VIPV SHADING MODEL APPROACH BASED ON LAND USE TYPE

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ABSTRACT: Yield prediction of VIPV is very important in order to be able to determine the impact VIPV can have in supporting the energy transition. The first step in predicting the yield is to determine the irradiance on the vehicle. For this the shading on the vehicles need to be known. However shading modelling of VIVP is quite difficult due to the dynamic behavior resulting from the movement of the vehicle. Previously we reported on the use of a generic shading model. In this paper we report on the specific challenges regarding the use of that model and propose an improved model for determining the shading factor for VIPV.
Keywords: VIPV

1 INTRODUCTION

As the number of electric vehicles (EVs) increases, the dependency on charging from the electricity grid increases. To be less dependent on the charging infrastructure, there is an increasing interest in innovative technical solutions that enhance the driving range of EVs without the need for grid charging. Vehicle integrated PV (VIPV) is one of the solutions. To estimate the impact of VIPV on the reduction on grid demands, yield models are needed that accurately describe the effect of shadow on the PV yield. Different shading models have been developed, [1-9] but only a few of them have been (partly) validated by experimental data [10, 11]. In the SolarMoves project [12] we have used a generic shading model to determine the average shading for vehicles. [13] This model distinguishes between different road types, but uses the same shading factor for different vehicle types and use cases. This generic shading function has been validated using experimental irradiance data from irradiance sensors that are mounted on different vehicles driving accross Europe. [14] The results show that the shading function used in the model overestimates the real shading function. Below we determine the challenges in the model validation and suggest an improved model for the shading on VIPV.

2 SHADING MODEL VALIDATION

2.1 Generic shading model

In our previous work we used the generic shading model as shown in Fig. 1, with a sinusoidal seasonal distribution of the daily average shading factor. It is a combination between the work from Cobbenhagen [2], who introduced the sinusoidal behavior, and Araki [15] who made the distinction between different route types. The numbers have been adapted slightly to better match the Dutch situation.

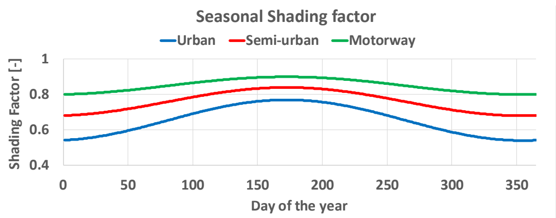

Figure 1: Seasonal shading factor for different road types. The shading factor is the fraction of the solar light received by the VIPV during a trip on a certain road type in comparison to the amount of solar light received on a trip without any shading losses.

2.2 Measurement campaign

To validate the model, 31 sensors (see Fig.2) have been installed on various vehicles, ranging from passenger cars to heavy duty vehicles. The vehicles have been driving through Europe since March 2024 and for the current analysis data has been collected until beginning of March 2025. In total the sensors have traveled a distance of over 1.028.219 kilometers. To determine the shading factor, the measured irradiance has been compared to satellite data. Details on the sensor and on the analysis can be found in [16,17].

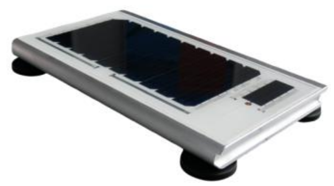

Figure 2: Picture of the sensor unit as developed by Fraunhofer ISE and used for the irradiance measurements.

2.3 Model validation

As a first step, solar elevation and azimuth angles were calculated using the python-based programming library PVlib for the given location and timestamps of all data points. This information was used to filter the dataset. Next, land use types were added to the dataset by integrating OpenStreetMap (OSM) land use types. The data obtained from OpenStreetMap was categorized based on land use types into three primary groups: 'Urban Road', 'Semi-Urban Road', and 'Motorway'. This classification allowed to group the dataset and calculate the average energy ratio for each day of the year per road type. The result is shown in Fig. 3.

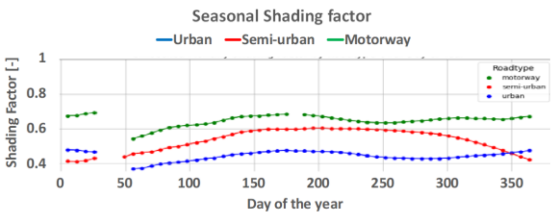

Figure 3: Seasonal shading factor for different road types as determined from the measurement campaign

Overall, a distinct separation between the three classifications can be observed, similar to the modeled distribution of Fig. 1, with 'Motorway' experiencing the least shading, followed by Semi-Urban and, lastly, Urban roads, which incur the most shading loss. However, the measurement data reveals that all categories demonstrate a lower energy ratio, indicating a larger shading loss in the dataset compared to the assumptions made in the model.

Further data analysis showed that it is extremely difficult to make an accurate prediction of the actual irradiance on the vehicles at a specific point along the route because:

a. The shading loss at a specific route point on partially clouded days cannot be determined as the reference irradiance is always measured at a different location compared to the vehicle sensor. As a result, irradiance dips due to clouds occur at a different time and thus the ratio of the reference dataset to the vehicle dataset does not reflect the shading at that time.
b. As a result, a direct relation between the shading loss and a specific road type on these kind of days cannot be derived.
c. The derived general shading loss is influenced by the conditions during parking. In the measurement campaign it was noted that parking was often done in the shade, which strongly increases the overall shading factor.
d. The derived general shading loss for a day, is influenced by the different land use types during the trip.

When looking at individual trips and taking into account the major road type, in some cases a good match is achieved between the shading model and the measured shading loss.

3 IMPROVED SHADING MODEL

To improve the shading model and derive more accurate road type specific shading factors, a more detailed analysis of the land use distribution along a trip is performed. To do this, the road points along the trip are plotted using ArGIS which are overlayed on the the Bestand Bodemgebruik (Land use) map from the Bureau of Statistics (CBS) in the Netherlands distinguishing 7 different land types the land types: [18]

1. Traffic Terrain
2. Built
3. Semi-built
4. Recreation
5. Agricultural
6. Forest and open
7. Inland Waters

The land type distribution at each road point along the trip is analyzed by looking at the land type distribution in a circle around the road point, where the diameter of the circle is determined by the sensor gps accuracy. See an example in Fig. 4 for 3 road points.

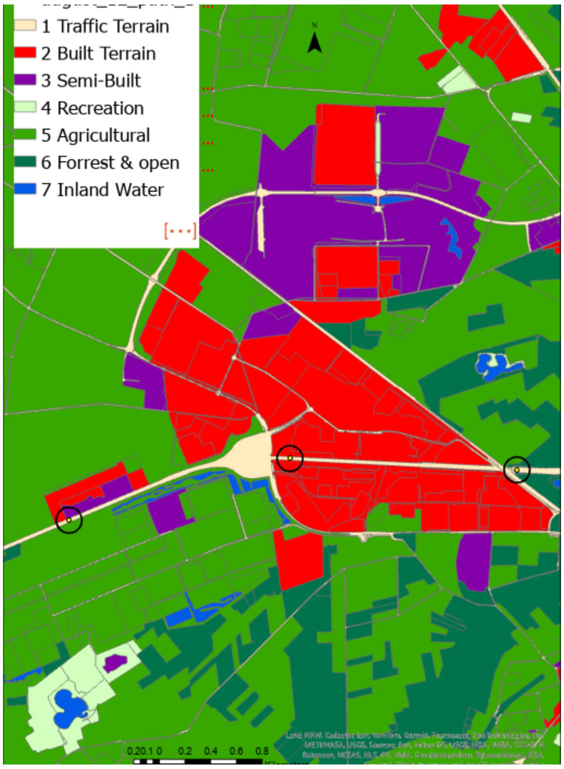

Figure 4: Example of an ArGIS overlap of 3 road point data (black circles) with the different land use types.

This approach was used on a trip with a truck that drove in the Netherlands on August 12, 2024. The total trip is shown in Fig. 5.

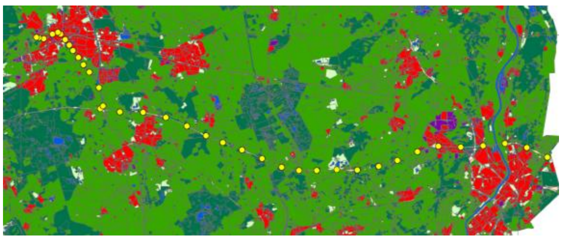

Figure 5: Overlap of the trip (yellow points) on ArcGIS map.

Fig. 5. Shows the distribution in land use types for the trip.

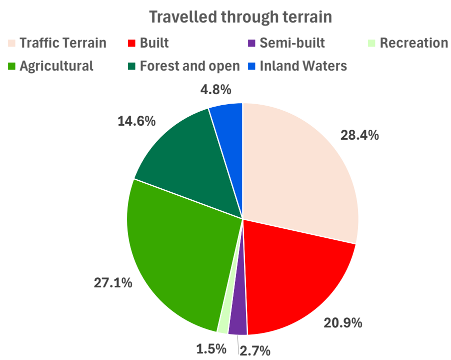

Figure 5: Distribution of land use type over the total trip.

The resulting land type distribution at each road point is shown in Fig. 6.

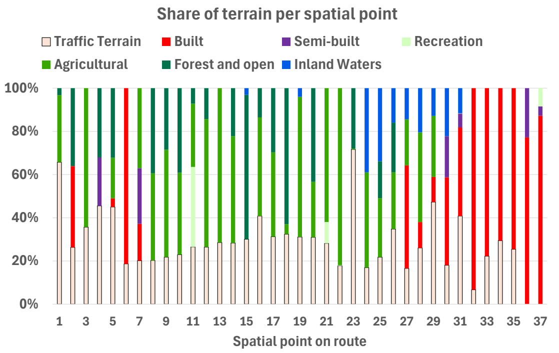

Figure 6: Distribution of land use type per road point for the specific trip.

As can be seen there is not a single point where only one land use type is present, but there are several for which one type is dominating. However, the majority of the points has a mix of land use types.

The shading factor at each of the road points is then parameterized assuming a linear combination of shading factors per land use type.

$$Irr(truck)_j \; = Irr(Sat) * \sum_{i=1}^{7}(a(j,i) * sf(i)) \quad \textbf{Eq.1}$$

Where:
Irr(truck), measured truck irradiance
Irr(Sat), satellite irradiance data
a(j,i), fraction of land type i at route point j
sf(i), shading factor for the specific land type

Fig. 7 shows the measured truck irradiance on August 12, 2025 as well as the irradiance measured at a nearby weather station. As can be seen in the morning and in the afternoon there are two time slots without any clouds, whereas the truck was parked in the shade around 9AM and 3PM and some clouds were passing by between those parked moments. For this reason we only looked at the trip in the morning to ensure that there was no influence of a possible time difference in the effect of clouds on the irradiance.

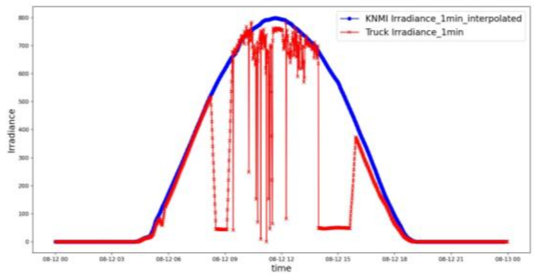

Figure 7: Measured truck irradiance data (red) and measured irradiance form a nearby weather station (blue).

Fitting the factors of Eq. 1 using the measured data at each point then results in the specific shading factors per land use type. The fitted irradiance is shown in Fig. 8 together with the measured data for the truck.

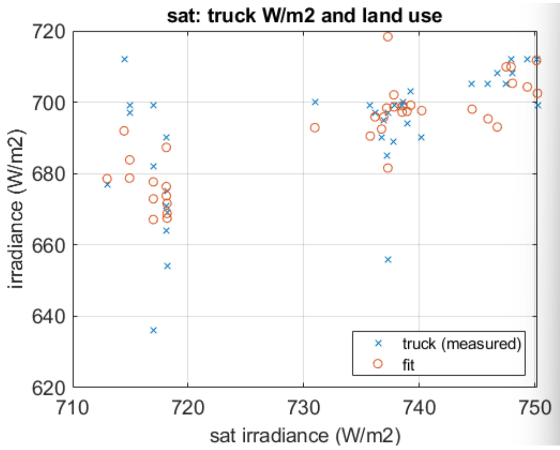

Figure 8: Measured truck irradiance data (blue crosses) versus satellite irradiance data together with the fitted truck irradiance (red circles) data using Equation 1.

The resulting fit gives a correlation factor of 0.70 and the following numbers for the shading factor are found:

Traffic Terrain	0.91
Built	0.94
Semi-built	0.97
Recreation	0.94
Agricultural	0.96
Forest and open	0.96
Inland Waters	1.02

As can be seen, the inland water shading factor is 1.02 which means that the truck irradiance for that land type would be more than the satellite irradiance. This is not realistic. Also the rather low correlation factor indicates that the obtained shading factors are not yet accurately describing the measured shading and more analysis on the specific road points is needed to determine possible outliers due to:

- Overpasses
- Tunnels
- Land type ‘forest and open’ combines two opposite land types when it comes to shading, which could influence the fit

4 CONCLUSIONS & OUTLOOK

A first attempt has been made to define the measured irradiance loss on a truck at several route points and correlate that to the shading factor of 7 different land use types. A linear model fit resulted in a correlation factor of 0.7 and a non-physical shading factor for Inland waters of 1.02. This data set was limited and might contain route points which deviate from the typical land types due to overpasses or tunnels. Besides that, the combination of ‘forest and open’ combines two extremes when it comes to shading and should be split. A more detailed data analysis on these points will be performed for this dataset, as well as additional data in order to improve the fit. Next step will be to use the model to predict the shading factor for other trips as well and compare them with measured data.

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9 ACKNOWLEDGEMENTS

This work is financed by the Dutch Ministry of Economic Affairs and Climate and the DG Move service contract number MOVE/B4/SER/2021-651/SI2.887931– MOVE/2022/OP/0003.