TelDeZon analysis of Zonnefabriek PV installations - 2016

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Contents

1. Introduction

Tel de Zon program is an initiative of Stichting Monitoring Zonnestroom in collaboration with Utrecht University to monitor the weekly yield of photovoltaic (PV) installations in the Netherlands. It was organized within the Dutch Solar Days 2016 from the 30th of May until the 5th of June and 3073 PV owners participated; see Figure 1 for the geographical spread over the country.

The goal of this project was to review the operational performance of domestic PV installations. Participants were asked to keep track of the electricity that was generated from their panels for one week. Operational details such as tilt, orientation, type of modules and inverters were also provided for each individual installation. The program was a great opportunity for PV owners to understand how their systems operate and to measure their performance. Also, it was a valuable source of information for Utrecht University to conduct a large scale research on the decentralized domestic solar power production.

2. Theoretical Background

The time and weather dependent nature of solar power makes it difficult to apply the conventional performance indicators that are used for the regular power plants. In order to compare and evaluate different systems normalized indicators are necessary [1].

The most common indicator is the final system yield, which is the net energy delivered for the specific period divided by the rated power output of the installed array and it has units kWh/kWp [2]. It is a convenient way to compare the energy produced by different PV systems as it normalizes the energy produced according to system size. It has the advantage to be a straightforward indicator as the only measurement that it requires is the actual produced energy. However, it varies widely by climate, by the length of the assessment period and by how the two parameters are defined (e.g., array DC level or inverter AC output) [3]. Final system yield Y_f is given from the following formula:

$$Y_f = \frac{E}{P_o} \qquad (1)$$

with E the generated amount of energy in kWh, and P_0 the PV capacity in kWp. Performance Ratio (*PR*) is another indicator that is widely used as a measure of the quality of the PV system that is independent of the location. It is stated as percent and describes the relationship between the actual and theoretical energy outputs of the PV plant. The actual energy yield is the utilizable AC electricity that is measured at the feed in meter and it is divided by the amount of energy that could be generated if the system always operated under Standard Test Conditions without any losses [4]. The difference between 100% and the *PR* value aggregates all the possible energy losses including inverter efficiency, wire losses, panel degradation, mismatch, shades, dust, thermal inefficiencies and system failures [5]. *PR* is a dimensionless quality indicator and it is calculated by dividing the final system yield Y_f by the reference yield Y_r [2].

$$PR = \frac{Y_f}{Y_r} \tag{2}$$

3. Methodology

3.1 Quality Check

Participants were asked to subscribe for the Tel de Zon action and fill in an online form, providing information for their system and the weekly energy yield during the Solar Week. Zonnefabriek provided an excel table with all this information for 465 systems. The data set went through a thorough quality check to detect errors that occurred during the data entry.

3.2 Irradiation

According to PR definition and the given formula (2) the total plane of array irradiation is necessary. For that reason the data from Royal Meteorological Institute of the Netherlands (KNMI) was used, as they are measuring hourly the global horizontal irradiation from 1951 till the present day at several stations spread over the country.

The incident global horizontal irradiation can be divided into three components, the beam component from the direct irradiation on the horizontal surface, the diffuse component and the component from ground reflections. The contribution of the diffuse component to the total value could be from 25% on a sunny day up to 80% on a cloudy day [6]. Furthermore, as it is dictated by best practice techniques, the majority of the solar panels are tilted toward the sun to maximize the amount of solar radiation on the cell surface.

Therefore, solar radiation incident on an inclined surface has to be calculated by converting the value measured on a horizontal surface to that incident on the tilted surface of interest. However, this is not possible by just applying the geometrical relationship between the two surfaces as the diffuse radiation comes from every point of the sky [6].

A number of models for determining the solar global irradiation on inclined surfaces derived from the global horizontal have been developed and according to studies, the model described by Olmo et al. was found to have the best match between the predicted and the experimental values [7]. Moreover, it has the advantage to depend only on the clearness index and avoids the separation of the solar beam in to direct and diffuse components. A detailed description can be found in Appendix A.

4.Performance Analysis

4.1 Irradiation and Performance Indicators

The total global horizontal irradiance (GHI) during the Solar Week on a national level was 33 kWh/m^2, which is significantly lower than the previous years, 43.7 kWh/m^2 and 41.9 kWh/m^2 for 2015 and 2014 respectively. Between Monday and Friday there was heavy rainfalls and low irradiance. The last 2 days of the Solar Week the sky was clear and as shown in Figure 2 the average daily GHI was more than 6 kWh/m^2.

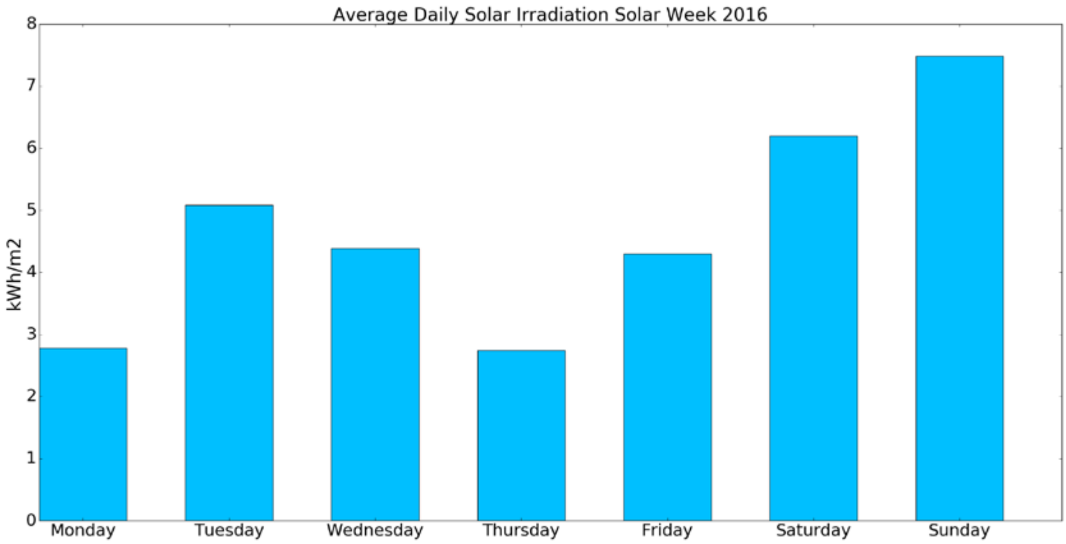

Figure 2. Average daily GHI for the solar week.

The **average weekly specific yield was 25.6 kWh/kWp**. Its distribution is shown in Figure 3. The distribution is very wide, which can be explained by the variation of the weather in the Solar week (Figure 4). Irradiation in the North was much higher in the Northern part of the Netherlands, and precipitation was very high in the South and Southeast. Also, the temperature distribution over the country was wide.

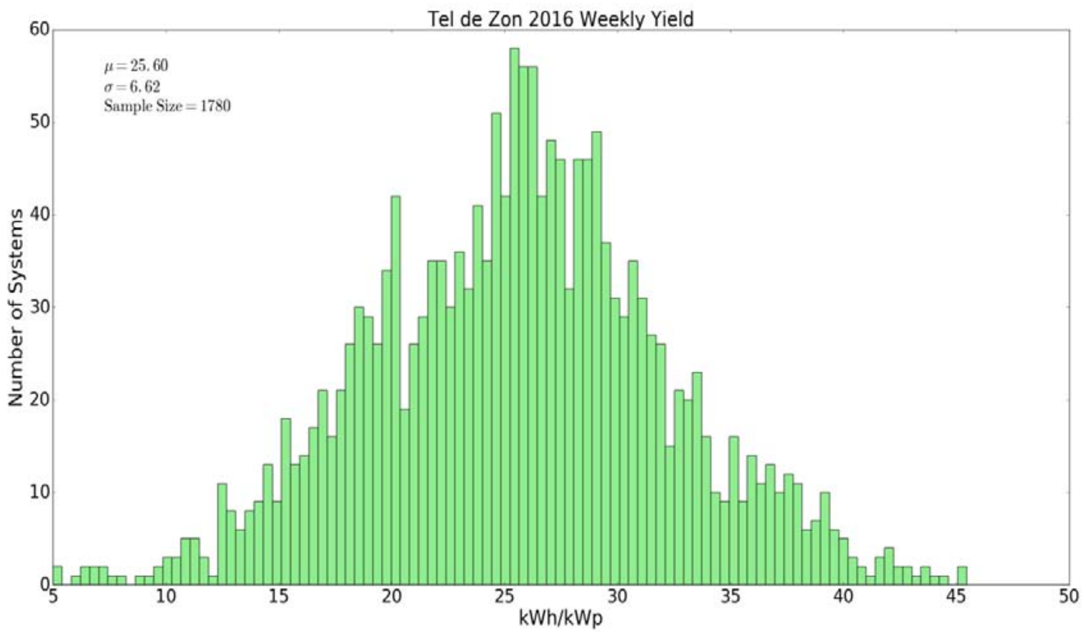

Figure 3. Weekly yield distribution

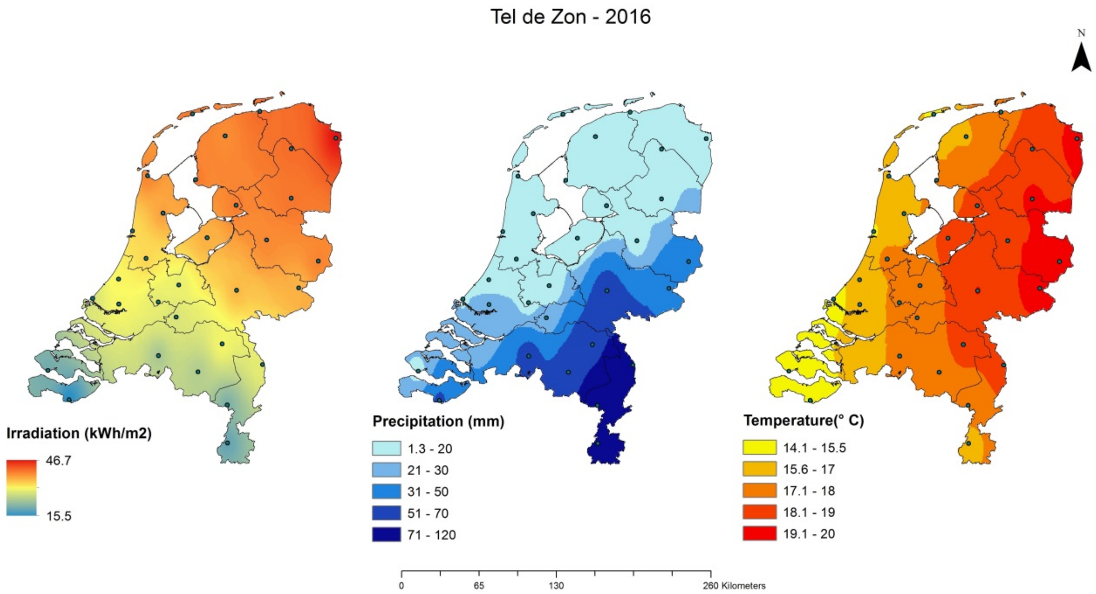

Figure 4. Irradiation, Precipitation and Temperature maps.

The average weekly specific yield for the Zonnefabriek systems was 27.6 kWh/kWp, so somewhat higher than the yield for other individual participants. The distribution is shown in Figure 5.

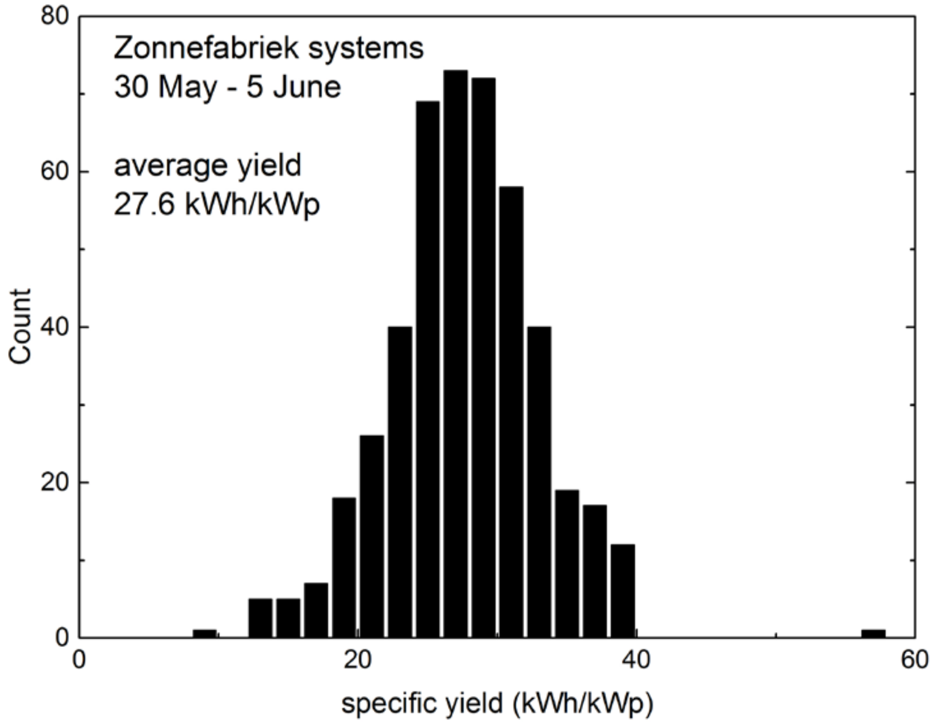

Figure 5. Weekly yield distribution Zonnefabriek systems

The **average PR is 77%**, see Figure 6. Systems that operate with PR values less than 60% represent 10.8% of the total sample. Average performance (PR in the range 60%-70%) has 16.6% of the sample while good performance (PR in the range 70%-85%) has 44.4% of the sample. Finally 28.2% of the installations have exceptional performance (PR bigger than 85%).

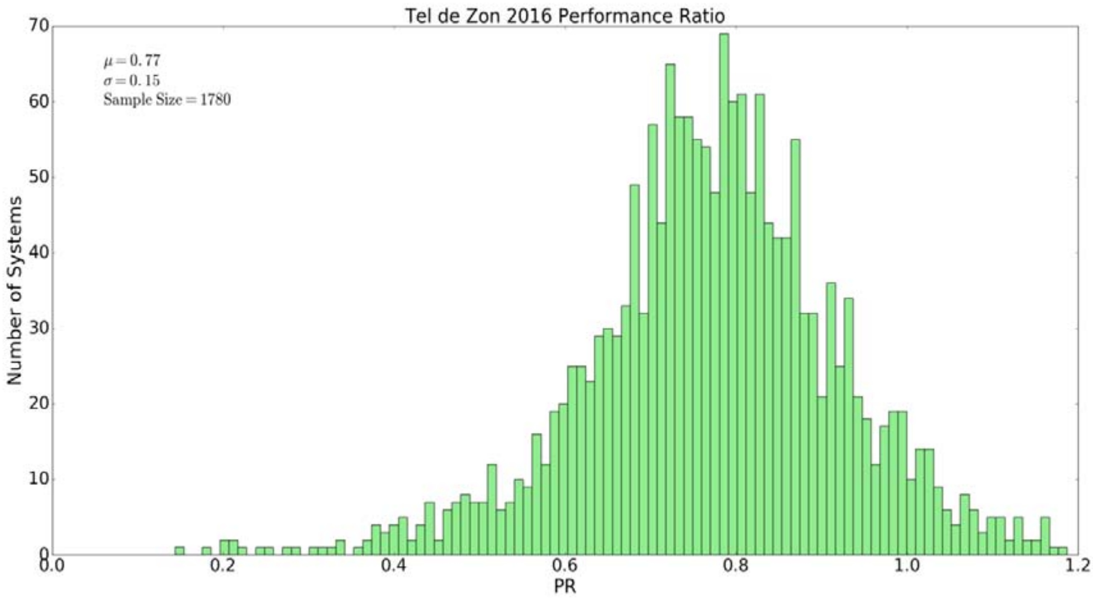

Figure 6. PR distribution

The average performance ratio for the Zonnefabriek systems was 0.83, clearly higher than the yield for other individual participants. The distribution is shown in Figure 7.

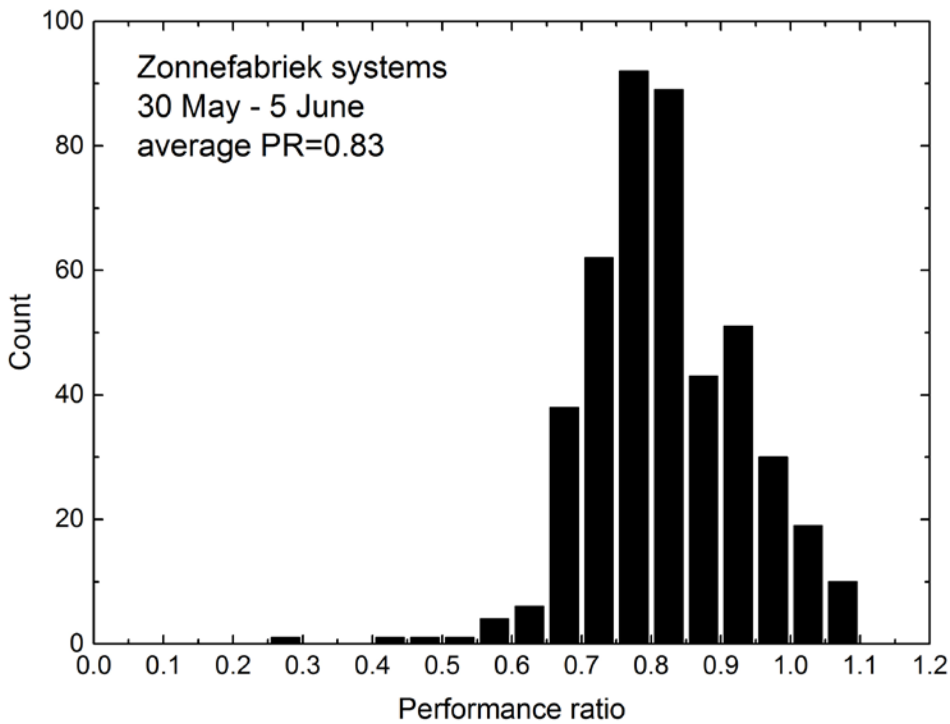

Figure 7. PR distribution for Zonnefabriek systems

In the accompanying excel file (zonnefabriek-TdZAug16.xlsx) the columns Average_On_Panel_Irradiation, Weekly_Yield and PR have been calculated based on the excel file provided by Zonnefabriek. The column Station provides the numerical code of the nearest KNMI station. Note that some unrealistic values have been excluded from the analysis.

4.2 Effects of Shading

One of the most important factors that affect the performance of PV systems is shading. The effect of shading is hard to quantify since it depends on the amount of shade that covers the panels but also varies according to the architecture of the whole system. Based on the PR distribution, some (PR<70%) of the Zonnefabriek systems may suffer from some shading.

4.3 Geographical Variation

The solar irradiation in the Netherlands differs between the coastal part and the mainland of the country as it is depicted in Figure 8, which is constructed based on KNMI measurements.

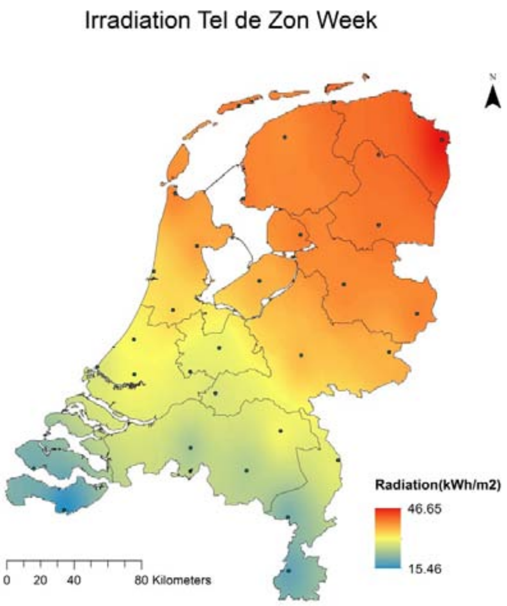

Figure 8. Global horizontal irradiation during the Solar Week.

The difference of incoming irradiation affects the specific yield of the systems. As it is shown on the left side of Figure 9 systems located in the northern part of the country produced on average 50% higher yields during the solar week. The incoming irradiation and the yield follow a similar trend; higher irradiation in the northern part and lower in the southern part leading to higher yields in the North than the South. However, performance ratio as it is expected is not affected by irradiation. Most of the systems seem to be performing well at a performance ratio between 0.7-0.9. Some underperforming systems can be identified from the right map of Figure 9.

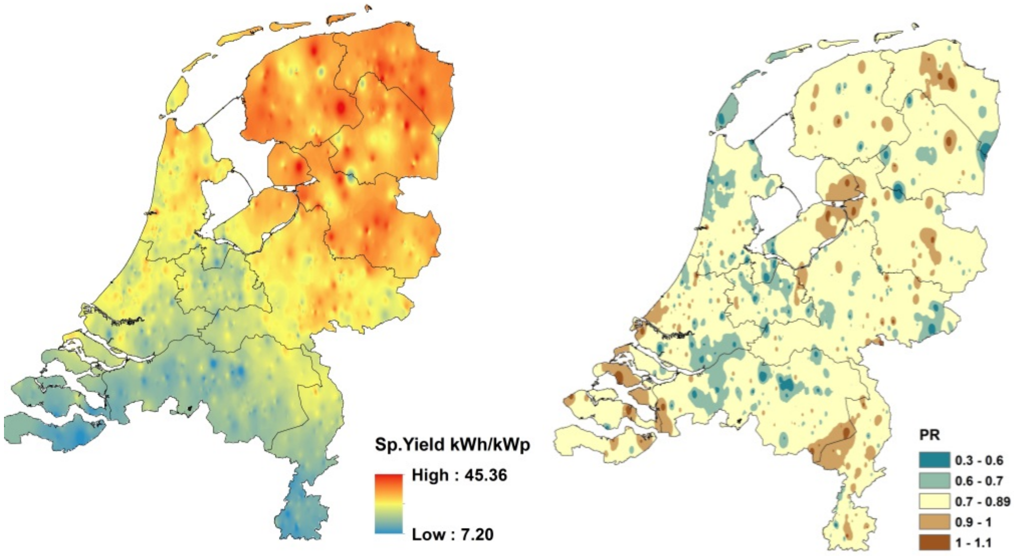

Figure 9. Specific Yield and Performance Ratio maps.

Yield and PR maps for the Zonnefabriek installations are shown in Figures 10 and 11. Although the number of installations is less than 500, the maps show that some of these installations do not perform as expected.

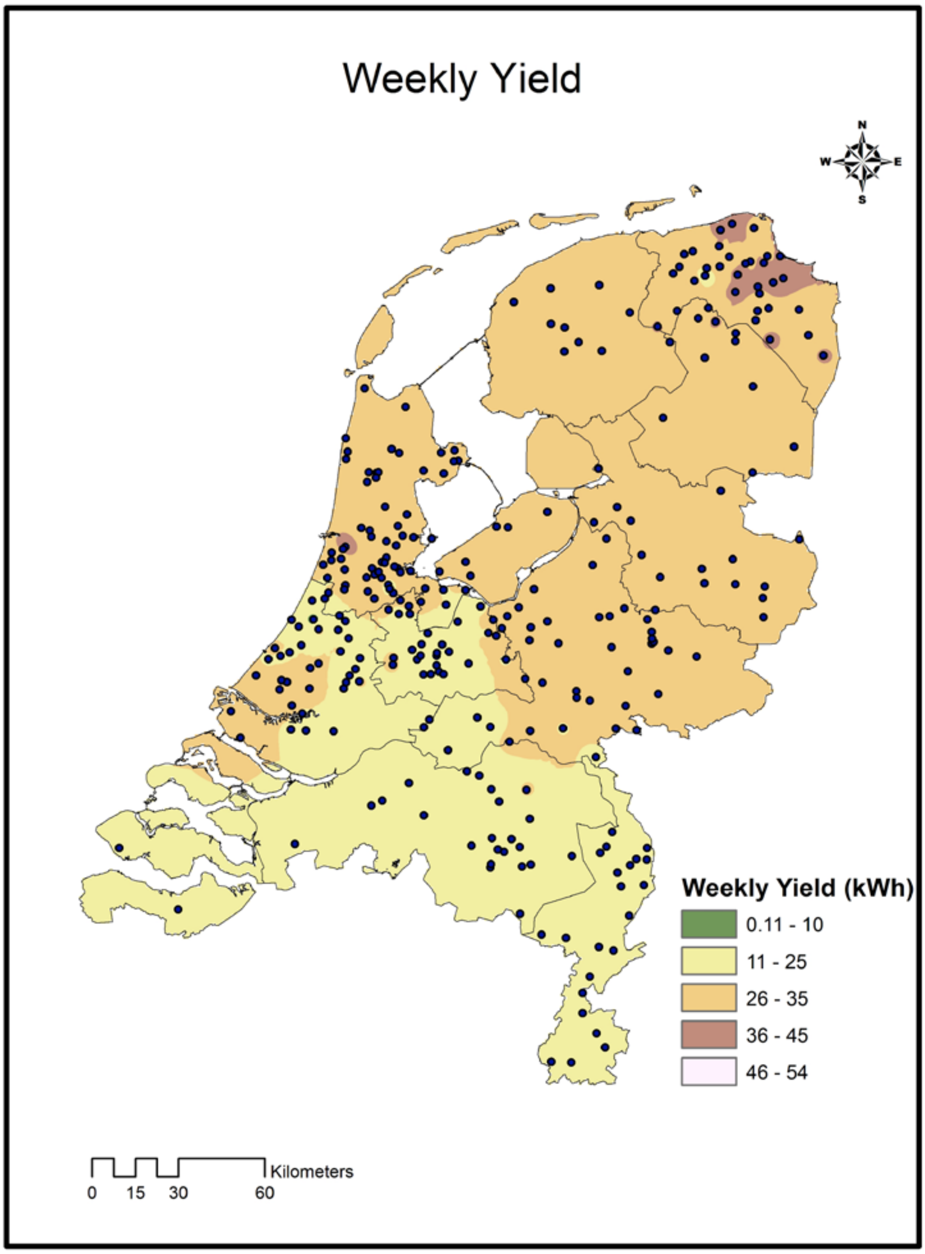

Figure 10. Specific yield (kWh/kWp) map for Zonnefabriek installations.

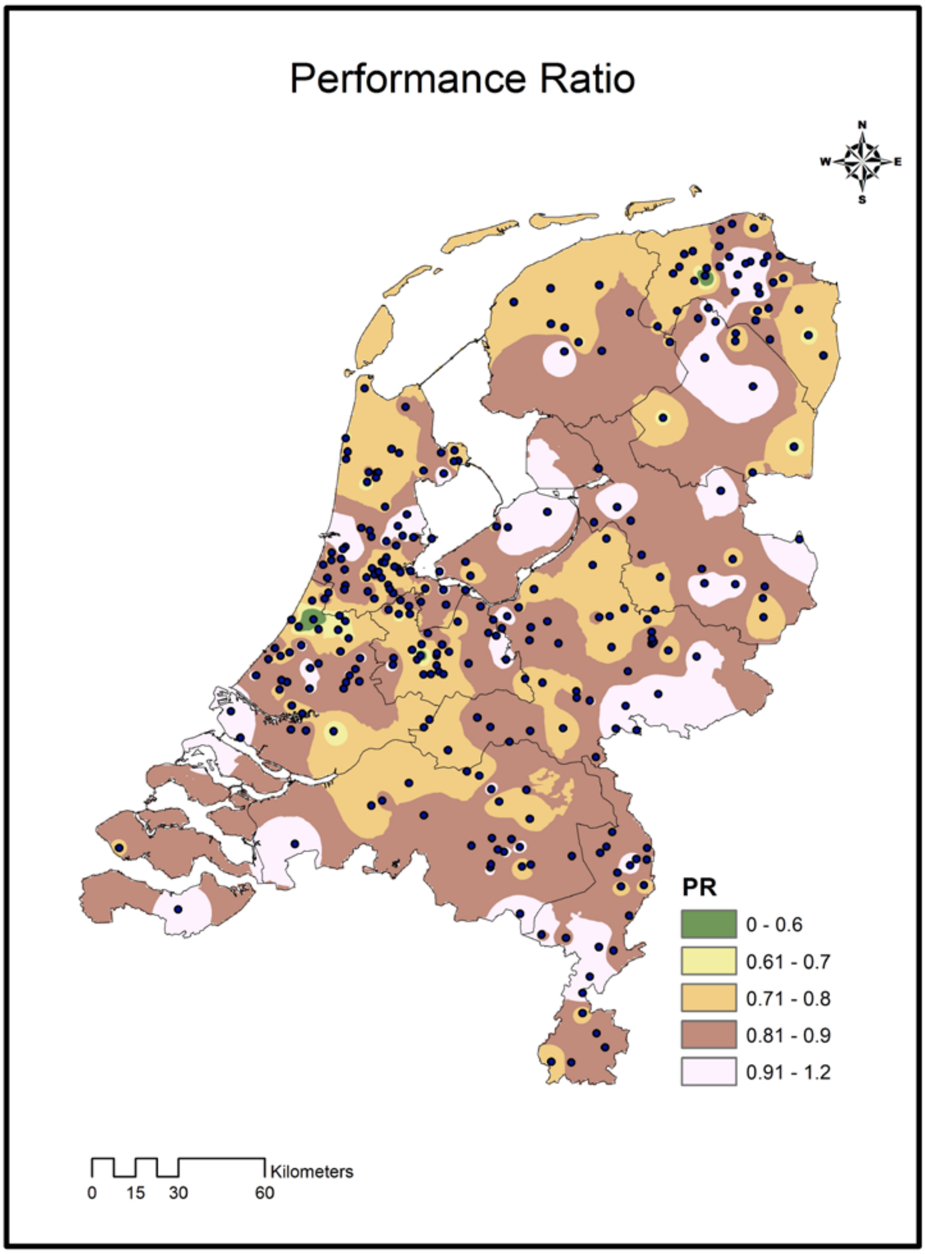

Figure 11. Performance Ratio map for Zonnefabriek installations.

5 Conclusions

Tel de Zon is one of the first large scale studies of PV performance indicators in the Netherlands. It revealed for the third time since 2014 that the majority of the installations have good performance but there is still room for improvements. Zonnefabriek installations on average perform better than the Dutch average.

It is crucial to continue with large scale initiatives as they will raise the awareness for PV technology and they will help PV owners to understand how their systems operate and how they are affected by various factors.

Unfortunately the limited time resolution of PV yield (weekly basis) did not allow for more detailed analysis results. Moreover, the adoption of accurate irradiation measurements from satellite data is expected to improve the accuracy of calculations.

References

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Appendix A: Olmo model

The global irradiance I_β on an inclined surface derived from the corresponding global radiation I on a horizontal surface is given by the following equation [8]:

$$I_\beta = I\psi_0 F_c \quad \text{(A.1)}$$

Where ψ_0 is a function of the incident angle θ and the solar zenith angle θ_z. F_c is the component of the anisotropic reflections from the ground (see Figure A.1).

$$\psi_0 = \exp\left[-k_t(\theta^2 - \theta_z^2)\right] \quad \text{(A.2)}$$

$$F_c = 1 + \rho sin^2(\theta/2) \quad \text{(A.3)}$$

Where, ρ is the albedo of the surface and in this research a constant value of 0.25 was used. The hourly clearness index k_t is the ratio of the global horizontal irradiance to the extraterrestrial horizontal irradiance which has an average value of G_0=1367W/m^2. The θ and the θ_z angles are given by the following formulas:

$$cos\theta = sin\delta(\varphi - \beta) + cos\delta cos\varphi cos\omega \quad \text{(A.4)}$$

$$cos\theta_z = sin\delta sin\varphi + cos\delta cos\varphi cos\omega \quad \text{(A.5)}$$

Where β is the tilt of the panel and ϕ is the latitude. The solar hour ω is the angle through which the Earth has rotated since solar noon [10]:

$$\omega = (15^o h^{-1})(t_{zone} - 12h) + (\psi - \psi_{zone}) \quad \text{(A.6)}$$

Where t_{zone} is the local civil time, ψ is the longitude and ψ_{zone} is the longitude where the solar and the civil time coincide. Declination, δ is defined as the angle between the Sun's direction and the equatorial plane:

$$\delta = \delta_0 \sin\left(\frac{360^o(284 + n)}{365}\right) \quad \text{(A.7)}$$

Where n is the day of the year and δ_0 is 23.45°. The definition of the angles that are used as coordinates are presented on the following figure.

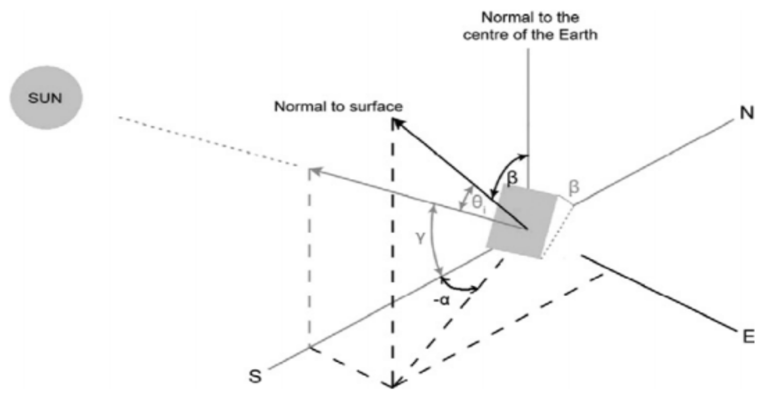
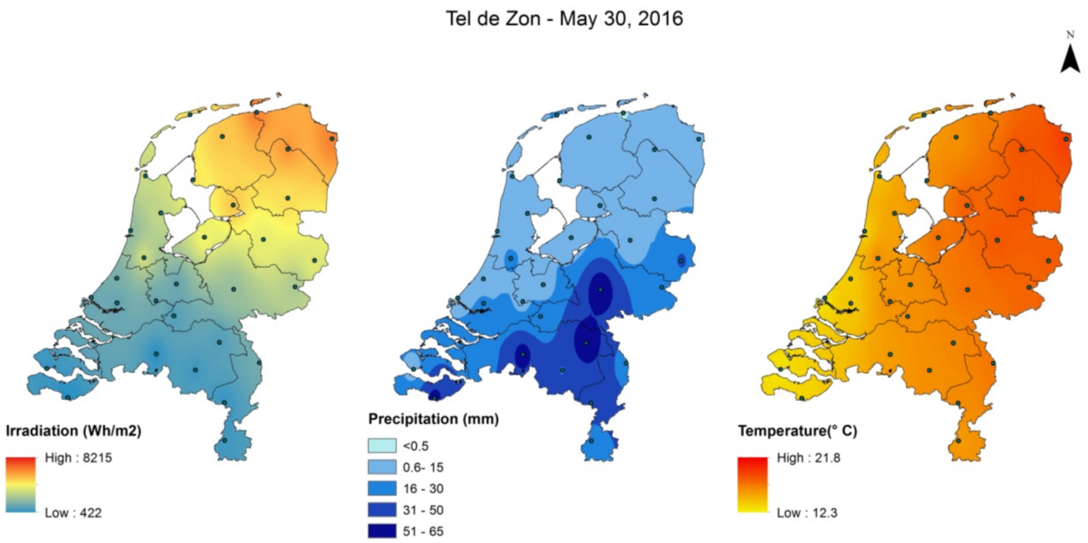
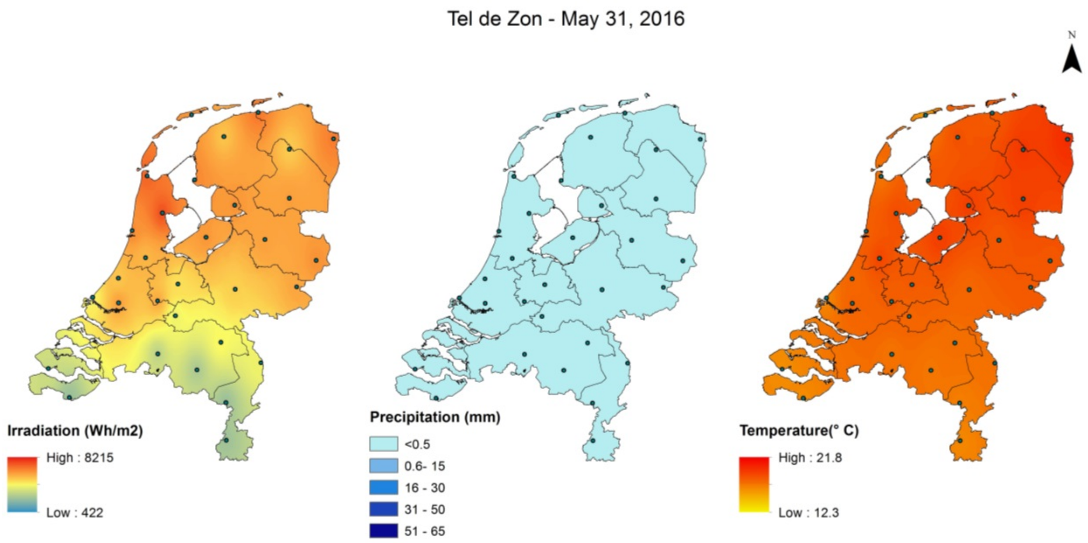


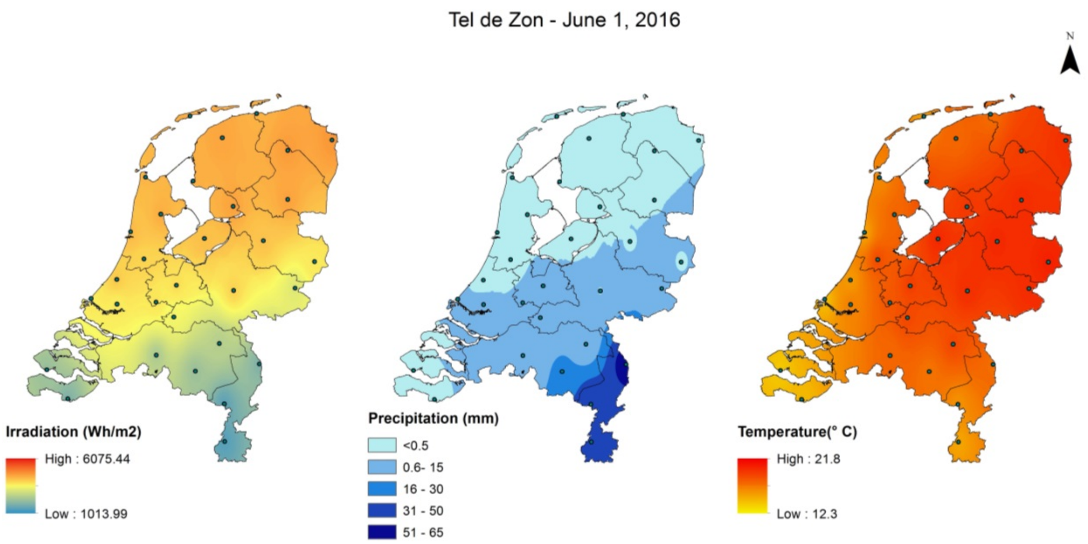
Figure A.1. Sky dome showing solar zenith geometry [7].

For every individual installation the above formulas have been calculated using Python 3.4 scripts. The GHI data was retrieved for each PV location from the closest meteorological station based on the geographical coordinates of each location. In total, data from 31 KNMI stations were used. The average distance between the KNMI stations and the PV systems was 14.5 km.

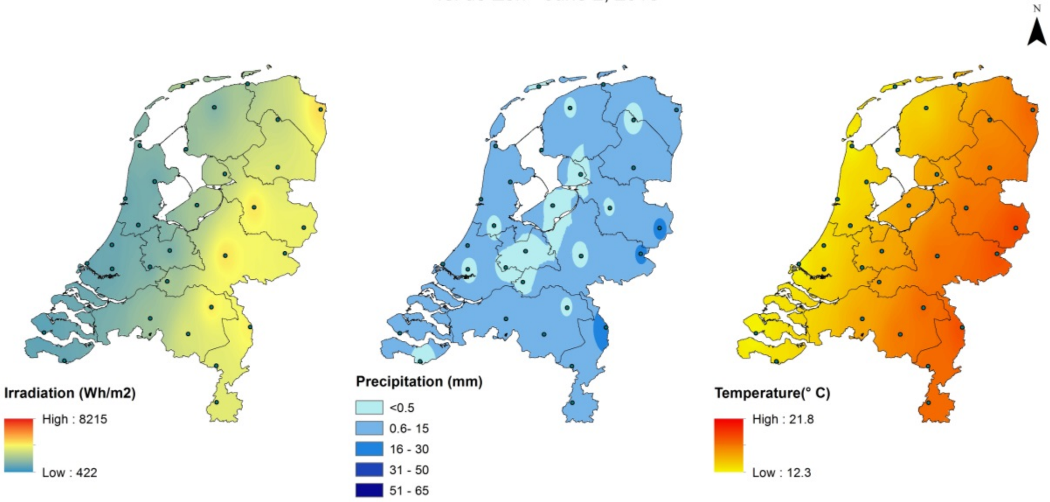
Appendix B: Daily Irradiation, Precipitation and Temperature maps







Tel de Zon - June 2, 2016



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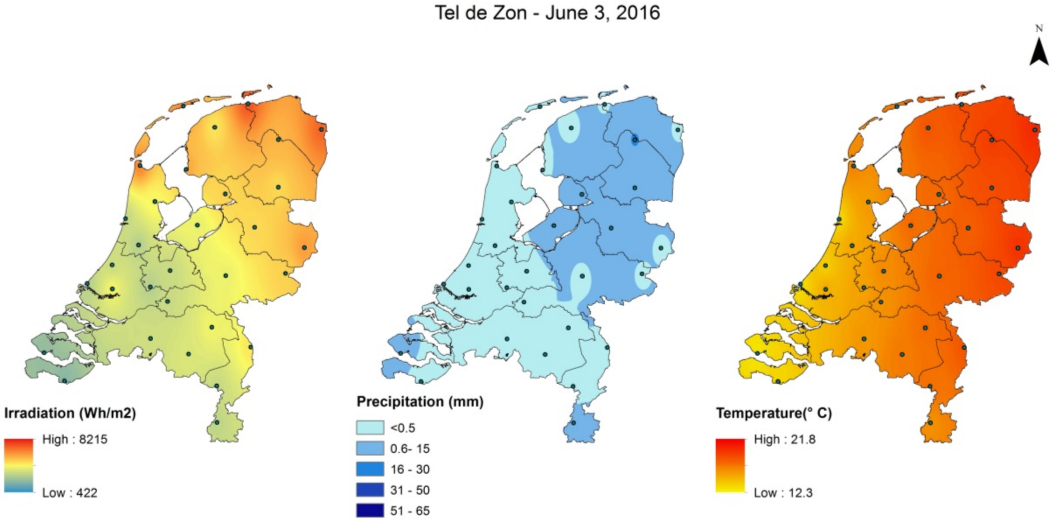

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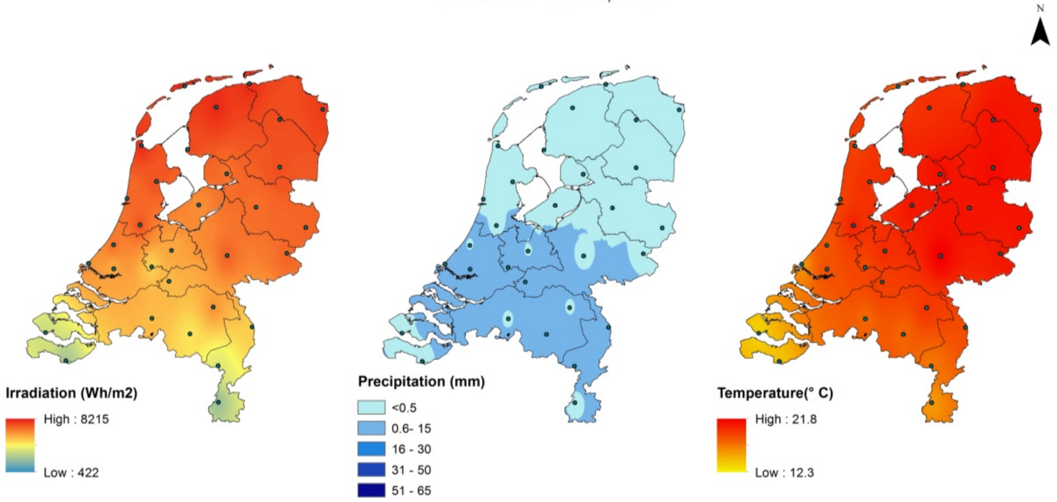

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