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► **To cite this version:**

Frits van Der Eerden, Erik Salomons, Arno Eisses. Effects of solar panel fields on sound propagation. Forum Acusticum, Dec 2020, Lyon, France. pp.857-861, <10.48465/fa.2020.0275>. <hal-03233652>

HAL Id: hal-03233652

<https://hal.science/hal-03233652v1>

Submitted on 26 May 2021

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EFFECTS OF SOLAR PANEL FIELDS ON SOUND PROPAGATION

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ABSTRACT

The Dutch Ministry of Infrastructure and Water Management investigates the realization of photovoltaic solar panel fields in the vicinity of their roads and highways. These fields can have a width of tens of meters or more and may be located between a road and a residential area. One of the research topics is the effect of the panels on the sound propagation of road traffic noise, as the acoustic properties of the ground will change. For situations where the acoustic effect is significant one can, for instance, provide recommendations when applying standard noise calculation methods. To determine the acoustic effect numerical models have been applied up to 200 meters distance from the road, for different geometries and orientations of the panels. A downwind situation was taken into account. Sound level measurements using a loudspeaker source were conducted, as well as meteorological measurements, to validate the model results.

1. INTRODUCTION

The Dutch organization Rijkswaterstaat, part of the Ministry of Infrastructure and Water Management, manages national roads and highways and its neighboring areas. It is investigating the use of solar panel fields within these areas. One of the consequences of a realizing such a field can be a change in traffic noise levels at residential areas due to a change of the acoustic properties of the (ground) surface.

In this paper the calculated acoustic effect is presented for a typical situation as shown in Figure 1. The reference situation consists of a slightly elevated road and a grass soil between the road and the residential area. The solar panel field has a width a 60 meters, with a height of 1 meter and is acoustically hard. By comparing both situations the acoustic effect is determined.

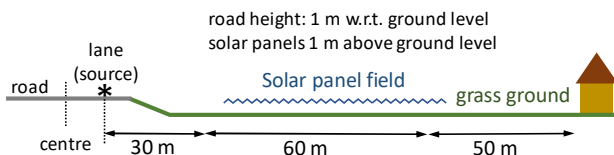


Figure 1. Impression of a solar panel field next to a road.

The solar panel field in this case is a so-called East-West configuration, see Figure 2. In contrast to the South situation, the produced energy is distributed more during the day.

Numerical results are presented in Section 2.1. A finite element method (FEM-Comsol®) has been used, including an absorbing grass soil and a representative downwind situation. The horizontal angle of the solar panels has been set to 20 as well as 8 degrees.

In Section 2.2 the Dutch standard calculation method is applied for the same situation as a comparison. In this case the solar panels are represented by a raised ground section; acoustically hard and flat.

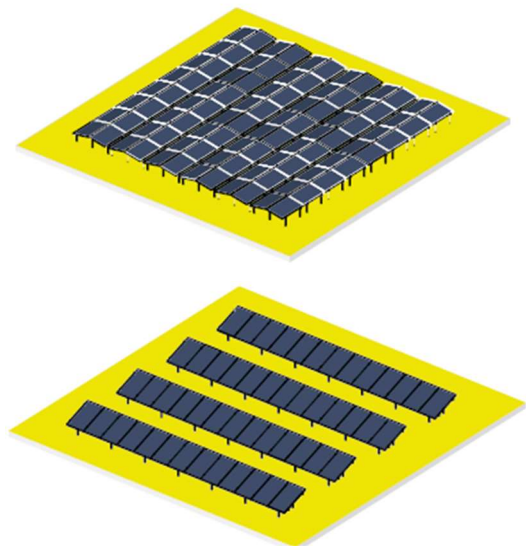


Figure 2. Top: East-West configuration. Bottom: South configuration [1].

In order to validate the FEM results, measurements with a loudspeaker source were conducted. Along 4 different lines across a solar panel field microphones were placed, each for downwind condition. Results of the measurements are presented and discussed in Section 3. Finally, Section 4 ends with conclusions.

2. CALCULATED RESULTS

2.1 Numerical results (FEM)

To determine the sound propagation up to several hundreds of meters, for a downwind and ground absorption due to a grass soil, the Parabolic Equation method (PE) is known as a suitable and fast method. However, it is difficult to take into account the solar panel geometry.

Such a geometry can be easily modelled with a boundary or finite element method (BEM/FEM). If also a realistic downwind situation has to be taken into account FEM Comsol multi-physics® can be used. In this case a

logarithmic sound speed profile is used, with a wind speed of 5 m/s at 10 meters height.

In Figure 3 an impression of the modelled two-dimensional FEM domain is given. The top figure shows the complete domain up to 200 meters distance. A point source is located at 0 meter at ground level and there are 8 triangular panels between 15 and 50 meters distance. Sound level results are shown for 250 Hz. A perfectly matched layers is applied on both sides and at the top.

At these distances a downwind refraction can be seen, as well as a (small) absorbing ground effect. A comparison between PE and FEM results without panels showed a very good correspondence at 200 meters.

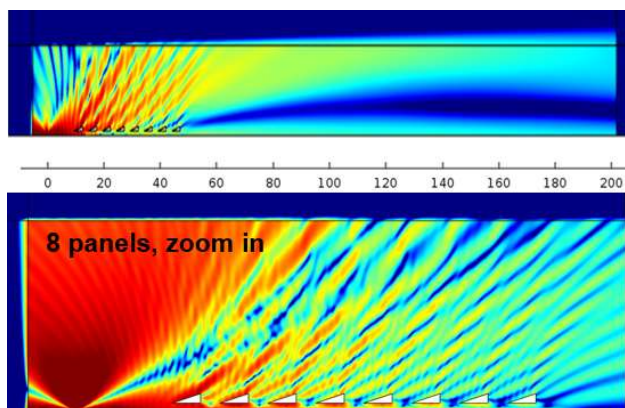


Figure 3. Top: Impression of calculated sound field at 125 Hz for a downwind situation over 8 panels and a grass ground. Source at ground level at 0 meters. Bottom: zoom in on the 8 panels.

Next, the typical situation as shown in Figure 1 has been modelled. The solar panel field consists of a continuous concatenation of 1 meter long panels with an upward and downward horizontal angle of 20 degrees, between 30 and 90 meters from the source. The reference situation is without solar panels.

For both situations the sound level in octave bands has been calculated, using 9 frequencies in each band. The difference between both situations is shown in Figure 4 for the octave bands 250, 500 and 1000 Hz. A yellow or red color indicates an increased sound level compared to the reference situation. A blue color indicates a reduced level.

For this two-dimensional situation the acoustic effect varies between ± 5 dB. Also, this effect strongly depends on the location behind the solar field, especially the height. In general traffic noise can be seen as a line source, so that it is expected that the variations as a function of (at least) the location is less prominent compared to the two-dimensional results with a point source.

Similar results are presented in Figure 5 for a reduced slope angle of 8 degrees, as used for the solar panel field measurements, see Section 3. At 250 and 500 Hz the acoustic effect is more pronounced than for 20 degrees. This is in line with the expectation that a higher

roughness with 20 degrees causes more scattering of sound and thereby the ground effect will be smaller (at 8 degrees there is more resemblance with a flat hard ground with increased levels).

For traffic noise the sound level in dB(A) is generally used, which is dominated by the 1000 Hz band.

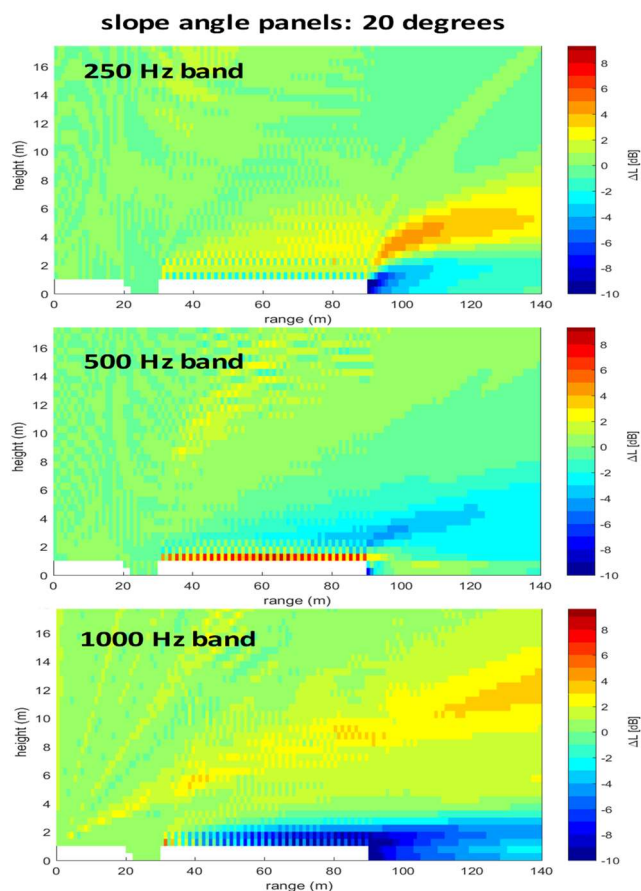


Figure 4. Calculated effect of placing solar panels (yellow and red colors indicate an increased level) on a grass soil for the octave bands 250, 500 and 1000 Hz.

On overview of the acoustic effect at 150 meters distance is given in Table 1. Using the results of both slope angles (indicated by min/max) in octave bands. The result in dB(A) is obtained by weighting with a traffic noise spectrum.

		effect of adding solar panels (dB)						
		octave band (Hz)						total dB(A)
height (m)		31,5	63	125	250	500	1000	
1,5	min	-1	-1	-3	-1	-1	-3	-2
	max	-1	-1	-1	+3	+3	-1	0
5	min	-1	-1	-3	+3	-2	-3	-1
	max	-1	-1	-1	+8	0	0	+1

Table 1. Effect of adding solar panels in dB, based on numerical FEM results for a downwind situation and.

Although spectral differences up to +8 dB are shown (=increased level), the difference in dB(A) is between -2 dB (=reduced level) and +1 dB.

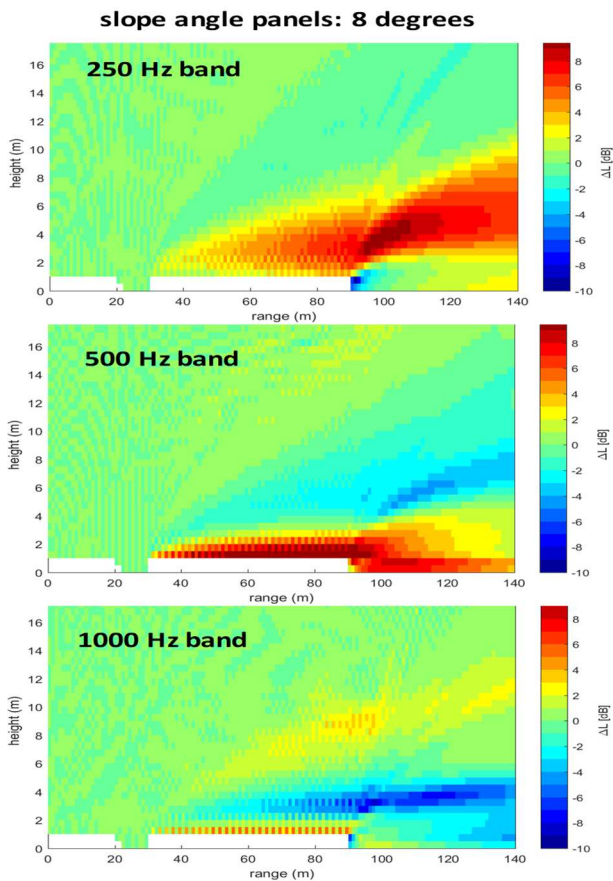


Figure 5. Calculated effect of placing solar panels (yellow and red colors indicate an increased level) on a grass soil for the octave bands 250, 500 and 1000 Hz.

2.2 Standard calculation method (Dutch SRM2)

An estimate of the acoustic effect of adding a solar panel field has also been calculated with the Dutch standard calculation method for traffic noise [2]. The surface with solar panels is changed to acoustically hard ($B=0$) and raised with 1 meter. For the situation of Figure 1 a line source of 2 km has been used. The results are presented in Table 2. This method predicts an increased sound level between 1 and 2 dB(A).

The increase in octave bands is the highest for the 250 Hz band. This is the result of a sound level reducing ground interference, for the absorbing ground, that will be reduced when the solar panels are installed.

Note that this band does not have a large contribution to the total level in dB(A).

height	effect of adding solar panels (dB)							total dB(A)
	octave band (Hz)							
	31,5	63	125	250	500	1000	8000	
1,5 m		+0,1	+2,1	+4,9	+2,8	+1,8	+2,1	+2,0
5,0 m		0,0	+1,8	+2,3	+1,3	+0,7	+0,7	+0,8

Table 2. Effect of adding solar panels in dB, using a hard elevated ground in the Dutch standard calculation SRM2.

A similar increase for the 250 Hz band, even higher, can be seen in Figure 5 for the numerical results using a point source. Although in that case the roughness of the ground is higher, due to the 8 degree slopes.

It is expected that a completely flat surface for the solar panel field overestimates the acoustic effect. This is demonstrated in Figure 6, which compares the numerical results in the 1000 Hz band for a flat surface (0 degrees) and a field with an 8 degree slope for the panels. The blue colors indicate a reduced effect due to the roughness.

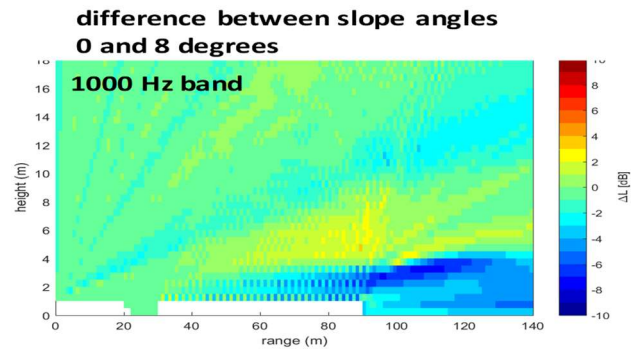


Figure 6. Calculated effect (FEM) between a slope angle of 0 (flat) and 8 degrees (rough) for the panels. Blue color indicates a reduced effect for 8 degrees.

3. MEASUREMENTS

3.1 Measurement set-up

For a validation of the numerical results, measurements have been carried out across a solar panel field with a set of loudspeakers as a point source. An impression of the solar panel field is shown in Figure 7. The upper photograph shows the 8 degrees slope of the solar panels, each with a length of 1 meter and with a maximum height of 1 meter. The loudspeakers were situated in front of the field and set to several heights, e.g. 1,35 and 2,0 meters.

Figure 8 shows 6 lines for which the measurements were carried out. The position of the loudspeaker is indicated with a black dot, the location of 4 microphones with red dots. The distance from the loudspeaker varied up to 220 meters. The height of the microphones was 4,5 meters. All heights with respect to ground level.

Measurements were carried out on two separate days. For each day 2 lines were measured across the field and 1 line next to the field as a reference. On day 1 there was an eastern wind, measured with a meteorological mast capable of measuring the wind and temperature at several heights. In this way the sound speed profile could be determined during the measurements. On day 2 a southern wind prevailed.

The measurements were done prior to the numerical calculations. However, by looking at the numerical results shown in Figure 5 it can be seen that the height of the microphone at 4,5 meters relatively close behind the solar field will be sensitive for a representation of the difference in sound levels.



Figure 7. Impressions of the solar panel field for which several measurements with a loudspeaker were carried out.

Line 1 in Figure 8 is across the field perpendicular to the ridge lines of the panels. Line 4 is parallel to the ridge lines. The results in Section 3.2 are given for line 2 (with reference line 3) and line 4 (with reference line 6). These are both for a downwind situation at approximately 30 degrees across the field.

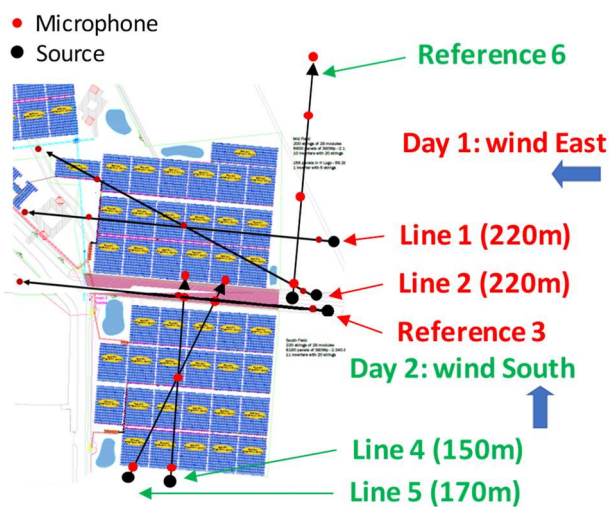


Figure 8. Measurement lines across the solar panel fields, for two different wind directions and days. Line 4, see top figure 7, Line 1 see middle figure 7.

3.2 Results

The loudspeaker generated frequency sweeps and pink noise. Both results are presented for microphones positions 3 and 4, respectively close to the end of the field and approximately 30 meters further.

Figure 9 shows the results for line 2 (configuration 2), for the source heights of 1,35 and 2,0 m.

At these source heights the sound level difference is negative, indicating a reduction due to the presence of the solar panel field.

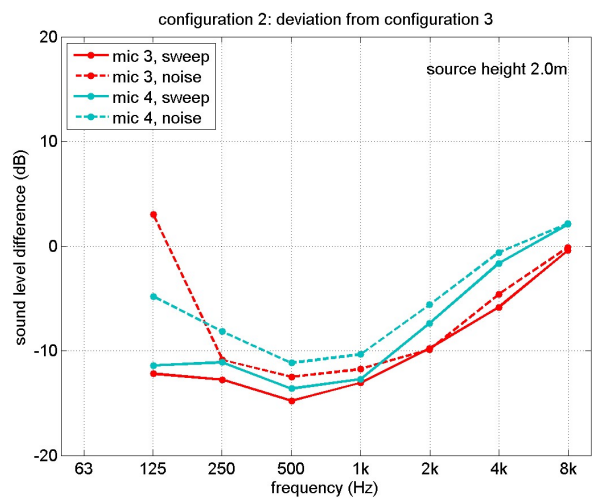
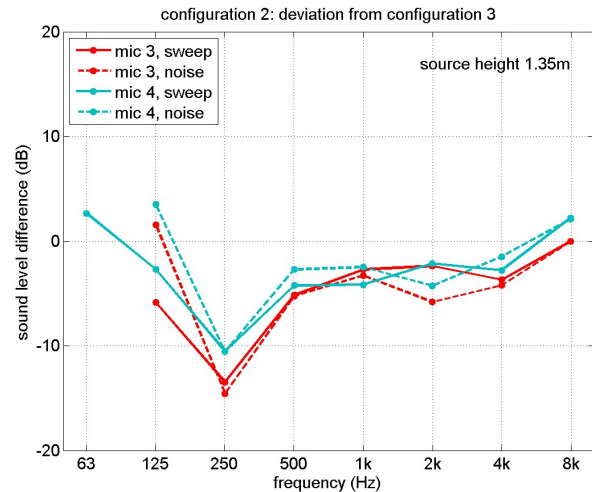


Figure 9. Measured sound level difference in octave bands between Line 2 (30 degrees difference with wind direction) and Reference line 3. Top: source height 1,35 m. Bottom: source height 2,0 m.

Next, in Figure 10 the results for day 2 are shown. These are expected to be similar as both lines are at similar angle across the field, a difference of about 30 degrees, with a similar downwind.

For the second day the results, in particular for microphone 4, are positive, indicating an increased sound level due to the solar panels.

We were not able to reproduce the measurements with numerical results, especially a reduction of 10 dB at

250 Hz on day 1, as well as the increase of more than 10 dB at 1000 Hz on day 2. Both for a 1,35 m high source.

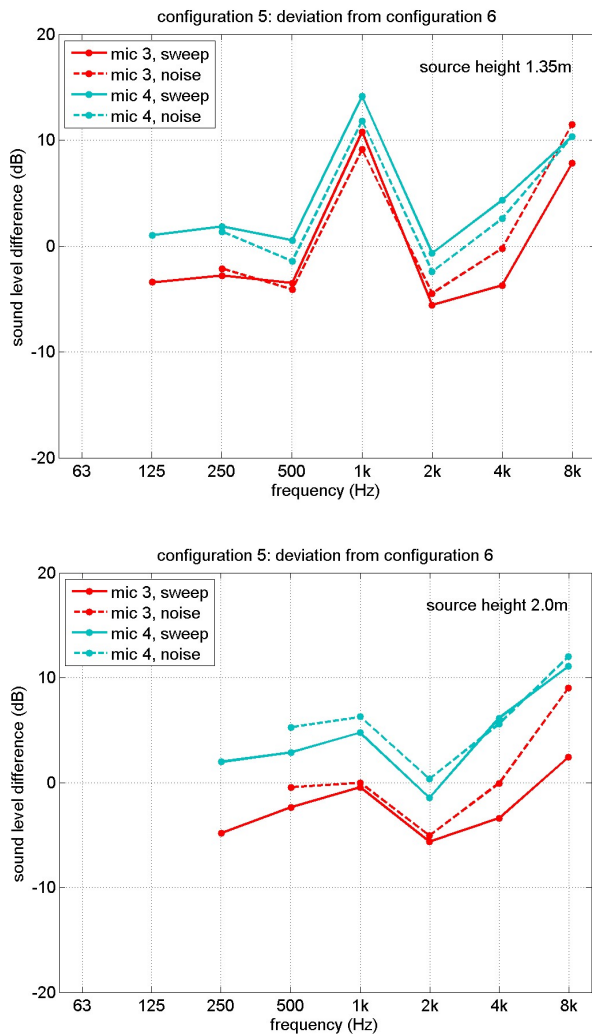


Figure 10. Measured sound level difference in octave bands between Line 5 (30 degrees difference with wind direction) and Reference line 6. Top: source height 1,35 m. Bottom: source height 2,0 m.

We reason that the measurement results are not suitable for the model validation, unfortunately. For instance, the difference across the panels for line 2 and 5 is only 30 degrees, but the spectral results show variations of more than 10 dB between these lines for almost all octave bands.

Also, when looking at the numerical results, a small variation of the microphone height can lead to a large difference of the sound level. The use of more microphone heights is recommended.

Finally, two different reference lines have been used, as two wind directions were used. The sound level difference depends on the sound absorbing properties of each of these reference lines. Both reference line have been compared, but the differences that were found do not explain the 10 dB difference as indicated before. Note

that the sound absorbing properties may differ in location, but also in time.

4. CONCLUSIONS

The acoustic effect on the sound propagation by adding a solar panel field between a road/highway and a residential area has been investigated with numerical calculations and with measurements. The solar panels had an of East-West configuration and a height of 1 meter.

The numerical FEM results, using a point source, indicate that typical differences of ± 3 dB can be expected in octave bands. With the Dutch standard calculation method, using a line source, only increased sound levels are predicted. However, this method cannot take into account the roughness of this field, which is likely to decrease these levels.

Measurements across a solar panel field were carried out with a loudspeaker and microphones at 4,5 m height. A reference ground next to the field was used for comparison. The results showed both reduced and increased octave band levels of more 10 dB. These results could not be reproduced with the numerical method. The numerical results demonstrate that the acoustic effect is sensitive to, in particular, the microphone height. For future measurements multiple microphone heights are advised.

5. ACKNOWLEDGEMENT

The calculations and measurements were carried out with the support of Rijkswaterstaat.

6. REFERENCES

- [1] Zonnewijzer, Gelderse Gebiedsgids voor zonnevelden, Gelders Energieakkoord, 2019
- [2] Dutch standard traffic noise model (calculation method SRM2), Reken- en meetvoorschrift geluid 2012 (RMG2012), Staatscourant Nr. 11810, 27 juni 2012
(an English translation of the model description is available through the Electronic Physics Auxiliary Publication Service (EPAPS) of the American Institute of Physics: see EPAPS Document No. E-JASMAN-126-051911)