore not possible. In this report a selection will be made of the essential wireless systems used in inland navigation: VHF radio, AIS and C2000.

The minimum specifications of nautical systems are laid down in standards, while the actual values are manufacturer-specific. Between different systems, the sensitivity specifications are also different, because applications require it or due to changes in technology that make that possible. The simulations will therefore be based on the minimum requirements set out in the standards for nautical communication systems (such as VHF radio, AIS, GNSS[23], etc.). The effect on navigational radar has not been studied, see 5.1.4.1

5.1.4 *Acceptable increasement of ambient noise with AIS and VHF radio*

AIS and VHF are used in inland navigation and at sea. At sea, the permitted capacities for AIS are a maximum of 12.5 Watts (unless it concerns a tanker or the safety of ship and crew is at stake) and at VHF at 40 Watts. On inland waterways, AIS class A may in principle emit high power, in practice 1 or 2 Watts of transmitting power is used. Mobile VHF radios may not use more than 1 Watt of transmitting power[24]. The assumptions for the simulations are based on inland shipping, which is why low transmission powers have been calculated.

The levels of protection around airports (see section 2.1.3) show a picture that is specific to the type of application. There is no specific protection value for all wireless systems: Some degree of interference is accepted.

The current standards for VHF radio and AIS[25] specify the maximum acceptable degradation. For VHF[26], a relegation of 6 dB of SINAD will be used. In the applied narrowband FM modulation in VHF, a SINAD degradation of 6 dB, at low signal strengths, corresponds **to ≈3 dB high-frequency SNR degradation** (see explanation in 2.1.2). In other words: an increase of the system noise of the respective system by 3 dB leads to a degradation of the audio SINAD value of 6 dB. For AIS, an increase in the standard minimum signal value of 6 dB due to "extreme conditions" (such as noise) should still lead to an acceptable decoding of AIS data (Packet Error Rate < 20%)[27].. See section 15.2.1.2

The acceptable noise increases according to the AIS and VHF standards are 6, respectively 3 dB (based on audio 6 dB SINAD to high frequency 3 dB).

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[23] ITU-R M.1371-5, (02/2014), Technical characteristics for an automatic identification system using time division multiple access in the VHF maritime mobile frequency band
[24] rp41nl_pg_062017.pdf (ccr-zkr.org), blz. 25
[25] IEC61993-2, 2012, Maritime navigation and radiocommunication equipment and systems – Automatic Identification Systems (AIS) – Part 2
[26] ETSI EN 301 929 V2.1.1 (2017-03)
[27] IEC61993-2, 2012, paragraaf 15.2.1.2

The strictest requirement of 3 dB will be used here in the simulations because the frequency bands coincide.

In contrast to IMT2020 networks, there are only a limited number of base posts set up in the Netherlands that provide C2000 with coverage. There is also no question of multiple providers that can fill any gaps. Based on the ambient noise level, as applied until the construction of PV installations, problems with outdoor communication in the C2000 network rarely occurred in the past. However, the roll-out of PV installations has led to serious deterioration of coverage on land, particularly in districts where many PV Installation[28] have been installed. It must be prevented that this situation is repeated in waterways, because this could give rise to serious safety risks (think of rescue operations of drowning people where the deployment of emergency services is required).

Based on the receiver sensitivity standards that apply, simulations were carried out of the coverage areas of AIS class B (2 Watt), and VHF radio equipment (1 Watt). In addition, an external noise increase has been assumed in such a way that the system noise is increased by 3 dB, resulting in a deterioration of the received signal-to-noise ratio (SNR) at the AIS and VHF radio by 3 dB.

Table 4 shows a number of ship - TC scenarios on the basis of which the coverage and catchment areas are calculated.

Table 4: Ship – TC scenarios

Situation	**System**	**Power [Watt]**	**Cable loss [dB]**	**Gain (antenna) [dBi]**	**Antenna height [meter]**
TC	VHF radio	1	2	2	20
Ship 1	VHF radio	1	2	2	4
	AIS CSTDMA	2	2	2	4
Ship 2	VHF radio	1	2	2	10
	AIS CSTDMA	1	2	2	10
Ship 3	VHF radio	0,5	3	-6	4

Table 4 shows the results for the coverage area range at 3 different system noise increases. Table 6 indicates a number of catchment ranges, based on the data such as The calculations are determined for an audio SINAD value of 20 dB.
Note: The results are available as graphical plots in Appendix B

[28] Solar Magazine - Verstoring C2000: 'Agentschap Telecom kan omvormers zonnepanelen van markt weren'

Table 5 Influence of the increase in system noise on the radio range at the same signal quality (SNR/SINAD)

Link		**Range with system noise increasement:**	
		0 dB	**3 dB**
VHF radio:	Ship 1 to bridge/lock	15,5 km	13 km
AIS:	Ship 1 to bridge/lock	18 km	15,5 km
VHF radio:	Ship 2 to bridge/lock	18 km	15,5 km
AIS:	Ship 2 to bridge/lock	21 km	18 km
VHF radio:	Ship 3 to bridge/lock	9	7,5

From the "Regeling communicatie en afmetingen rijksbinnenwateren[29]" an estimate has been made of the size of the areas in which traffic control centers communicate with VHF radio. In Table 6, the maximum care distances of some traffic posts (TCs) have been calculated. No data on the catchment areas could be obtained from bridge and lock posts. The information is partly obtained from the report "Overzicht antennehoogtes 27092021" of Rijkswaterstaat.

Table 6 Examples of traffic and bridge/lock posts, where the greatest distance is listed as the care area.

Area, VHF radio channel nr. [ ]	**Kilometre section *) [km]**	**Antenna height / direction [m / °]**	**Transmission-power [dBW] / [W]**	**Care-range [km]**
TC Sector Wijk bij Duurstede, 60	Amsterdam-Rijnkanaal km 59,5 tot km 63,5	19, omni	-16 / 0,025	3
	NederRijn/Lek km 924,3 tot km 930	19, omni	-16 / 0,025	4
TC Nijmegen, sector Nijmegen, 4	Waal km 890,5 tot km 881,5	20, 95	2,3 / 1,7	5
TC Nijmegen, sector Millingen, 5	Waal km 881,5 tot km 864,2	18, 110	0 / 1	9
TC Tiel, sector Tiel, 69	Waal km 917,0 tot km 905,0	20, 90	-4.5 / 0.35	8
Sluis Born, 22		20, 20	-4 / 0.4	

*) Position in kilometers from the origin of a river or canal.

The largest VHF radio catchment area distance in Table 6 is 9 km. Not all TCs could be investigated, there may still be some with a slightly larger catchment area.

The results of the simulations in Table show that an increase in the noise level by 3 dB results in a reduction in the range from 2 to 3 km with a constant signal quality. It has been assumed that the systems on ships are well laid out, with no margins

[29] wetten.nl - Regeling - Regeling communicatie en afmetingen rijksbinnenwateren - BWBR0010360 (overheid.nl)

being maintained for system tolerances, shielding or poor installation of the antenna. An increase in system noise of 3 dB corresponds to a deterioration of the audio SINAD of about 6 dB. Within the VHF standard, that is still acceptable. See section 5.1.4.
With a greater increase in system noise, the minimum audio (SINAD) and data quality (AIS) can no longer be guaranteed, which may reduce the coverage areas than the desired care required as shown in the examples in Table 6..

Because VHF and AIS are considered essential means of communication and navigation (see section 2.1.6.2), it is advised to tolerate a maximum increase in system noise of 3 dB for VHF radio and AIS.

5.1.4.1 From system noise increasement to external noise contribution by PV-installations

Based on the range simulations (Table 5) and the resulting maximum noise increase deemed acceptable, it can be calculated how much external noise field strength may be generated to stay within it. The starting point was the ambient noise as shown in the curve of Figure 15. Table 7 shows the values of interfering fields for a system noise increase of 3 dB.

Table 7 Interfering field strengths that lead to a 3 dB increase in the system noise of a receiver

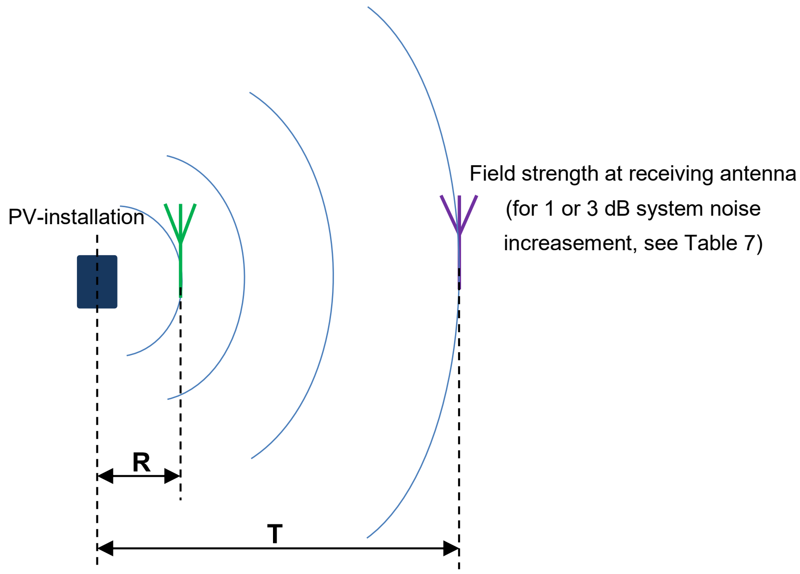
System		**Receiver noise temperature [K]**[30]	**Field strength at receiving antenna [dBµV/m]*)**
			3 dB system noise increasement
VHF radio/AIS (VDES)		4800	11,1
C2000[31]	BS / MS	578 / 1154	9,6 / 12,2
GNSS[32]		170	17,1
IMT2020:[33],[34]			
800 MHz	BS / MS	81 / 222	9,8 / 12,4
900 MHz	BS / MS	81 / 222	10,9 / 13,4
1500 MHz	BS / MS	81 / 222	15,3 / 17,9
1800 MHz	BS / MS	81 / 222	16,9 / 19,6
2100 MHz	BS / MS	81 / 222	18,2 / 20,8
2600 MHz	BS / MS	81 / 222	20,1 / 22,7
3500 MHz	BS / MS	81 / 222	22,7 / 25,2

*) There are as yet no radiating standards for equipment for frequencies > 1000 MHz, therefore the same values that apply between 230 and 1000 MHz have been assumed, see Table 1.

The standards for high-frequency emissions do not exceed 6 GHz and radar navigation on inland waterway vessels operates at frequencies higher than 9 GHz[35].

[30] Based on the applicable application standards.
[31] ETSI TS 100 392-2 V3.9.2 (2020-06), Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI), par. 6.6.2.4
[32] Based on various commercial products, the noise numbers are << 2 dB
[33] ETSI 3GPP TS 36.101 V16.5.0 (2020-03), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (Release 16), par. 7.3.
[34] ETSI TS 136 104 V15.3.0 (2018-07), LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (3GPP TS 36.104 version 15.3.0 Release 15).
[35] RICHTLIJN VAN HET EUROPEES PARLEMENT EN DE RAAD van 12 december 2006 tot vaststelling van de technische voorschriften voor binnenschepen en tot intrekking van Richtlijn 82/714/EEG van de Raad, blz. 244

It is therefore not possible to carry out simulations that determine the effects of PV installations on navigation radars..



R = Reference measuring distance at which the standard determines the maximum field strength for a PV system (see values in Table 1).

T = Distance to the "Target" where the effect of the PV installation is observed.

Figure 16 Permissible noise field strength due to a PV installation.

Figure 16 shows the relationship of the (interference) field strength at the PV installation and the receiving antenna. The distance "R" is a defined value: 3, 10 or 30 meters. Each distance has a different field strength value. For small objects, usually 3 meters is applied, as the installation becomes physically larger 10 or 30 meters. "T" is the distance to the object being examined (the receiving antenna).

6 Results

In this chapter the results of simulations and calculations are presented for the optical and radio related interferences caused by solar panels and inverters.

6.1 Coexistence calculations PV installations and maritime communication and navigation

The extent to which high-frequency noise generated by a PV installation reaches a receiving antenna is determined by the distance, the presence of obstacles and the heights of the PV installation and receiving antennas. Obstacles are kept out of the calculations (because the effects of this can be large, this requires specific customization). In situations of PV installation near waterways, in most cases there will be an open area. The individual heights of ship and shore antennas as well as the mounting height of the PV installation will be used as variables in the calculations.

6.1.1 Construction PV installations

PV installations are made up of solar panels that are connected in a string or individually to an inverter that turns the DC voltage into alternating voltage. There is no "standard solution" for the conversion from direct to alternating voltage, but there is a trend to connect multiple groups of solar panels to one large inverter. In fact, such a large inverter is composed of several smaller ones, but in terms of production and maintenance it is easier and cheaper to carry out as one system. From an EMC point of view, products must meet the requirements not only individually, but also as a complete installation. If the cabling between solar panels and inverters is not installed correctly, or adequate filters are missing from the inverters, the cables and solar panels will start to work as transmitting antennas, which can significantly aggravate the EMC effects of an inverter.

The appearance of a PV installation therefore consists of two main aspects: the direct radiation of the inverter and the wiring between inverter and solar panels. Loops in the wiring with a large surface area should be avoided at all times. Incidentally, that is also to the advantage of a PV installation itself, because the antenna effect is two ways. Reducing loops also reduces the chance of damage from nearby lightning discharges. Poor connections (connectors) in the wiring can further contribute to the antenna operation and thus enhance the radiation effects.

6.2 Distance calculations for PV installations with expected radiation emissions that exactly meet the standard

6.2.1.1 PV installations with generated power ≤ 20 kVA versus > 20 kVA

Modern solar panels individually deliver 350 to 400 W peak power, with dimensions of 90 x 160 cm. An installation with a capacity of ≤ 20 kVA will consist of 50 to 60 panels and fill a contiguous area of approximately 80 m2 . Such an installation can still be considered a "point source" if the distance is more than 100 meters. The emission requirements are 40 dB microvolts/m at a measuring distance of 10 m.

PV installations with an electrically generated power greater than 20 kVA can occupy several hectares of surface area. The examples are numerous in the Dutch landscape today. See Figure 17 as an example at Hoogezand.

Figure 17 Solar park with 90,000 panels at Hoogezand[36]

The size of such a park can no longer be considered as one point, but must be seen as a zone. Measuring the field strength standard of 50 dBµV/m at a distance of 10 meters therefore has a limited significance given the size. The entire field as a whole will emit much more than that maximum "individual" value, but due to the definition of the way of measuring and the enormous size of these types of parks, that cannot be tested.

It is difficult to determine the cumulative effect of all inverters, but that of the most significant ones closest to a maritime receiver installation. Figure 18 illustrates why the near and far measurements cannot be compared well with large PV installations. If measured at a short distance, the contribution of systems left and right (5 and 7) of inverter 6 will be limited, at greater distances from the edge of a field, the nearby noise sources will also contribute and a fairer picture will be obtained of the total generated interference field. The antenna symbols figure as the sources of interference, namely the inverters. In practice, the radiation will be emitted more distributed by means of the cabling.

The example of Figure 18 shows that at a distance of 100 m inverters 5 and 7 contribute almost as much (and the adjacent inverters also contribute significantly!)

[36] Zonneparken in Groningen op een rijtje - Zonnepanelen Planet

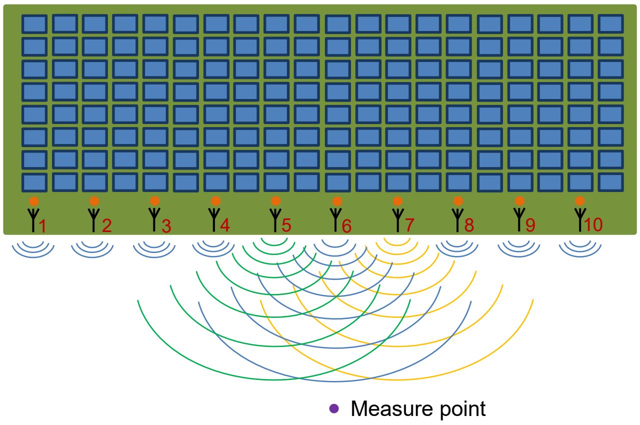


Figure 18 At a greater distance from the PV installation, it becomes clear that in addition to converter 6, the adjacent inverters 5 and 7 make an almost equal contribution to the interference field.

Depending on the design of a PV installation, the standard value of one inverter (and connected solar panels) may not be assumed, but a (much) higher value must be taken into account due to the cumulative effect as illustrated in Figure 18.

N.B.:
The calculations in this report have assumed that at a great distance (>> 100 m) over the route that is travelled in parallel along a large PV installation, the field strength value meets the (calculated back) guideline of 50 dB microvolts/m at 10 meters for large PV installations with a capacity of > 20 kVA. So a maximum measured value of 30 dBµV/m at a distance of 100 meters over the entire length of an installation.

6.2.2 Which systems are simulated and under what conditions

In shipping, specific nautical equipment, but also civil communication equipment is used. Many bridges, locks and traffic stations can be reached not only via the VHF radio, but also by telephone via the mobile network. However, the primary means of making contact is the VHF radio.
The civil IMT2020 infrastructure is set up on user capacity (read: amount of data and number of users), not on scope, apart from a few very specific locations in the Netherlands. The networks of providers consist of cells, often no more than a few kilometres in diameter. The range of such a cell is determined by the amount of data traffic and the interference of neighbouring cells. The cell is "interference limited", not limited to the ambient noise. As a result, a limited amount of noise from electronic equipment hardly restricts the use of mobile phones throughout the cell, including the edges.
Calculations and simulations for the telecom networks are only indicative, because the standards with regard to the ambient noise have no meaning due to the mutual interference. For this reason, 800 and 900 MHz simulations have been performed for 1 and 3 dB system noise increases, but the effects should be interpreted as indicative. The exact interference margins that providers use depend on the situation. The results of the IMT- 2020 simulations are only included in the appendix because they do not fall under the essential inland navigation means of communication or the responsibility of Rijkswaterstaat. Therefore, no conclusions can be drawn for the installation of PV systems based on the IMT2020 simulations.

For the distance calculations, the maximum "norm field strengths" of Table 7 was used where the limit 3 dB system noise increase is reached.

The attenuation between a PV installation and a "target" antenna is calculated according to the two-beam propagation model. The individual heights of PV installation and antennas[37] are variables. Large-scale PV installations are often set up on former agricultural land at a height of approximately 1.5m. The inverters and wiring are also approximately at this height. For private homes and buildings, roofs are usually the first choice, therefore a height of 10m.

The calculations were carried out on small installations with a capacity ≤ 20 kVA (mostly private) and installations with a power > 20 kVA for a system noise increase of 3 dB.

In section 6.2.2.5, Table 8 and Table 9 show the distances to be maintained at a number of common PV installation and antenna heights, limiting the system noise increase to 3 dB.

6.2.2.1 *Distances to PV installations with a power of less than 20 kVA and a PV height of 1.5m*

The height variations apply to both base and mobile stations (antennas). See Table 7 for the applied disturbance field strength values.

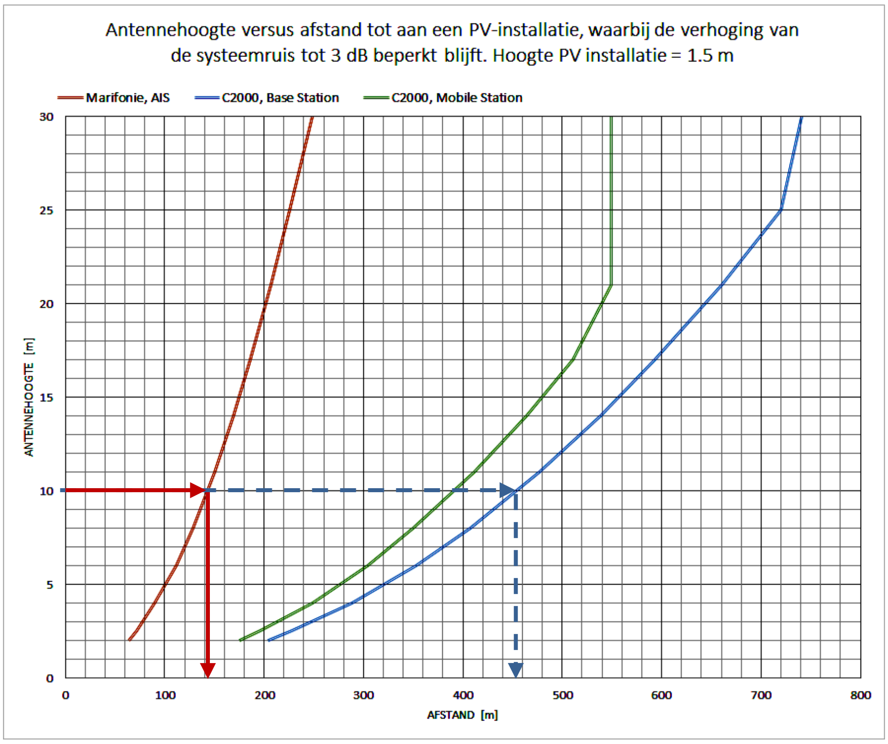


Figure 19 Distance between a PV installation versus the height of the receiving antenna at a field strength of 40 dBµV/m (AIS and VHF radio) / 47 dB microvolts/m (C2000) (measured at a distance of 10m from the PV installation).

[37] https://www.isi.edu/nsnam/ns/doc/node218.html

Interpretation of the curves
If only AIS and VHF radio (red line) apply to a shore station where, for example, the receiving antenna is set up at a height of 10 meters, a PV installation may be placed at a distance of 140 meters. If there is also a C2000 base station installation at the shore station, the distance must be increased to 455 meters (blue line).

6.2.2.2 *Distances to PV installations with a power of less than 20 kVA and a PV height of 10m*

The height variations apply to both base and mobile stations (antennas). See Table 7 for the applied field strength values.

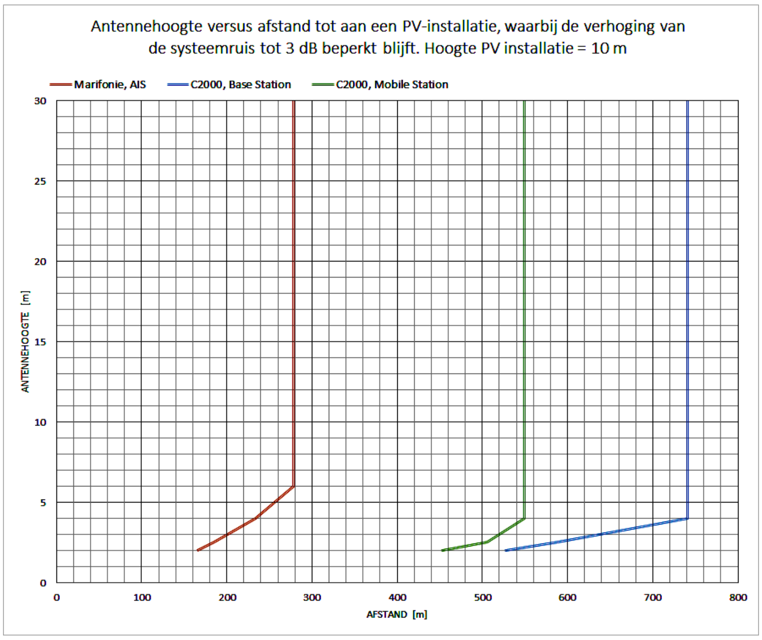


Figure 20 Distance between a PV installation versus the height of the receiving antenna at a field strength of 40 dB microvolts/m (AIS and VHF radio / 47 dB microvolts/m (measured at 10m distance from the PV installation).

6.2.2.3 *Distances to PV installations greater than 20 kVA and PV height of 1.5m*

The height variations apply to both base and mobile stations (antennas). See Table 7 for the applied field strength values.

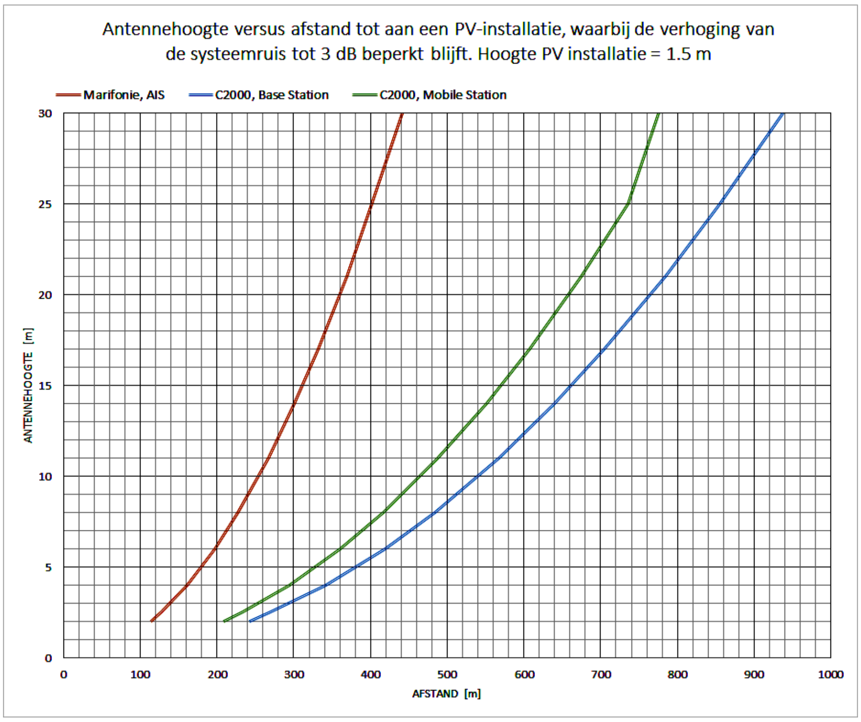


Figure 21 Distance between a PV installation versus the height of the receiving antenna at a field strength of 50 dB microvolts/m (measured at a distance of 10m from the PV installation.

6.2.2.4 *Distances to PV installations greater than 20 kVA and PV height of 10m*

The height variations apply to both base and mobile stations (antennas). See Table 7 for the applied field strength values.

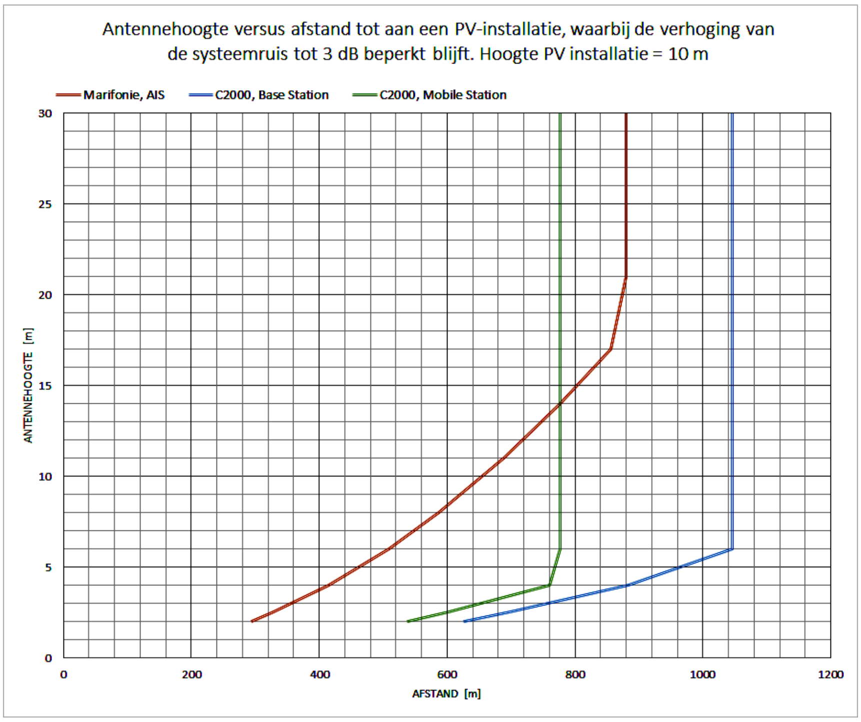


Figure 22 Distance between a PV installation versus the height of the receiving antenna at a field strength of 50 dB microvolts/m (measured at a distance of 10 m from the PV installation)

6.2.2.5 Distance to PV installations at maximum emission values according to the norm

In the tables below, the distances between a ship or shore station and a PV installation are calculated in which the system noise increase at the receiving party increases by a maximum of 3 dB. The mounting height of the PV installation and the antenna heights are the variables. Three common antenna heights were chosen, namely 4, 10 and 20 meters. The PV installation heights are based on 1.5 meters (a field with solar panels) and 10 meters (such as solar panels on a roof or mounted against a wall).

Table 8 Minimal distance between PV installation and VHF radio, AIS and C2000 antennas in meters (m), assuming maximum emission values according to the EMC standard (see Table 1), for PV installations with less than 20 kVA of power.

Antenna height (ship or shore station) [m]	PV height = 1.5 metre			PV-height = 10 metre		
	VHF radio/AIS [m]	C2000 [m]		VHF radio/AIS [m]	C2000 [m]	
		MS	BS		MS	BS
4	90	248	288	234	549	741
10	143	392	455	278	549	741
20	202	549	644	278	549	741

Table 9 Minimal distance between PV installation and VHF radio, AIS and C2000 antennas in meters (m), assuming maximum emission values according to the EMC standard (see Table 1), for PV installations with more than 20 kVA of power.

Antenna height (ship or shore station) [m]	PV height = 1.5 meter			PV-height = 10 meter		
	VHF radio/AIS [m]	C2000 [m]		VHF radio/AIS	C2000 [m]	
		MS	BS		MS	BS
4	161	295	342	415	760	883
10	254	466	541	657	776	1046
20	360	659	765	880	776	1046

6.3 Determination of acceptable radiation emission at a fixed location of a PV installation

The approach in section 5.1.4 is based on a PV system whose appearance exactly matches the EMCD (referring to the maximum norm values as shown in Table 1) where the distance between the interfering system and the receiving antenna and set-up heights are the variables.

With increasing height of the receiving antenna and/or the PV system, the signal losses decrease, and the interference field strength of the PV installation must be reduced in order not to cause interference to the receiving party. This leads to a result in which the PV installation is allowed to produce a maximum electromagnetic noise emission, limiting the system noise increase to 3 dB. Table field strength values are used as a reference. Furthermore, the same measurement method was used as when setting the EMC radiation standards. The following heights were used for the receiving antenna: 4, 10 and 20 m, for the PV installations 1.5 and 10m.

The field strength results in Table 10, up to and including Table 12 apply at a measuring distance of 10 meters to the PV installation.

There is a propagation path between a PV installation and receiving antenna. As with the previous calculations, this is made up of two components: a Free Space and a two-ray model. Depending on the heights of the transmitting part (the PV installation), the receiving antenna and the frequency at which the system operates (VHF radio, AIS, C2000, etc.), the point at which the models merge shifts. This explains why some curves have a different angle of inclination than others: the frequency is then strongly different.

Especially when the unobstructed visibility area is large (PV and receiving antenna are several meters above the environment), the curves at 800 and 900 MHz largely fall over each other. As the heights increase, the differences between them are smaller or even absent, because there is no difference in the propagation path. This mainly plays from frequencies ≥ 390 MHz.

6.4 Interpretation and implementation of the simulation results

In this chapter, simulations have been carried out from two starting points:
1) The situation where a PV owner only knows that his system is "compliant" (i.e. complies with the EMCD regarding high-frequency emissions), but has no information about the actual emissions of the system. The maximum permitted high-frequency emission shall be taken into account,
2) 2. The expected high-frequency emissions are known in advance. Based on this data and the height of the objects, a distance is calculated at which no unacceptable interference can be expected.
From the graphs, the distance where the PV installation can be placed can be read.

In inland navigation, VHF radio, AIS and C2000 are considered critical communication systems. Ship and shore radar are also included, but the standards to which the EMCD refers do not provide a definitive answer about the permissible levels for electromagnetic interference fields above 6 GHz.

The interpretation of the results assumes that it is possible to set requirements for the maximum high-frequency emission by a PV installation. This is probably only possible if the plot on which the PV installation is placed falls under the management of Rijkswaterstaat, or if the communication is regarded as critical, article 5 of the EMCD[38] *could possibly be invoked.*

Section 6.2 assumes a high-frequency emission value equal to the standard (see Table 1). The curves indicate per frequency band (to which a means of communication is attached) what the minimum distance should be between the receiving antenna and the PV installation. The nearest edge of the solar park is the boundary, not the middle of the PV field. Assuming that the critical means of communication and navigation are VHF radio, AIS and C2000 decisive, the most stringent curves for VHF radio, AIS or C2000 should be used to determine the minimum distance. See Figure 23.

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[38] DIRECTIVE 2014/30/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, Article 5, Free movement of equipment

Assuming that a PV system can demonstrate that it has a lower high-frequency emission than the maximum value set by the standard, or can be adjusted for this purpose, calculations have been carried out in section 6.3 with curves that give the high-frequency emissions as a parameter. Figure 23 shows a graph in which along the y-axis the field strength values (measured at a distance of 10 meters from the PV installation) are shown what the PV installation must comply with..

In the example, a PV installation is planned at a distance of 258 meters. The maximum field strength that the installation may then produce to keep the noise increase in AIS and VHF to 3 dB is along the Y-axis, and here is 41 dB microvolts/m.

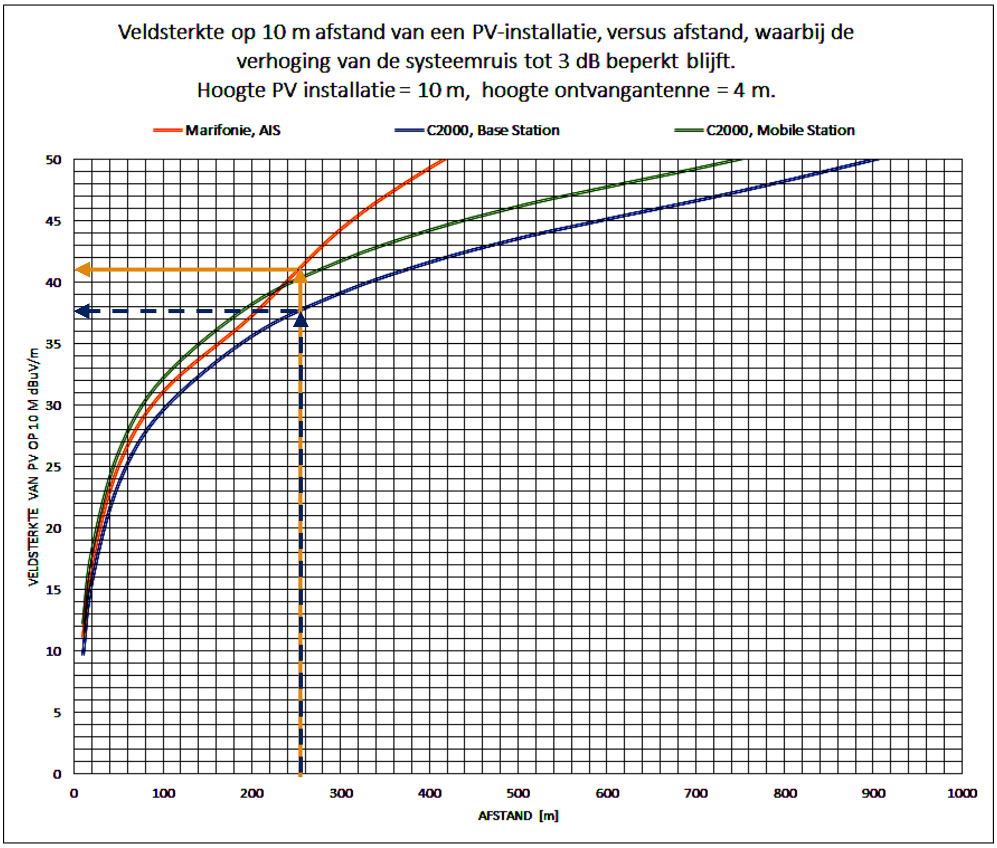


Figure 23 Example of situation with various communication systems and the maximum permissible high-frequency interference field strength (measured at a distance of 10 meters from the PV installation) where the increase in system noise is limited to 3 dB.

In the example of Figure 23, if there is also a C2000 base station (dark blue line) of a lower maximum acceptable field strength, then only with an AIS and VHF radio station. The lowest field strength value is leading. In the example 37.5 instead of 41 dBµV.

Table 10 Maximum field strength that a PV installation may emit in order to limit the system noise increase at the receiving antenna to 3 dB. Distance PV installation, receiving antenna and receiving antenna set-up height versus field strength.

VHF radio en AIS						
Distance from PV installation to receiving antennas	**Max. field strength at PV-height = 1.5m [dBµV/m]**			**Max. field strength at PV-height = 10 meters [dBµV/m]**		
	Antenna height [m]			**Antenna height [m]**		
	4	**10**	**20**	**4**	**10**	**20**
10	11	11	11	11	11	11
20	17	17	17	17	17	17
50	30	25	25	25	25	25
100	42	34	31	31	31	31
200	54	46	40	37	37	37
300		53	47	44	41	41
400			52	49	43	43
500				53	45	45
600					48	47
800					53	49
1000						51

Table 11 Maximum field strength that a PV installation may emit in order to limit the system noise increase at the receiving antenna to 3 dB. Distance PV installation, receiving antenna and receiving antenna set-up height versus field strength.

C2000 bae station (BS)						
Distance from PV installation to receiving antennas	**Max. field strength at PV-height = 1.5m [dBµV/m]**			**Max. field strength at PV-height = 10 meters [dBµV/m]**		
	Antenna height [m]			**Antenna height [m]**		
	4	**10**	**20**	**4**	**10**	**20**
10	10	10	10	10	10	10
20	16	16	16	16	16	16
50	24	24	24	24	24	24
100	30	30	30	30	30	30
200	41	36	36	36	36	36
300	48	40	39	39	39	39
400	53	45	42	42	42	42
500		49	44	44	44	44
600		52	46	45	45	45
800			51	48	48	48
1000				52	50	50

Table 12 Maximum field strength that a PV installation may emit in order to limit the system noise increase at the receiving antenna to 3 dB. Distance PV installation, receiving antenna and receiving antenna set-up height versus field strength.

C2000 handheld (MS)						
Distance from PV installation to receiving antennas	**Max. field strength at PV-height = 1.5m [dBµV/m]**			**Max. field strength at PV-height = 10 meters [dBµV/m]**		
	Antenna height [m]			**Antenna height [m]**		
	4	**10**	**20**	**4**	**10**	**20**
10	12	12	12	12	12	12
20	18	18	18	18	18	18
50	26	26	26	26	26	26
100	32	32	32	32	32	32
200	43	38	38	38	38	38
300	50	42	42	42	42	42
400		47	44	44	44	44
500		51	46	46	46	46
600			48	48	48	48
800			53	51	50	50

6.5 Visual nuance

In this chapter we discuss the results for visual nuance and give the resulting guidelines. Before we move on to the discussion of the results, we repeat some definitions:

Term	**Definition**
Viewing direction	The viewing direction of the observer (skipper, lock employee, etc.). The direction is given as a number of degrees. This is the compass angle that the observer is looking at. A viewing direction of 90° means that the observer is looking west.
Azimuth	Azimuth refers to the compass angle of the solar panels. The compass angle indicates the direction in which the front of the solar panel is pointed.
Angle of inclination	The angle of inclination indicates the angle between the solar panel and the ground. An angle of inclination of 90° means that the solar panel is perpendicular to the ground (and therefore upright). An angle of inclination of 0° means that the solar panel is flat on the land is lying.

It is good to realize that an observer with a viewing direction of 0° (towards the north) is looking directly at the front of panels with an azimuth of 180° (towards the south).

The measure we use to quantify the amount of hindrance is the "number of hours in which annoying reflections occur per year". By annoying reflections in this report we mean reflections that cause an afterimage for an observer. The number of hours per year indicates how often the hindrance occurs. In the Netherlands, the sun shines about 1470 hours a year. By relating the number of hours of hindrance per year to this number, insight can be gained into whether a certain number of hours of hindrance should be considered as many or few.

The analysis we perform distinguishes annoying reflections in six areas of the field of vision. That is why six "counters" are kept with the number of hours of hindrance per year for each viewing direction. If a reflection is annoying, it is checked in which part of the field of view it is located. A distinction is made between "above" and "below" (the observer's eyes) in combination with "left", "middle" or "right" (from the viewing direction). It happens in many calculations that solar panels, for example, only generate annoying reflections if they are placed on one side of the observer. The field of view is thus distributed as in Figure 24.

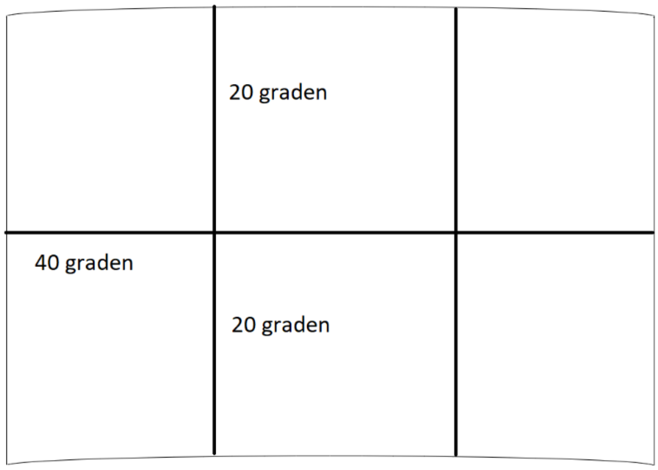


Figure 24 Viewing field divided into six areas with dimensions 40°x20°.

The calculated amount of hindrance per year is included with this report for each simulated situation in Excel format. In this Excel file it is easy to find for each viewing direction and panel orientation what the expected amount of hindrance per year will be. Nevertheless, we carry out another analysis in the following sections in order to arrive at verbatim guidelines.

6.5.1 Analysis of viewing directions

Initially, we analyse the three different variables (viewing direction, solar panel, azimuth and solar panel inclination) separately. This section analyses the viewing direction. It is valuable to know whether certain viewing directions run an extra risk of hindrance or, on the contrary, run a greatly reduced risk.

Figure 25 shows how the number of hours of hindrance differs per viewing direction, on average over all solar panel orientations. Specific solar panel orientations can be above or below average.

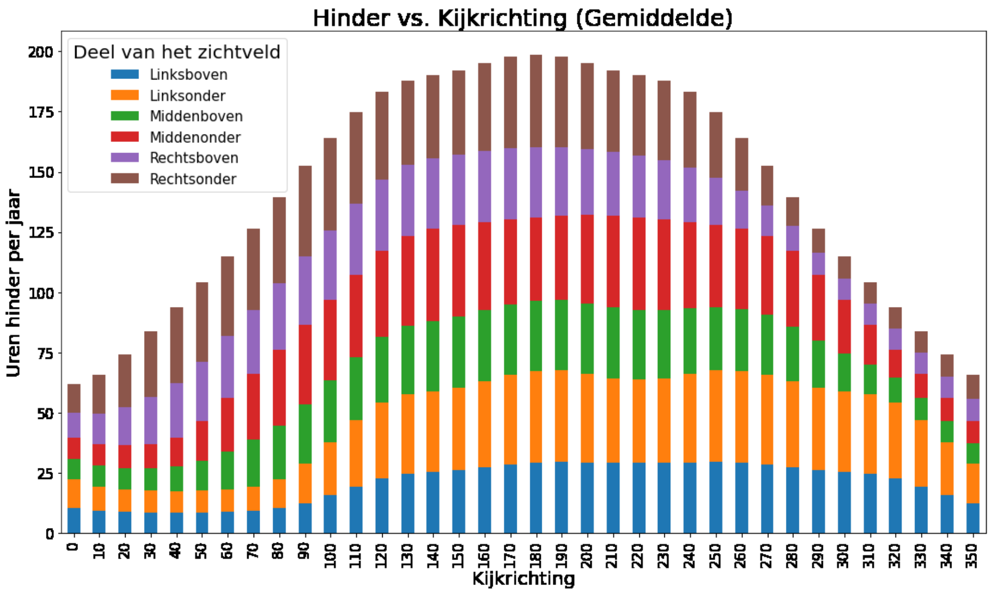


Figure 25. Average number of hours of hindrance per year per viewing direction. Average over all simulated solar panel orientations.

It is clear that the hindrance peaks around viewing directions of 180°. In other words, on average, viewing directions to the south are most affected by reflections. This assumes that all solar panel orientations occur equally often. In practice, this is not necessarily the case and, for example, south-facing panels are many times more common than north-facing panels. The graph says more about the risk of hindrance from an arbitrarily oriented solar field.

It's important to put the average in perspective. Although we can conclude on this basis that on average less hindrance occurs for northward viewing directions, it is not necessarily the case that northern viewing directions always run less risk. The maximum hindrance experienced by northern and southern viewing directions is both about 650 hours per year. That is the "worst-case" setup for both viewing directions. Because of these outliers due to the worst-case oriented solar panels, we do not draw up a general guideline for the viewing direction, as it would become too complicated.

6.5.2 *Analysis angle of inclination*

The angle of inclination of the panels mainly determines from which height (in relation to solar panels) the reflections are visible. Panels with a small angle of inclination lie quite flat on the ground and therefore strongly reflect the sun upwards. Panels with a large angle of inclination, on the other hand, are upright and therefore often reflect the sun towards the ground. Depending on where in the field of view the panels are located, a panel can therefore be safe or annoying. This can also be seen in Figure 26. The figure shows that on the left side of the graph (small angle of inclination) the panels almost only cause hindrance if they are under the eyes of the observer, while on the other side of the graph there is only discomfort if the panels are above the observer's eyes.

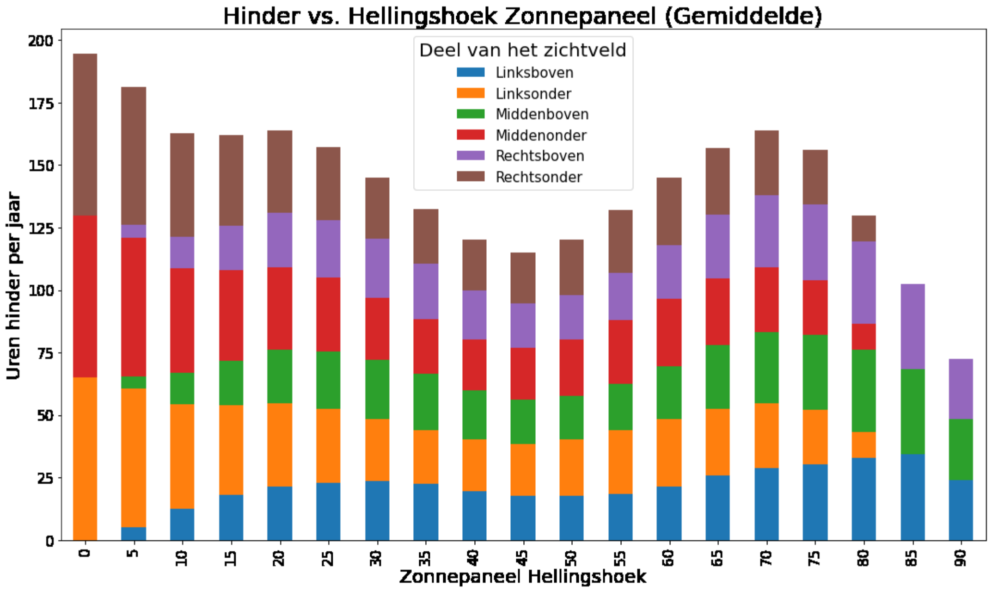


Figure 26. The number of hours of hindrance per year plotted against the angle of inclination of the solar panels. Per bar, an average of all simulated viewing directions and azimuths of the solar panels is.

In addition to the part of the field of view in which reflections are visible, Figure 26 shows a trend in the total height of the bars. It seems as if there is some kind of "wave" to be seen.

Further analysis shows that the "worst-case" setups of solar panels have an angle of inclination of around 25° or 70°. The reason that panels with a healing angle of 25° or 70° can cause more hindrance is due to the orbit of the sun. An observer looking towards solar panels with this orientation sees the sky at the angles of inclination where the sun is often located.

In addition, analysis shows that solar panels with a low angle of inclination cause hindrance relatively more often compared to solar panels with a higher angle of inclination. The reason for this is that the solar panels that are very flat can reflect in any viewing direction, while panels that are upright can only reflect in half the viewing direction, the other half sees the back of the panels.

Since the angle of inclination has a direct influence on the amount of hindrance, we draw up two general rules of thumb:

1. Solar panels with an angle of inclination of 10° or less generate visual hindrance in many directions.
2. Solar panels with an angle of inclination of around 25° or 70° generate twice as much hindrance in the worst situations as otherwise oriented panels.

6.5.3 *Analysis azimuth*

The azimuth of the solar panels mainly determines in which viewing direction reflections are visible. We also analyse this parameter first in isolation. The average number of hours of hindrance per year is plotted in Figure 27 against the azimuth of the solar panels. Again, the other parameters per bar are averaged: the viewing direction and the angle of inclination.

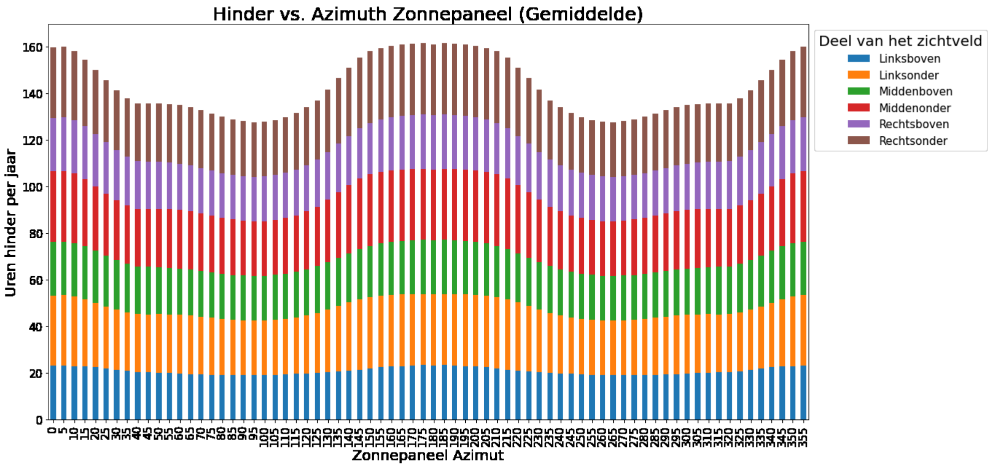


Figure 27. The number of hours of hindrance per year plotted against the azimuth of the solar panels. Per bar is averaged over all simulated viewing directions and inclination angles.

It can be seen that solar panels with an orientation of 85° or 275° cause relatively less hindrance than other setups. Further analysis shows that this pattern is not broken by, for example, "worst-case" outliers. That is why we draw up the following general rule of thumb:

1. Solar panels with an azimuth around 85° or 275° generally generate less hindrance than solar panels with other orientations.

6.5.4 *Combined analysis*

While analysing the three different parameters in isolation is good for gaining insight and establishing some general rules of thumb, the reflection problem is not easy to describe with some guidelines. After all, the nature of the problem is that reflections are very specifically visible and therefore vary quickly with different solar panel orientations and viewing directions. For this reason, all research into reflection problems is based on computer simulations. In this report, we have reduced the entire reflection problem to just three essential parameters: the viewing direction, the solar panel azimuth, and the solar panel inclination angle.

Because we have distorted the reflection problem into a three-dimensional problem, it is possible to find a middle way between the very specific computer simulations (with ten or more dimensions) that have been the norm until now and the very general guidelines that have been drawn up (often with one dimension). Because we only have three parameters, it is possible to visualize the results in their entirety. We do this by making a separate graph for each viewing direction with the number of hours of hindrance per year for each solar panel orientation. These 36 (one for each viewing direction) graphs indicate which solar panel orientations (combination of azimuth and inclination angle) are dangerous and which are safe for each viewing direction.

The complete set of graphs can be found in Appendix C. Here we give two examples that indicate how the graphs should be read. Figure 28 shows the number of hours of hindrance per year for an observer looking north and Figure 29 shows the same, but for an observer looking south. The contours indicate the number of hours of hindrance, on the x-axis is the azimuth of the solar panels and on the y-axis is the angle of inclination of the solar panels.

Figure 28 shows that for an observer looking north, most solar panels do not pose any problems. However, solar panels with an angle of inclination around 70° (relatively upright) and an azimuth of around 180° (facing south) generate more than 600 hours of hindrance for this observer per year. 600 hours a year is a lot. This figure also shows that if the angle of inclination is reduced to 35°, the hindrance is reduced to between 0 and 50 hours per year. It is also possible to turn the panels towards the east (90°) or the west (270°) to reduce the hindrance for this observer to 0. A combination of rotation and other inclination is of course also possible.

Figure 29 shows the same contour plot, but for an observer looking south. It is immediately noticeable that this observer is much more likely to experience hindrance since there are many more panel orientations that cause hindrance. We see that for an observer heading south, the solar panels that were problematic for the northern observer (70° angle of inclination and 180° azimuth) are not a problem for a southern observer.

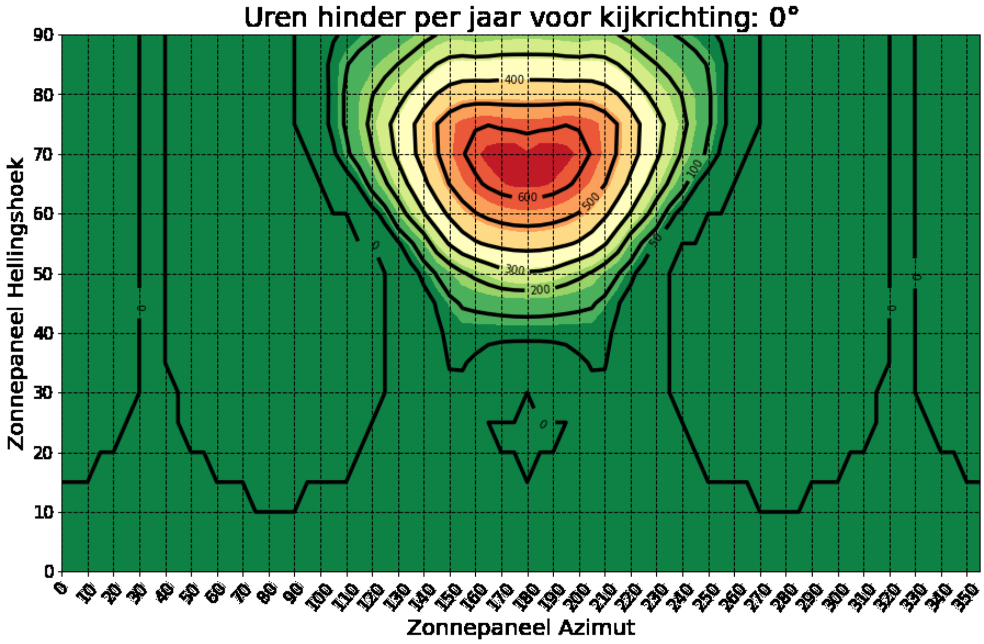


Figure 28. The number of hours of hindrance per year, for an observer looking north, depending on the solar panel orientation.

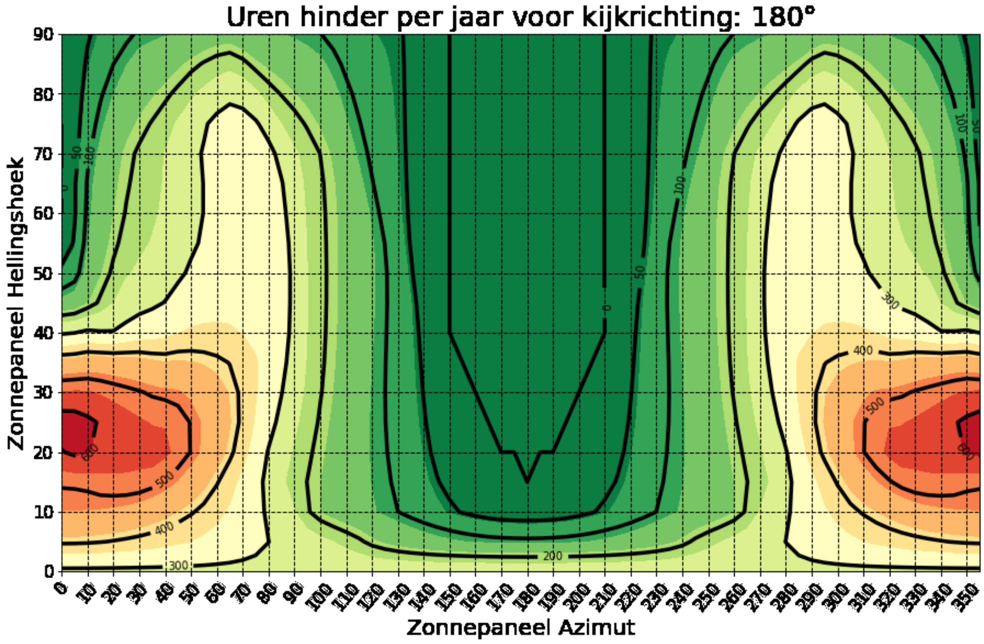


Figure 29 The number of hours of hindrance per year, for an observer looking south, depending on the solar panel orientation.

It will often happen that multiple viewing directions have to be taken into account. Take, for example, a waterway on which one can sail in two directions, from north to south and from south to north. The observers on this waterway then look north (sailing north) and south (sailing south). In this case, it must be examined in which region (combination azimuth and angle of inclination) of **both** contour plots the solar panels generate little hindrance.

For the four wind directions (and a number of corners around them) we can determine in this way which panels are or are not annoying. This brings us to the following guidelines, whereby we have maintained a (somewhat arbitrary) limit value of between 100 and 150 hours of hindrance per year. This value is based on the hindrance caused by direct sunlight. Sunlight that does not reflect on a solar panel but shines directly into the eyes of an observer can just as easily cause hindrance. No direct research has been done into the relationship between hindrance caused by sunlight and the number of accidents in a similar context (waterways in the Netherlands). Nevertheless, everyone accepts hindrance from direct sunlight and although people complain in some cases, they do not always do this. For this report, we have also calculated the amount of hindrance caused by direct sunlight for each viewing direction, given the same field of view, etc. It follows that in 25% of all viewing directions, hindrance from direct sunlight is less than 131 hours per year. The limit value of between 100 and 150 hours assumes that most people do not experience insurmountable problems due to sunlight when they sail / drive / look in the quarter of the viewing directions in which the sun itself causes the least hindrance. (See Figure 30 for illustration).

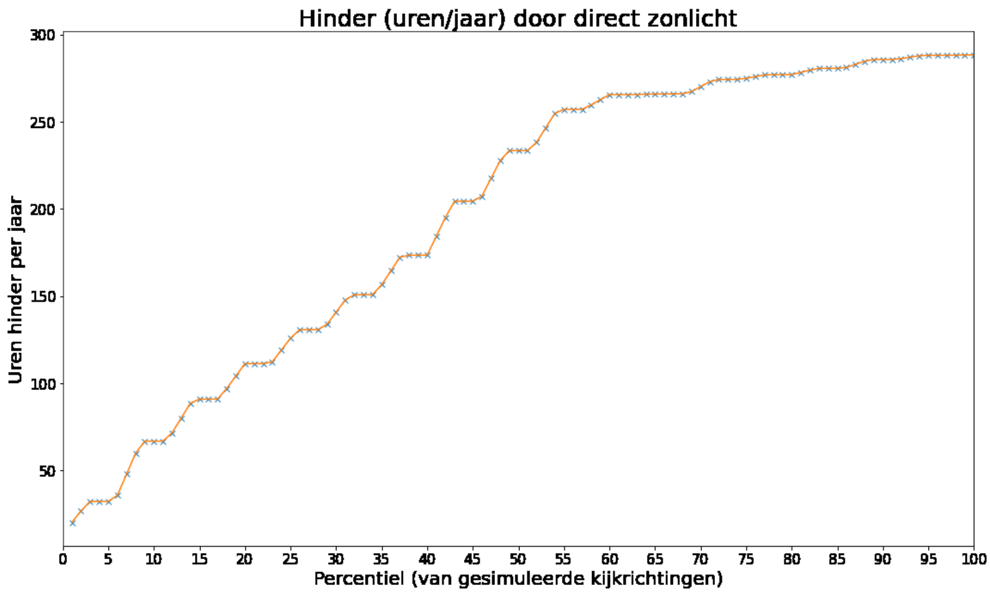


Figure 30. Hindrance (hours per year) due to direct sunlight. 25% of viewing directions experience less than 131 hours of hindrance per year.

We draw up some guidelines in text on the basis of the limit value. These guidelines are less precise than the contour graphs in Appendix C. After all, there is no accurate way to describe a winding curve in words. Because the guidelines define strict limit values and the calculated hindrance varies greatly, it will be the case that the solar panels that comply with the directive will in reality sometimes be just above and sometimes just below the limit value for hindrance. This is reflected in the supporting graphs, in which the "risky" areas are marked in a semi-transparent red colour. The supporting graphs, apart from the highlighted area, are the same as the contour plots in Figure 29 and Figure 29. The guidelines drawn up are as follows:

1. If the viewing direction is equal to the azimuth of the solar panels plus or minus 50°, then no or hardly annoying reflections occur. The observer then mainly looks at the back of the panel.

2. For northern viewing directions (315° to 45°), hindrance occurs mainly due to:
    a. South facing panels (90° to 280°) with an angle of inclination greater than 35°.
3. For eastern viewing directions (45° to 135°) hindrance occurs mainly due to:
    a. South-west facing panels (180° to 300°) with an angle of inclination greater than 35°.
    b. North-west facing panels (180° to 30°) with an angle of inclination less than 40°.
4. For southern viewing directions (135° to 225°) hindrance occurs mainly due to:
    a. North facing panels (220° to 140°) with an angle of inclination less than 45°.
    b. East (20°-110°) or west (250°-340°) facing panels with an angle of inclination greater than 40°.
5. For western viewing directions (225° to 315°), hindrance occurs mainly due to:
    a. Southeast-facing panels (40° to 220°) with an angle of inclination greater than 35°.
    b. Northeast facing panels (300° to 180°) with an angle of inclination less than 40°.

To illustrate these guidelines, figures 31 to 34 show the contour plots of the different viewing directions. Each plot shows, as before, for which orientations of solar panels there is a hindrance. In the plots, the "high-risk area" described above with the guidelines is indicated in red.

Note that these guidelines have maintained the somewhat arbitrary limit of 100-150 hours of hindrance on an annual basis. This is related to the hindrance caused by direct sun that people also experience. That does not alter the fact that in some cases this limit may be too strict, for example for a waterway where hardly anyone passes. However, it can certainly also be the case that Rijkswaterstaat decides to maintain a stricter standard for critical points where a lot of traffic passes (junctions, locks, etc.).

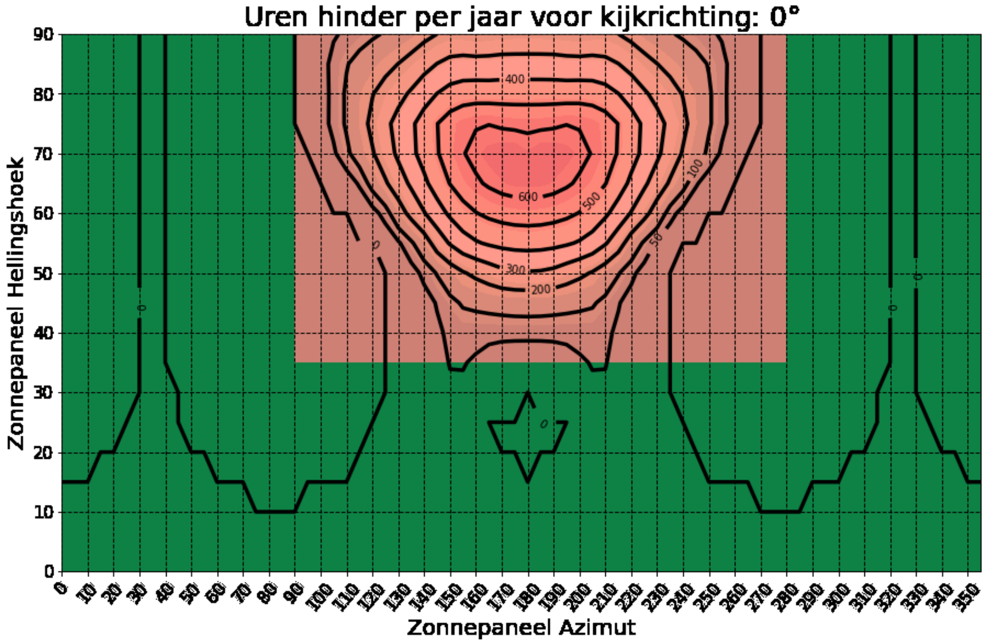


Figure 31 Risky solar panels for northern viewing directions.

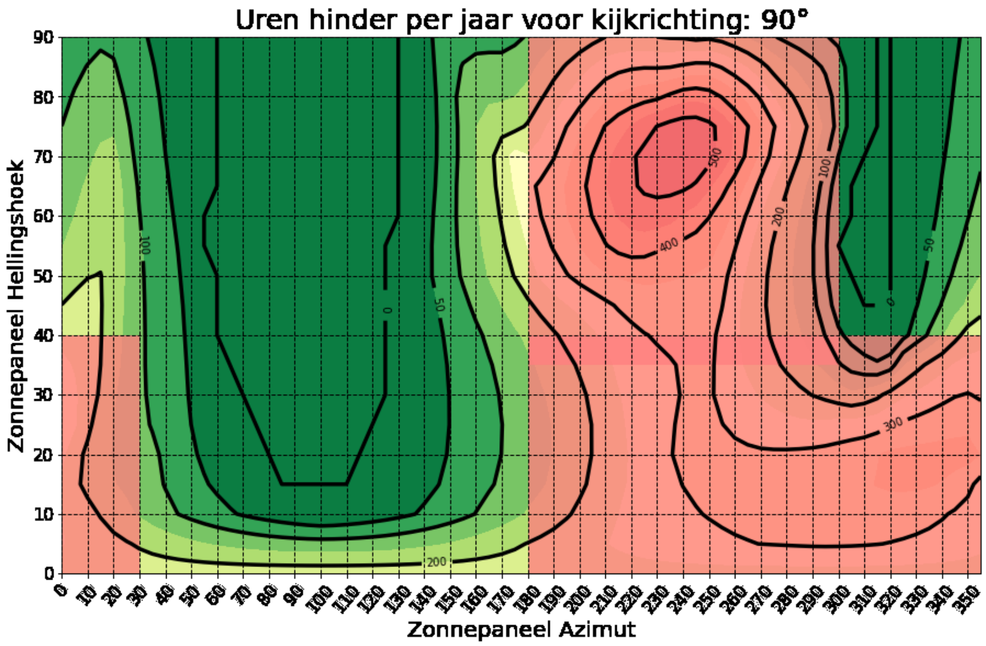


Figure 32 Risky solar panels for eastern viewing directions..

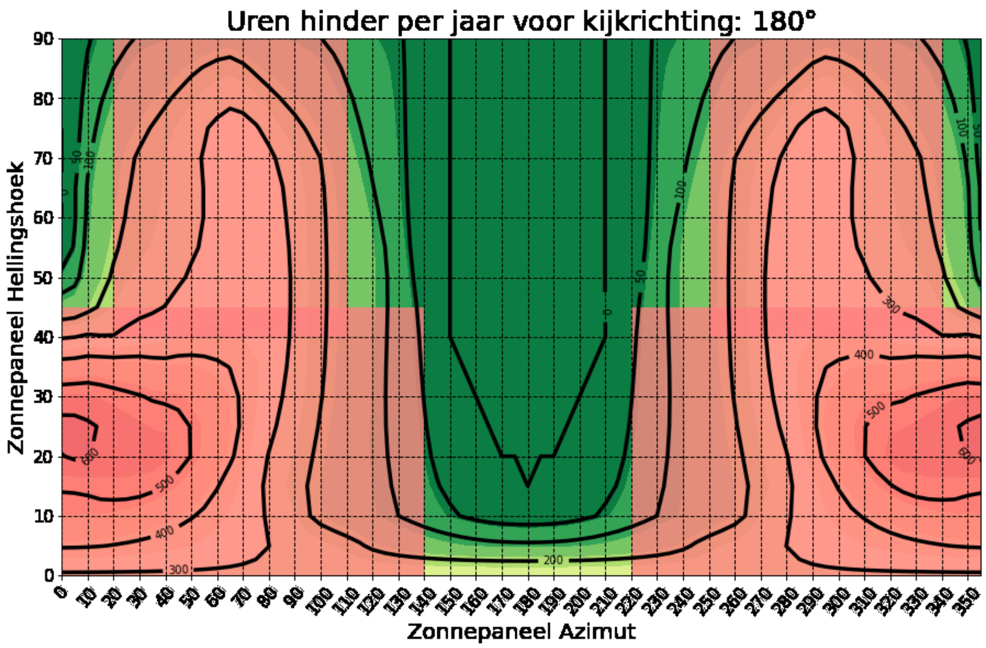


Figure 33 Risked solar panels for southern viewing directions.

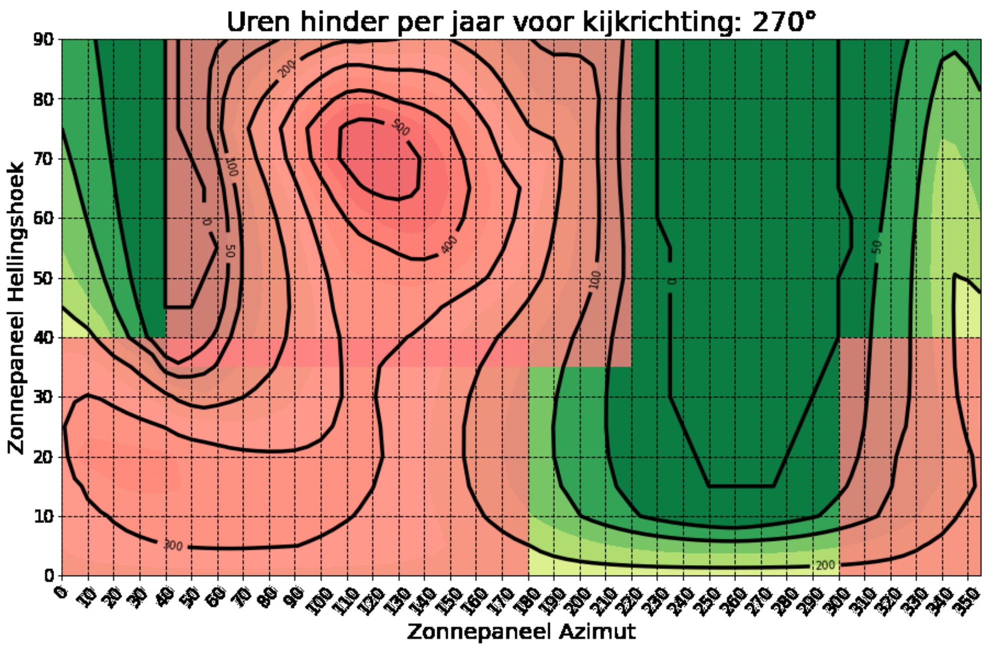


Figure 34 High-risk solar panels for western viewing directions.

7 Example protocols

Although TNO is not in a position to describe exactly what the processes within Rijkswaterstaat (should) be, in this chapter we give an example of how the results from this report can be used in practice. When reading, keep in mind that there are multiple ways to deal with the results.

7.1 Visual hindrance example

To determine whether a proposed solar field is safe to install, we use the step-by-step plan as shown in Figure 35..

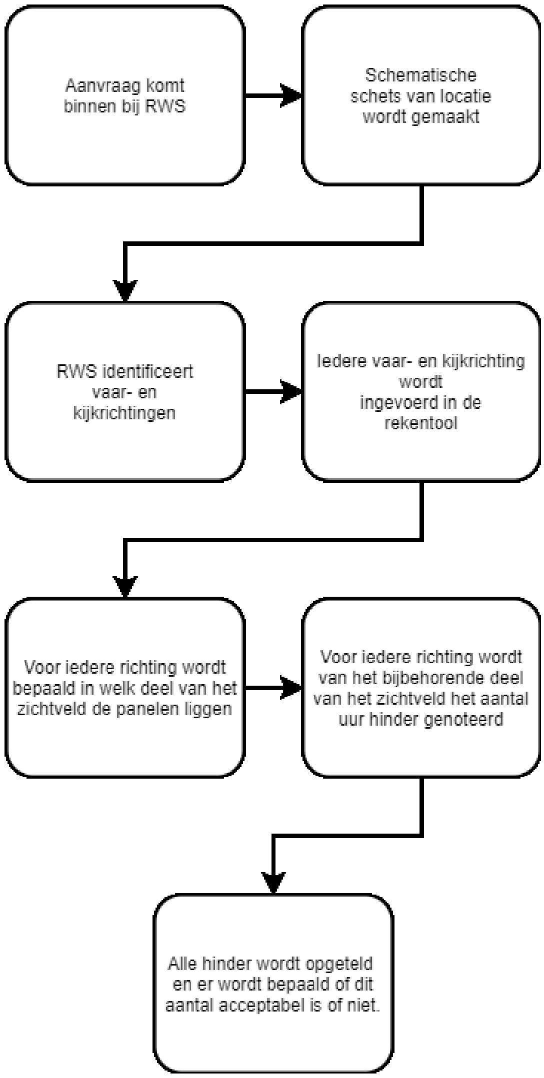


Figure 35 Example roadmap for approving or rejecting proposed solar fields along waterways.

As an example situation we take a practical example as occurs on the Beneden Merwede. An image of the location from Google Maps can be seen in Figure 36, including the location of the proposed solar field..

Figure 36 A map with a proposed solar field drawn in red. The solar field is located directly on the quay and is facing the water with the front.

This solar field would be placed close to a building and the panels would therefore be placed close to the wall. The angle of inclination of the panels is therefore 90° and the azimuth 185°. Simple schematic sketches of the proposed solar field can be found in Figure 37 and Figure 38.

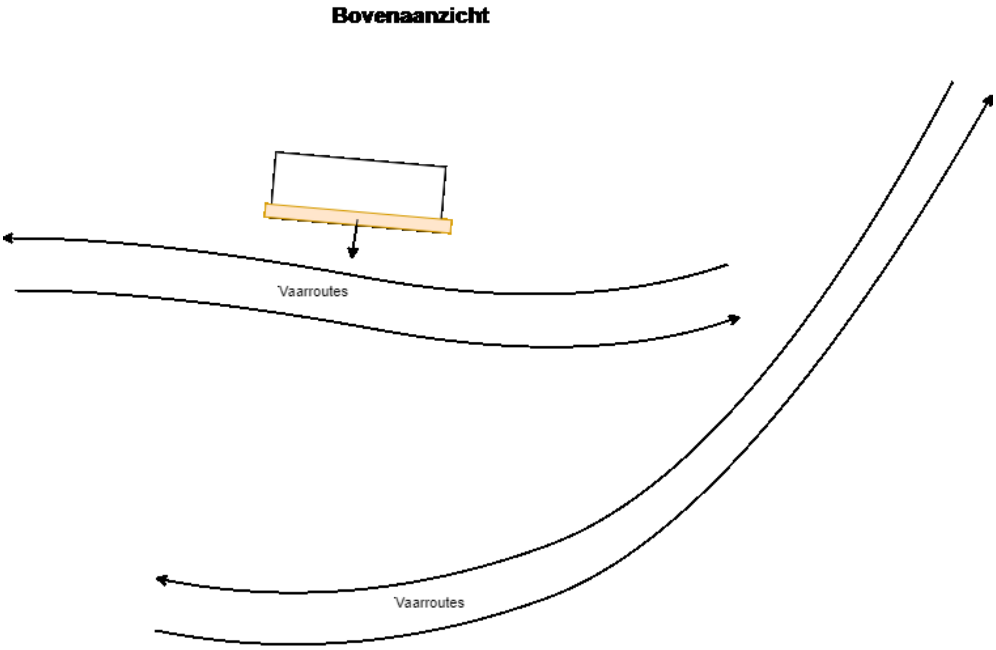


Figure 37. Schematic top view. In orange the proposed solar field.

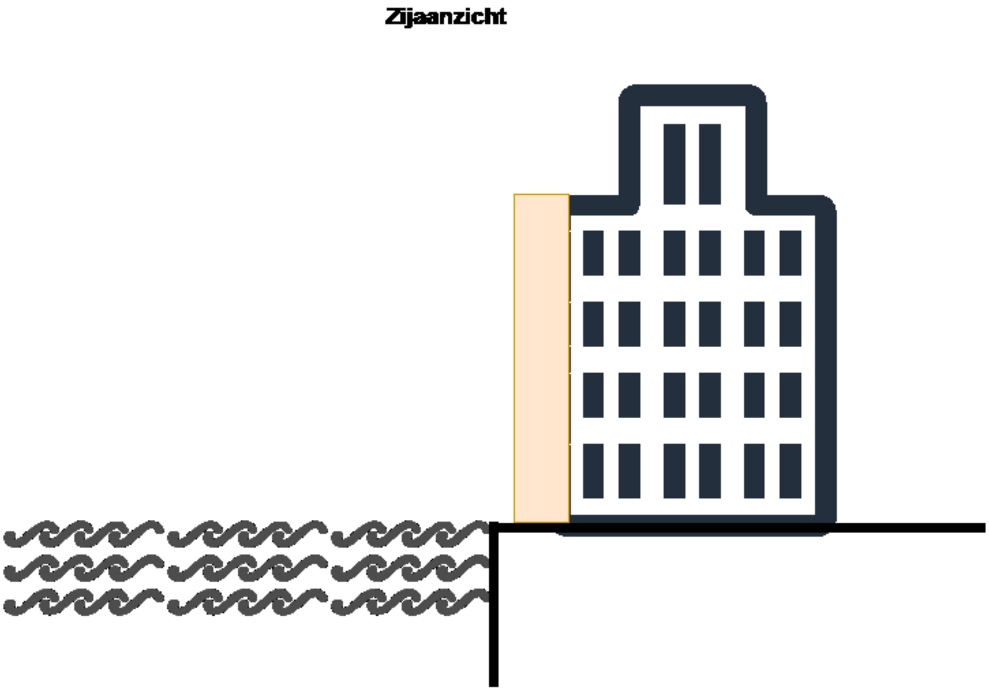


Figure 38 Schematic side view. In orange the proposed solar field.

The sailing and viewing directions in this example are quite simple, because the panels are only visible on the Beneden Merwede. The viewing directions are drawn (including field of view) in Figure 39.

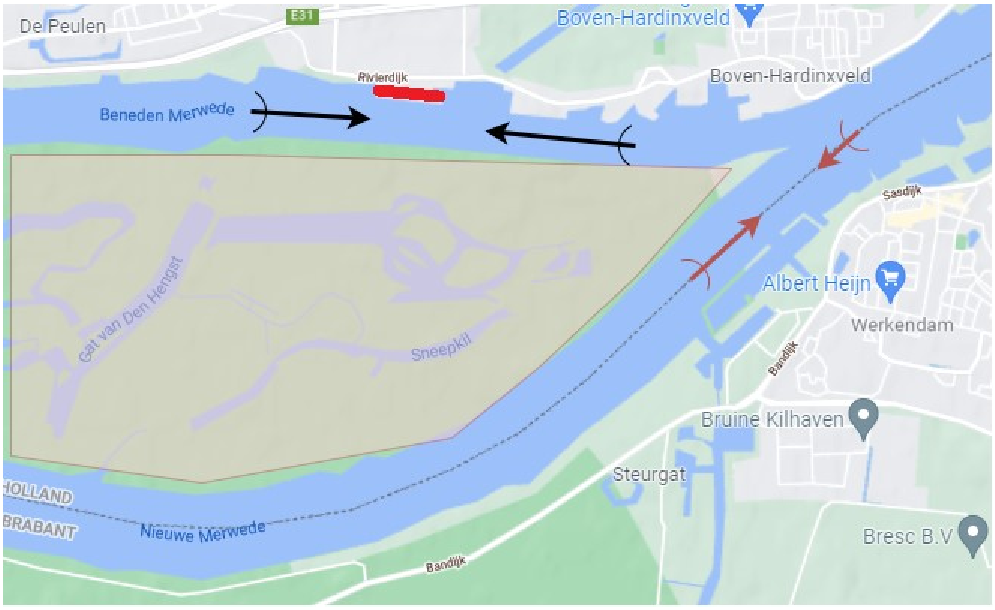


Figure 39 Sailing and viewing direction drawn in the map with proposed solar field (red). The two black viewing directions see the solar field and must therefore be calculated. The two red viewing directions have been viewed but it has been concluded that they do not see the solar field because the forest (with the red-rimmed plane) deprives them of sight.

In this example, only two viewing directions are included. To determine whether a different viewing direction also has a view of the panels (for example, because the forest does not obscure the view), one should look at the location itself. That goes too far for this example.

The identified viewing directions are eastern (black arrow left in Figure 39) and west (black arrow right in Figure 39). For the eastern viewing direction, the solar field is on the middle or left side of the field of view and for the western viewing direction on the middle or right side of the field of view. The results of the calculation tool can be seen in Figure 40 for the eastern viewing direction and in Figure 41 for the western viewing direction.

From these figures it can be deduced that hindrance occurs when solar panels are installed in the middle or left of an observer who sails / looks east. That is also the case in this situation. In addition, hindrance only occurs if the solar panels are placed above the horizon, i.e. above eye level, of the observer. That is also the case in this situation since the solar panels are placed against a wall of a warehouse. They will therefore be above eye level for at least some skippers.

We can carry out the same two checks for skippers heading west. For skippers heading west, the panels are on the right side of the waterway. They are placed against the shed and are therefore (partly) above eye level. In the accompanying figure we again find that this situation is hindered

Gegevens voor selectie

Hieronder volgt het resultaat voor de geselecteerde parameters. De hinder wordt gegeven in uren per jaar.

Kijkrichting	Zonnepaneel Azimut	Zonnepaneel Hellingshoek	Totale hinder	Hinder linksboven	Hinder linksonder	Hinder middenboven	Hinder middenonder	Hinder rechtsboven	Hinder rechtsonder
90	185	90	121.91	76.00	0.00	45.91	0.00	0.00	0.00

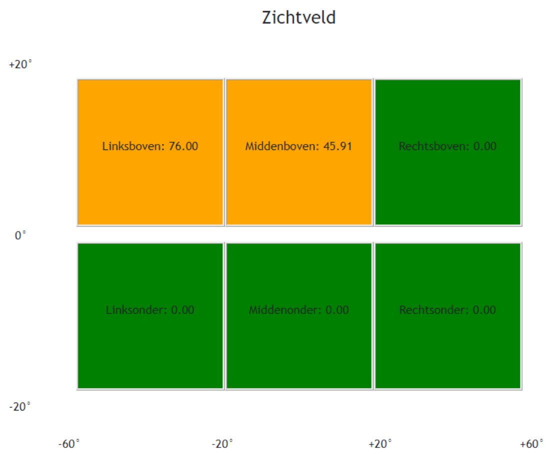


Figure 40 Result of the calculation tool for the proposed solar panels and an eastern viewing direction. It can be seen that in the left and middle upper part of the field of view there is a hindrance for this observer.

Gegevens voor selectie

Hieronder volgt het resultaat voor de geselecteerde parameters. De hinder wordt gegeven in uren per jaar.

Kijkrichting	Zonnepaneel Azimut	Zonnepaneel Hellingshoek	Totale hinder	Hinder linksboven	Hinder linksonder	Hinder middenboven	Hinder middenonder	Hinder rechtsboven	Hinder rechtsonder
270	185	90	92.39	0.00	0.00	30.67	0.00	61.72	0.00

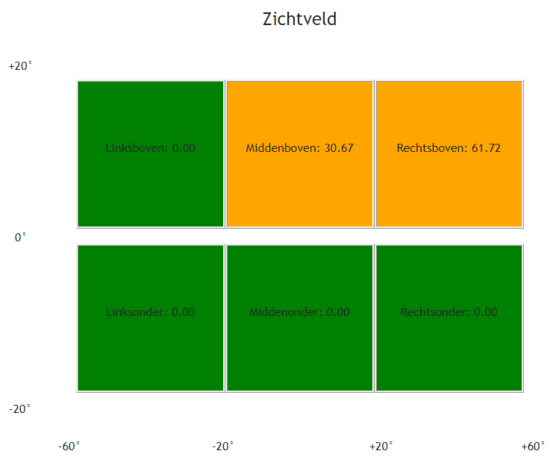
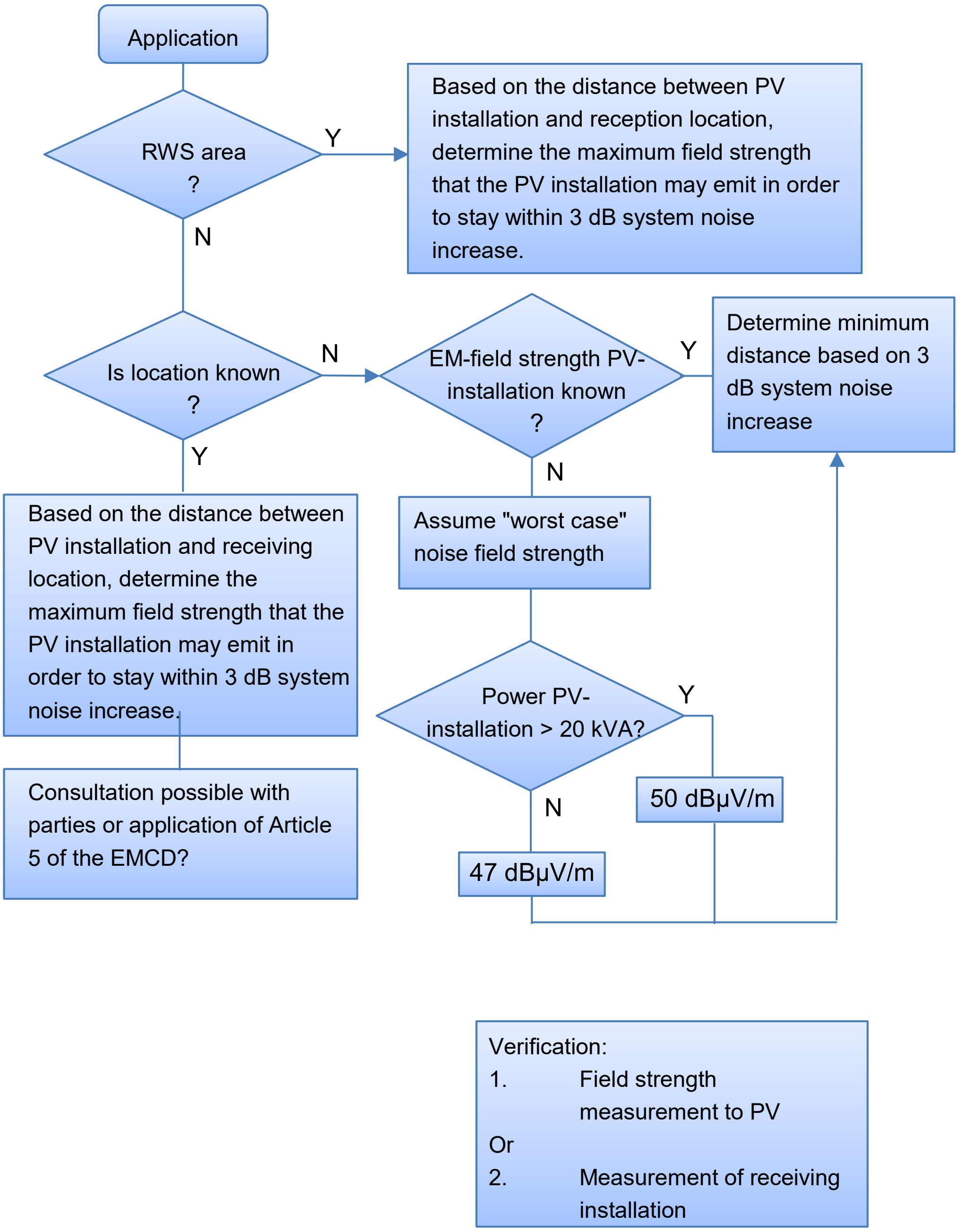


Figure 41 Result of the calculation tool for the proposed solar panels and a western viewing direction. It can be seen that in the right and middle upper part of the field of vision there is a hindrance for this observer.

We can conclude from these results that sun reflections that cause hindrance will in any case be visible to both viewing directions. The biggest hindrance of the panels is (maximum) 122 hours per year (in the western viewing direction it is 92 hours). Since the standard is not fixed, it is difficult to conclude whether this is acceptable, but it is in any case less than the 131 hours per year that was used earlier in this report as an (arbitrary) limit value. This makes these situations among the 25% most favourable situations as shown in Figure 30.

7.2 PV installation application procedures – electromagnetic nuance

This section contains a proposal for a process to assess applications. The flowchart below is suitable both for requests where the appearance of an installation is known and for requests where requirements can be set for the distance of the installation to a receiving location.



7.3 Other aspects of the EMCD and national Interests

The EMCD sets out the framework that equipment must meet before it can be placed on the European market. In order to combat trade barriers, there are conditions that must limit countries from issuing their own rules. Article 5 of the EMCD referred to earlier in this report allows countries to make an exception to this, for example to impose requirements other than those of the harmonised standards in a specific geographical area. However, permission must be obtained from the

European Commission. Agentschap Telecom reported to TNO that, as far as is known, no use has yet been made in the Netherlands.

Astronomical research institute Astron in Dwingeloo is conducting research with a huge antenna array, called LOFAR. This array consists of several fields that are filled with small antennas, and are mainly set up in Drenthe, but also at locations outside the Netherlands. The locations in Drenthe were chosen a long time ago for the absence of human activities) with potentially disturbing electronics). This was well before the introduction of the large-scale roll-out of PV installations. Astron has expressed the fear of a decrease in the sensitivity of the LOFAR antenna array and has concluded a covenant with the surrounding municipalities and the province of Drenthe. The construction of PV installations is not necessarily made impossible, but agreements on emissions apply.

8 Conclusion and recommendations

PV installations in the vicinity of a waterway can cause hindrance to shipping by disrupting electromagnetic communication and/or information signals and/or by blinding skippers.

With the help of the guidelines, data and tool provided in this report, visual hindrance (glare) by sunlight reflections can be determined which orientations of solar panels along which waterways can cause hindrance. The orientation of the panels and the viewing direction of the observer are particularly important here. In addition to hindrance caused by sunlight reflections, this report provides insight into how much glare one accepts from the direct sun.
The hindrance caused by direct sunlight can possibly act as a benchmark to assess new solar parks.

This report does not address reflections of artificial light that may be a hindrance, as these situations are very context-dependent. A sufficiently bright artificial light source can almost always generate annoying reflections if it is in the right place in relation to the solar panels.

Based on standards and norms, an acceptable value of the increase in ambient noise has been determined whereby the nautical communication and navigation systems can still meet the desired application requirements. On the basis of tables and graphs, distances can be determined for the installation of PV installations or limits can be set on the high-frequency radiation that a PV system must meet.

8.1 EMC aspects of PV-installations

8.1.1 Summary

Rijkswaterstaat uses various communication and navigation systems in shipping. This report places particular emphasis on inland navigation, although the results are also applicable to seagoing vessels on inland waterways as long as the conditions of antenna heights and transmitting power are met..

Companies, provinces and municipalities are planning fixed or floating PV installations in the immediate vicinity of waterways, so that the risk of serious disruption of radio communication is real. The results and conclusions in this report also apply to all these installations.

The simulations and calculations assume a system noise increase of a system with a maximum of 3 dB. The reception parameters of the radio or navigation system in question were decisive. Not only the increase in ambient noise, but that of the entire reception installation is decisive. Based on the acceptable audio SINAD degradation of VHF radio and the PER degradation at AIS, it is advised to accept a maximum system noise increase of 3 dB.

VHF radio and AIS are seen as essential means of communication and navigation. It is advised to tolerate a maximum increase in system noise of 3 dB for VHF and AIS. The calculations and curves are based on this.

PV installations can be divided into two categories: with a capacity smaller and greater than 20 kVA. For both, different standards apply to the high-frequency interference ("noise") that may be emitted. According to the standard, high-power installations may emit more noise than those with low power, but this does not have to be the case in practice.

The installation heights of the PV installations and antennas determine the range of the emitted noise of a PV installation. There is a maximum, because the strength of that noise is so low that at a distance of a few kilometres the noise will always disappear in the natural ambient noise.
Within a few hundred meters of a PV installation, it can happen that the height of a "target" receiving antenna does not matter very much. 20 m, or 30 m height received than the same amount of interference from the PV installation

8.1.2 *Conclusions and recommendations*

Electrical and electronic equipment, which includes PV installations, must comply with the EMCD. This directive determines, among other things, the maximum high-frequency radiation that a PV installation may produce. The essential requirements in the EMCD refer to the harmonized standards, but this is no guarantee that there will be no hindrance or malfunction from a PV installation. This is not covered by the EMCD, so the risk of serious disruption of radio communication is real.

Possible solutions are:

- On the basis of the calculations presented in this report, to consult with parties that want to place a PV installation in RWS acreage in order to come to agreements about the placement (distance) and the equipment to be used to limit the high-frequency radiation;
- Invoke Article 5 of the EMCD, which allows stricter EMC rules to be imposed on parties or to impose conditions on permit applications or notifications under the Water Act; it is primarily at the discretion of and up to the lawyers of RWS to give substance to this..

Although in practice it appears that professional PV installations in particular often meet the standards requirements[39]. , requirements will nevertheless have to be set for every PV installation that can potentially interfere with nautical communication and navigation. The actual appearance cannot be determined on the basis of a certificate of conformity. This is only possible when the supplier provides the laboratory measurement data and technical details of the inverters and the PV installation (wiring) so that the initiator (possibly with the help of an EMC expert) can make a good estimate of the appearance of the PV system to be installed. After construction, this must be closed by a radiation measurement, after which, if desired, additional measures can be taken so that the installation meets the set radiation requirements

C2000 has the highest risk of network degradation, followed by AIS/ VHF radio and GNSS systems. IMT-2020 is a standard of the ITU and includes the ongoing developments regarding mobile communications, i.e. 4G, 5G and future standards. Appendix B of this report shows the effect on an 800 MHz network (part of IMT-2020) where a large protection zone applies (so: "a lot of burden"). In practice,

[39] Uitspraken Agentschap Telecom tijdens overleg van 29 november 2021 op basis van ervaringen (metingen).

however, the consequences will be small due to the mutual cell interference. The effects on the interference limited catchment areas are not included in the simulations because it is not a maritime specific system.

The use of stricter EMC standards in the field of radiation can prevent further increases in disturbances of radio communication as a result of the increase in ambient noise. This would avoid alternative measures that would lead to substantial additional costs for RWS (such as additional base stations, support transmitters and repeaters for VHF radio, AIS, IMT-2020, C2000, DAB+, etc.).

In order to reduce the risk of disruption of maritime radio communications, the EU Directive 2014/30/EU of the European Parliament and of the Council on the harmonisation of member states' laws on electromagnetic compatibility should ideally be strengthened. Since this is outside the direct sphere of influence of RWS, we recommend that we seek support for this in a broader context.

The present study on interference by equipment is limited to 1000 MHz. Between 1 and 6 GHz, only a limited amount of information is available for an industrial environment. For frequencies higher than 6 GHz, no statement can be made about the high-frequency emission effects of equipment. It is recommended that further research be carried out into the (possible) EMI effects of solar parks on ship and shore radar

8.2 Visual hindrance of PV-installations

8.2.1 Summary

It is necessary for a participant in the boat traffic on a waterway, whether that is a waterway user or a shore official of Rijkswaterstaat, not to experience long-term hindrance from sun reflections in solar panels. Such hindrance may create situations in which they are less able to perform their sailing or supervisory task. In some situations, this can lead directly to danger.

In this report, based on the so-called SGHAT model, which is used worldwide to calculate sun reflections, we have simulated in a general sense the hindrance of solar panels that are in the field of view of an observer. The results of this research can therefore be applied generally (within the Netherlands).

To date, hindrance caused by sun reflections has almost always been calculated by calculating specific situations. In this report, a first step has been taken to move from specific calculations to more general guidelines. However, the specific nature of sun reflections remains problematic for the preparation of a generally applicable guideline. In generalizing the results, a compilation of graphs, included in Appendix C, was therefore chosen, in which it can be read how much hindrance is generated by specifically oriented solar panels, given an observer looking in a certain direction.

8.2.2 Conclusion

Due to the specific nature of the sun reflection problem, it has not been possible to draw up general guidelines and limit values to prevent hindrance (hourly on an annual basis) due to prevent or minimize light reflections. In order to give a number of tools for a first estimate for the choice of a specific setup for solar panels, we make the following proposal for some rules of thumb:

1. If the viewing direction is equal to the azimuth of the solar panels plus or minus 50°, then no or hardly annoying reflections occur. The observer then mainly looks at the back of the panel.
2. For northern viewing directions (315° to 45°), hindrance occurs mainly due to:
    a. South facing panels (90° to 280°) with an angle of inclination greater than 35°;
3. For eastern viewing directions (45° to 135°) hindrance occurs mainly due to:
    a. South-west facing panels (180° to 300°) with an angle of inclination greater than 35°.
    b. North-west facing panels (180° to 30°) with an angle of inclination less than 40°.
4. For southern viewing directions (135° to 225°) hindrance occurs mainly due to:
    a. North facing panels (220° to 140°) with an angle of inclination less than 45°.
    b. East (20°-110°) or west (250°-340°) facing panels with an angle of inclination greater than 40°.
5. For western viewing directions (225° to 315°), hindrance occurs mainly due to:
    a. Southeast-facing panels (40° to 220°) with an angle of inclination greater than 35°;
    b. Northeast facing panels (300° to 180°) with an angle of inclination less than 40°.

These rules of thumb say something about the total hindrance somewhere in the field of view. If it is known where the solar panels will be placed in relation to an observer, it is possible to use the attached data (appendix C and Excel /Dashboard) to determine in which part of the field of vision hindrance occurs.

8.2.3 Recommendations

In this report, a step has been taken towards the generalisation of guidelines for sun reflection hindrance. Although important, this generalization also means that information is lost because it is not easy to include in general guidelines. That is why TNO recommends that in the future we move towards an (online) dashboard in which it can be determined with the help of a few institutions whether reflection hindrance will occur in a certain situation. The SGHAT model was originally available for free in such a form but has been taken offline by Sandia National Laboratories..

In such a dashboard, it would also be possible to include mitigating measures that are difficult to formulate in general guidelines. Think of anti-reflective coatings or textured panels. This makes the results more manageable and ensures less research for the end users.

This report is based on a very large field of vision for the observer. While this does include all the sun reflections the observer can see, this approach is most likely on

the cautious side. Observers are often able to (temporarily) block a large part of their field of vision, for example by holding their hand along their face or above their eyes. It is also sometimes possible to close a sun visor or curtain to block sun reflections. It should be borne in mind that objects or vessels in the blocked field of vision cannot be observed.
In this report, we have assumed solar panels that reflect perfectly, that is, that have a perfectly smooth surface and therefore reflect like a mirror. In reality, glass surfaces are never perfectly smooth, especially since that is not necessary either The result of this is that the light rays of the sun do not stay nicely bundled after reflecting. Due to this effect and absorption by the atmosphere, the strength of the sunlight decreases slightly at greater distances. For distances smaller than 100m, this effect is hardly noticeable. Between 100m and 1km, the intensity of sunlight gradually decreases by about 80% (Ho, Ghanbari, & Diver, 2011). has shown that a decrease in refractive index from 1.5 to 1.25 only reduces hindrance by 11 %, while this (in the case of perpendicular incidence) reduces about 70% of the reflection . When assessing solar parks less than one kilometre away from the observer, the results from the current research can therefore be seen as a worst-case scenario. We do see starting points for working out a further analysis of the effect of distance between observer and solar panels in a follow-up study and including it in the aforementioned dashboard.

The afterimage boundary that is maintained in this report as the boundary on which reflections become annoying because they are too intense, is quite strict. Almost all visible reflections rise above this afterimage limit in terms of intensity. This is partly because, as indicated above, it is assumed that the solar panels are relatively close to the observer. A second cause, however, is more fundamental that the afterimage boundary in itself is already quite strict. As shown in previous research, for example, the TNO disability glare model allows more intense reflections while drivers can still perform the driving task (Alferdinck, Goede, & Buuren, Lichthinder sun reflection for road users – development assessment method based on disability glare, 2016).

Finally, in this report we do not take into account any obstacle that blocks the direct line of sight towards solar panels. In these situations, the observer will obviously not be bothered by sun reflections, regardless of how the solar panels are oriented.

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10 Used standards

- EN61000-6-4/A1: Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments
- NEN-EN 55011_2016_A1_2017 and, HF equipment for industrial, scientific and medical purposes (so-called ISM equipment) - Radio interference characteristics - Limit values and measurement methods.
- EN301929 V2.1.1 (2017-03), VHF transmitters and receivers as Coast Stations for GMDSS and other applications in the maritime mobile service; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU.
- 2014/30/EU Directive of the European Parliament and of the Council on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (recast).
- TETRA standaard: ETSI TS 100 392-2 V3.9.2 (2020-06), Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI)
- ETSI 3GPP TS 36.101 V16.5.0 (2020-03), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (Release 16), par. 7.3.
- ETSI TS 136 104 V15.3.0 (2018-07), LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (3GPP TS 36.104 version 15.3.0 Release 15).
- ITU-R M.1371-5, (02/2014), Technical characteristics for an automatic identification system using time division multiple access in the VHF maritime mobile frequency band.
- IEC61993-2:2012, Maritime navigation and radiocommunication equipment and systems – Automatic Identification Systems (AIS) – Part 2: Class A shipborne equipment of the automatic identification system (AIS)- Operational and performance requirements, methods of test and required test results.
- IMT2020: International Mobile Telecommunications-2020 (IMT-2020 Standard). See explaination: https://en.wikipedia.org/wiki/IMT-2020

11 List of abbreviations and concepts

AES	Aircraft Earth Station
ASM	Application Specific Messages
AIS	Automatic Identification System
BS	Base Station
C2000	Public Order and Security Communication system based on TETRA operated in The Netherlands
CE	Conformitè Europëenne
DAB+	Digital Audio Broadcast
EMC	Electro Magnetic Compatibility
EMCD	Electro Magnetic Compatibility Directive: Richtlijn 2014/30/EU
EMI	Electro Magnetic Interference
GMDSS	Global Marine Distress and Safety System
GNSS	Global Navigation Satellite System
HF	High Frequency (3 – 30 MHz)
IARU	International Amateur Radio Union
IMT	International Mobile Telecommunications
MF	Medium Frequency (0.3 – 3 MHz)
MS	Mobile Station (User Equipment, “UE”)
PER	Packet Error Rate
PV	Photo Voltaic (“solar cells”)
RF	Radio Frequency
RX	Receiver
SINAD	Signal Noise And Distortion
SNR	Signal-to-Noise ratio
TETRA	Terrestrial Trunked Radio
TX	Transmitter
UHF	Ultra High Frequency (300 – 3000 MHz)
VERON	Vereniging Experimenteel Radio Onderzoek Nederland
VHF	Very High Frequency (30 – 300 MHz)
VDES	VHF Data Exchange System
VDE	VHF Data Exchange
TC	Traffic Centre
VTS	Vessel Traffic Service
Wi-Fi	Wireless Fidelity

Term	**Definition**
Viewing direction	The viewing direction of the observer (skipper, lock employee, etc.). The direction is given as a number of degrees. This is the compass angle that the observer is looking at. A viewing direction of 90° means that the observer is looking west.
Azimuth	Azimuth refers to the compass angle of the solar panels. The compass angle indicates the direction in which the front of the solar panel is pointed.
Angle of inclination	The angle of inclination indicates the angle between the solar panel and the ground. An angle of inclination of 90° means that the solar panel is perpendicular to the ground (and therefore upright). An angle of inclination of 0° means that the solar panel is flat on the land is lying.