Performance evaluation
Sun City (Stad van de Zon)
Heerhugowaard, The Netherlands

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1. Introduction

The “Stad van de Zon” (Sun City) residential area in Heerhugowaard, the Netherlands, , has been designed to be a net zero CO_2 emissions area. This would be achieved by installing 3.75 MWp of photovoltaic systems, 100 hectares of forest and three wind turbines of 2.3 MW each. This will be the largest PV-related project in the world. Together with PV-projects in Alkmaar and Langedijk the project will have a total installed peak power of 5 MWp. The residential area has been built since 2002. 1.038 MWp had been installed on 700 houses until May 2006. The goal of 3.75 MWp in Sun City Heerhugowaard has been lowered to 2.45 MWp (Verberne, 2006).

There is an 18 month monitoring requirement for the systems in the project. There are two project developers: Hallokaties and Bouwfonds. Hallokaties has built and is building approximately 1000 systems, with a total capacity of 1.6 MWp. These systems are monitored with manual meter readings on a monthly basis. The Bouwfonds systems are equipped with a communication system based on PowerLine-Communication (PLC). These systems record energy delivered by the PV system and energy consumption by the household. These meters can be read out from different places.

Currently only a limited amount of data is available. 42 out of a total of 120 systems from Hallokaties in three streets have been monitored for 18 months. 42 households cooperated by manually reading and noting down the monthly meter value. The total peak power is 432 kWp for 120 systems.

Therefore in this report only the performance of the 42 systems in Zonnestelsel West in Heerhugowaard will be analysed. Special attention will be given to the monitoring approach.

In Chapter 2 the system characteristics will be described. Chapter 3 deals with the methodology of the monitoring and Chapters 4 and 5 deal with the performance of the systems in Zonnestelsel West and Vroonermeer. In Chapter 6 the method of data monitoring will be discussed. Conclusions are presented in Chapter 7 and recommendations will be given in Chapter 8.

2. Zonnestelsel West – system characteristics

Figure 1 PV houses in Heerhugowaard

The characteristics of the monitored systems are listed in Table 1.

Table 1 Characteristics of monitored PV systems

Zonnestelsel West	
Developer	Hallokaties CV
Number of systems	120
Monitoring	42 systems monthly hand filled data
Rated Power (per array)	3.6 kWp
Module manufacturer and type	BP 790
Number of modules (per array)	40
Inverter type	Fronius IG30
Location	Sloping roofs
Orientation	180°
Tilt angle	45°
Total power (monitored)	432 kWp
Monitoring data for period	March 2005 to July 2006

Figure 2 Monitored houses

3. Methodology of Monitoring

The 42 systems in Zonnestelsel West were monitored manually between February 2005 and July 2006. The initial and final value of the meter was manually read and recorded by someone from Koppen Vastgoed (Nieuwmegen *et al,* 2007). The system owners were asked to write down the monthly value of the meter and send these per email or mail. 42 households of a total of 120 cooperated in writing down monthly values. This is 35 % of the system owners, which can be considered as a large enough group to get statistically reliable data.

The reliability of the monthly data will be discussed in Chapter 5. The performance of the systems can be evaluated on basis of the 'Performance Ratio'. The Performance Ratio (PR) is defined as follows:

$$PR = \frac{\eta_{sys}}{\eta_{stc}} = \frac{\frac{E_{fi}}{H_i \cdot A}}{\frac{P_{stc}}{G_{stc} \cdot A}} = \frac{E_{fi} \cdot G_{stc}}{H_i \cdot P_{stc}}$$

With:
η_{sys} = system efficiency
η_{stc} = efficiency at STC
E_{fi} = energy yield (kWh)
H_i = solar irradiation in plane-of-array (kWh/m^2)
A = area of system (m^2)
P_{stc} = nominal modulepower (Wp)
G_{stc} = irradiation under standard test conditions (= 1000 W/m^2)

The performance ratio is an indicator for the losses in a PV-system, which depend on modules, inverters, irradiation patterns and other factors like shading, cabling losses, etc.

The solar irradiation in the tilted plane was calculated on basis of satellite data by the method used in PVSAT-2 (see for more information Drews, 2007). The calculated irradiation in the tilted plane was 1170 kWh/m^2.

4. Performance of Zonnestelsel West

The 42 systems in Zonnestelsel West were monitored from February 2005 to July 2006. The energy yield for one year varies roughly 3400 and 3600 kWh/calendar year, dependent on which month is chosen as a starting point. In Figure 3 a frequency distribution of the energy yield is shown. The yearly energy yield for the period May 2005 to April 2006 was 3404 kWh with a standard deviation of 3.7 %. The yearly energy yield from June 2005 to May 2006 was 3508 kWh with a standard deviation of only 2.1 %. The average performance ratios of this year were respectively 0.81 and 0.83 for the different periods concerned.

Table 2 Overview of energy yield for whole years

Year		Energy yield		Irradiation	PR
From	To	kWh	kWh/kWp	kWh/m^2	
February 2005	January 2006	3407	946	1175	0.81
March 2005	February 2006	3387	941	1161	0.81
April 2005	March 2006	3452	959	1181	0.81
May 2005	April 2006	3404	946	1172	0.81
June 2005	May 2006	3508	974	1174	0.83
July 2005	June 2006	3471	964		
August 2005	July 2006	3623	1006		

The delivered amount of electricity is respectively 941 and 1006 kWh/kWp per year. This is very high compared to the energy yields that are mentioned by e.g. SenterNovem, who mention a maximum of 850-900 kWh/kWp/year and a current average of approximately 700 kWh/kWp/year (Bosselaar and Gerlagh, 2006). The PV system supplier BP Solar expected an energy yield of 875 kWh/kWp/year, while the guaranteed energy yield was 760 kWh/kWp/year (Van Nieuwmegen *et al,* 2007). It should be mentioned though that 2006 was a year with a lot of sunshine and therefore a lot of irradiation.

In Figure 3 the frequency distribution of the energy yield for two different years are shown.

- The absolute difference between the average energy yield for the period May 2005 to April 2006 and June 2005 to May 2006 is 104 kWh. This difference is caused by the difference in energy yield between May 2005 and May 2006.
- The variation in energy yield between different systems for the same period can be because of the dates that the house owners recorded the data (see Chapter 5). The lower ends of the red distribution in Figure 3 are the result of one monthly low energy yield and several lower energy yields, with a higher than expected energy yield in the previous, excluded, month.

We can conclude that these 42 PV systems perform well above expectations. We cannot say much about the intermediate periods though.

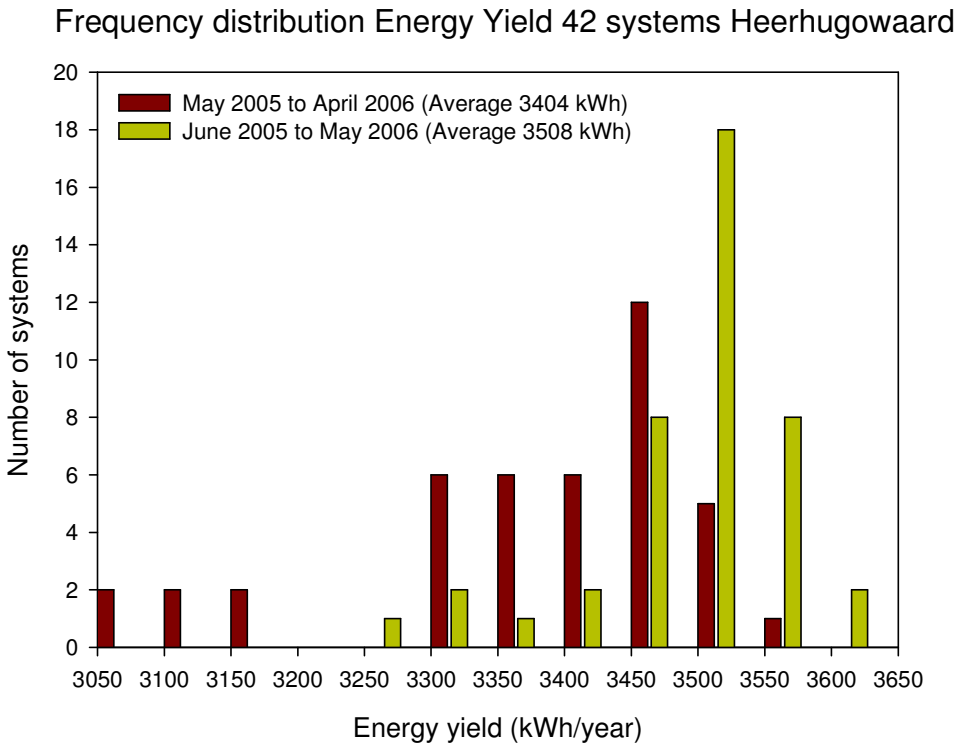

Figure 3 Frequency distribution of the energy yield for one calendar year from May 2005 to April 2006 (red bars) or from June 2005 to May 2006 (green bars)

5. Performance of Vroonermeer, Alkmaar

In the region Vroonermeer, Alkmaar, several projects have been realised. Monitor data are available only in graphical form. Hence no statistical analyses could be performed.

In the project “De Tuinen” (Vroonermeer Zuid, Alkmaar) PV systems have been installed on 152 houses with 3.4 kWp per house. The total installed size of this project is 516.8 kWp, with an expected energy yield of 2975 kWh per year per house. Figures 4 and 5 show the energy yield for one system in the period 2002-2005 and 2006.

For the period 2002-2005 an average energy yield of 3472 kWh is determined from the graph. For the year 2006 is the energy yield much lower at 2360 kWh, due to an unknown performance reduction in the summer months.

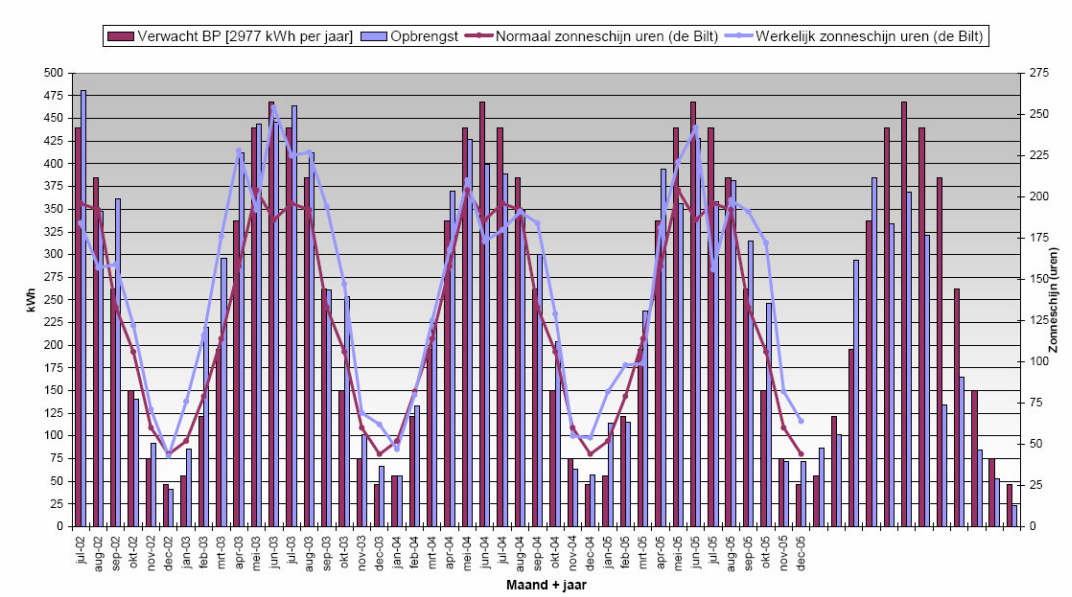

Figure 4 Expected (purple) and realized (blue) energy yield of systems in “De Tuinen” in the period 2002-2006.

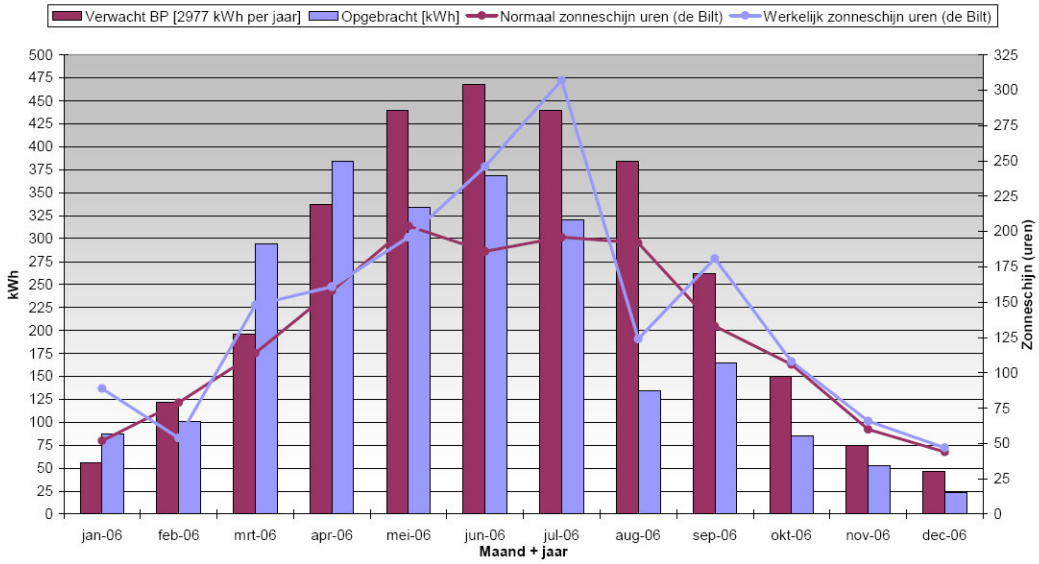

Figure 5 Expected (purple) and realized (blue) energy yield of systems in “De Tuinen” for the year 2006.

In the project Waterzoom (Vroonermeer Zuid, Alkmaar) 58 houses have been realised with 3.23 kWp PV systems, where the expected yield is 2826 kWh/year. Figure 6 shows data for one system, and a yield of 3225 kWh (September 2002-August 2003) is determined from this graph.

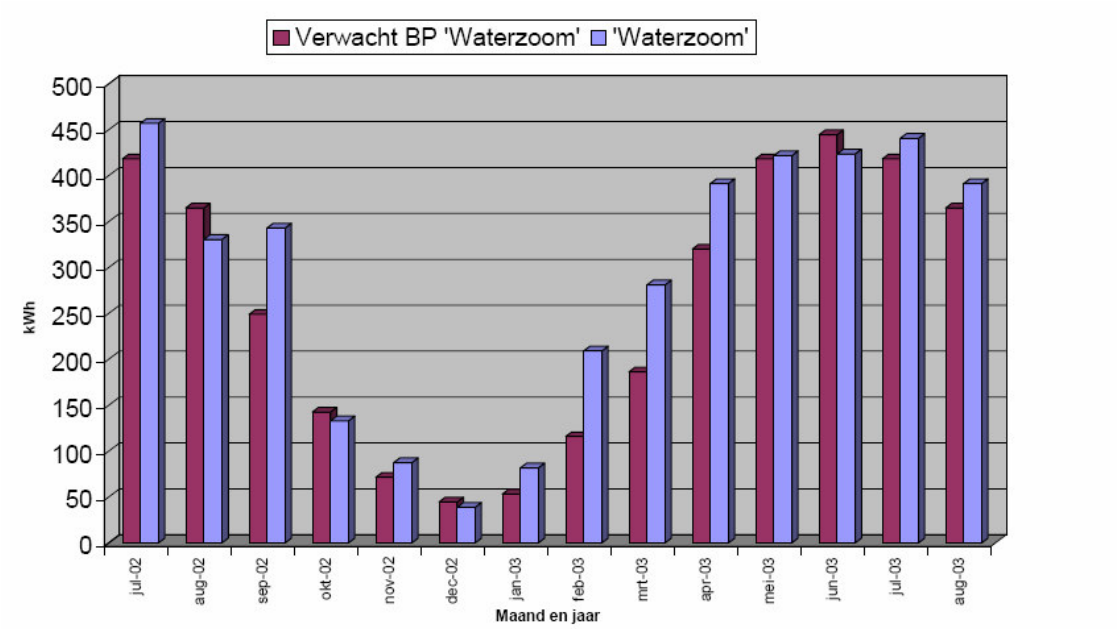

Figure 6 Expected (purple) and realized (blue) energy yield of one system in "Waterzoom" for the period 2002-2003.

6. Discussion of method of data monitoring

Hallokaties CV used a manual monitoring approach for a period of 18 months. The house owners manually read their energy yield meters every month, while Hallokaties CV went door to door to note down the meter readings initially and at the end of the 18 months. We would like to discuss different aspects of this approach. First of all if this method yields reliable monthly data, and if not what could be done to improve this? Secondly we would like to discuss the frequency of the energy yield measurement and the time frame of the monitoring.

From the monthly monitored data we noticed that there is quite some variation between the monthly values for the different systems. The likely cause of this is that the owners of the system did not note down the monthly values exactly on the first day of the month. In Figures 7, 8 and 9 the deviations from the average energy yield are shown. In Figure 7 a monthly energy yield that is more than 5 % higher than the average monthly energy yield for all systems is shown in blue, if it is more than 5 % lower than the average monthly energy yield it is shown in orange. White coloured boxes indicate that the energy yield is within 5 % of the average. Grey coloured boxes indicate that data is either not available or not included. In Figures 8 and 9, a similar approach is used with respectively 10 % and 20 %.

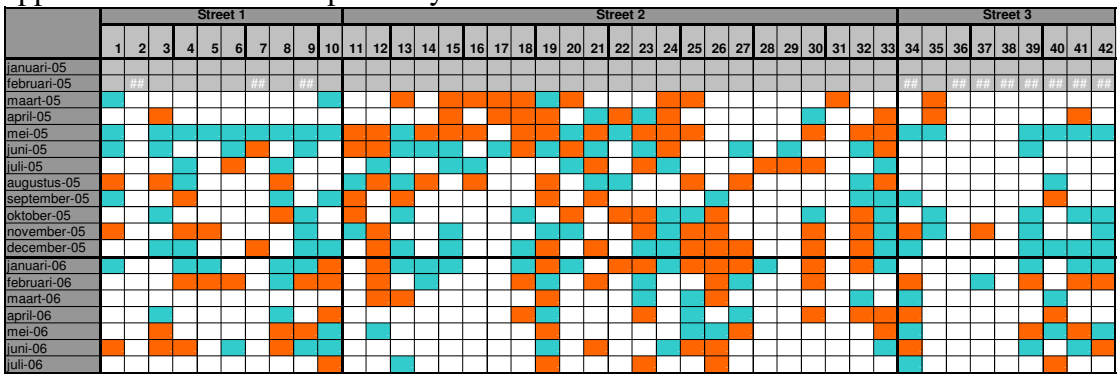

Figure 7 *Performance of the 42 systems over the 18 months: orange means the energy yield is more than 5 % lower than the average energy yield for that specific month: blue means the energy yield is more than 5 % larger than the average monthly energy yield.*

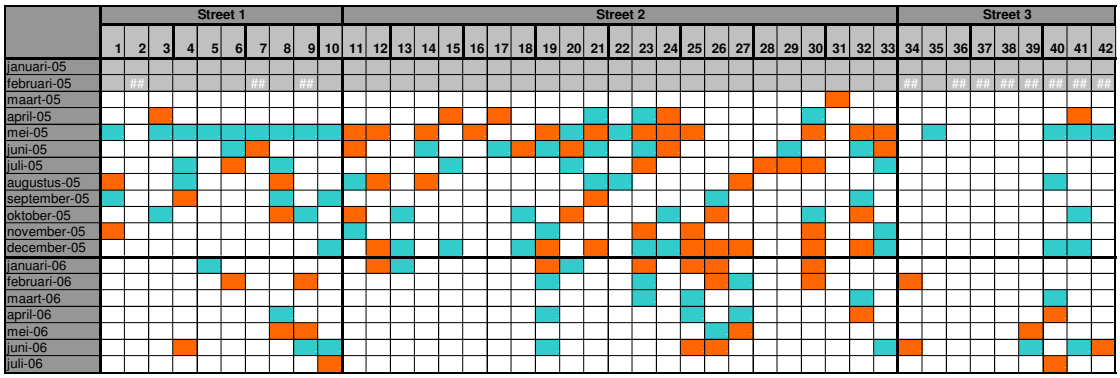

Figure 8 *Performance of the 42 systems over the 18 months: orange means the energy yield is more than 10 % lower than the average energy yield for that specific month: blue means the energy yield is more than 10 % larger than the average monthly energy yield.*

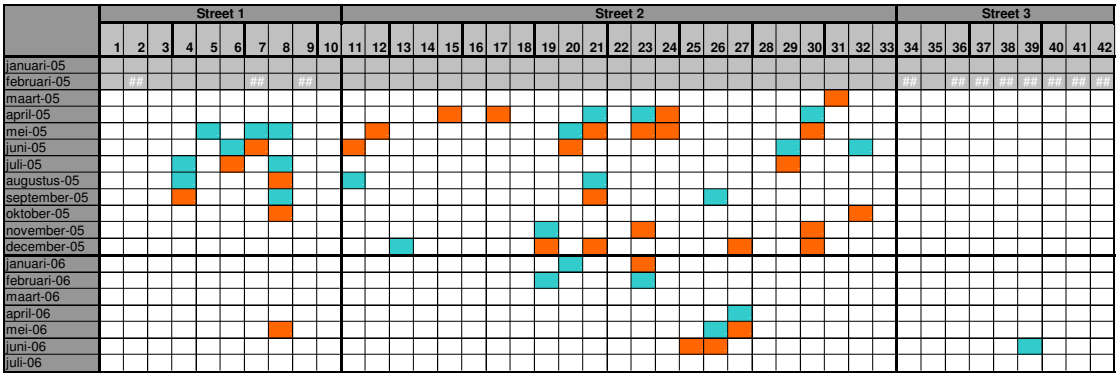

Figure 9 *Performance of the 42 systems over the 18 months (vertical axis): orange means the energy yield is more than 20 % lower than the average energy yield for that specific month: blue means the energy yield is more than 20 % larger than the average monthly energy yield.*

Please keep in mind that noting down the energy yield one day too late or too early, makes a difference of approximately 3 % of the monthly energy yield. In Figure 7 it can be seen that a lot of systems deviate more than 5 % from the mean energy yield. Partly this will have to do with the time of the meter reading, partly it could be small deviations between systems exact peak power. Especially if a system switches colours over the months, this could mean that it has to do with the day of the meter reading. Figures 8 and 9 show that there are quite some systems of which the energy yield deviates more than 10 and 20 % from the average. It is concluded that monthly energy readings by inhabitants are not very accurate. This could be improved by asking the inhabitants to write down the date and time of the meter reading. If the time of the meter reading is known, a correction to the monthly energy yield can be applied.

The reliability of yearly energy yields will be a lot higher. If the year runs from summer to summer and data is manually read a week too late or too early, there is an error of approximately 100 kWh/year, which is 3 % of the yearly energy yield. If a calendar year from January to December is used, an error of a week results in a 1 % influence on the yearly energy yield.

Monthly measured data is enough if systems are working well, as in Zonnestelsel West in Heerhugowaard. If there is a problem with the performance of a system, monthly data does not provide enough information to identify the cause of the problem. Hourly monitored data provides much more information and could lead to identification of e.g. shading or a permanent error. If the monthly data is actually analysed every month, it should lead to a quick technical performance check if a problem is noticed.

A monitoring period of 18 months is too short according to our opinion. It does prove that the initial installation and functioning of the system is correct. It does not lead to a quick detection of failures or defects for a long term perspective.

7. Conclusion

42 systems in Zonnestelsel West in Heerhugowaard were monitored for an 18-month period between February 2005 and July 2006. The 42 systems are working well and have a high energy yield. Dependent on which exact calendar year is chosen, the energy yield varies between approximately 3400 and 3600 kWh/year. This leads to a performance ratio of about 0.82. It can be considered as representative for the total of 120 systems in Zonnestelsel West.

The monthly meter readings by the system owners are not always accurate. This is for a large part caused by the manual reading of the meters at not the exact first day of every month. On a yearly basis the energy yields will be more reliable, because a possible difference of one or two days does not have a large influence on the yearly energy yield. Reliability of monthly data would improve if the inhabitants are asked to also note down the date and time of the meter reading.

Unfortunately no data was available for other systems in Sun City in Heerhugowaard, the Netherlands, and only data in graphical form was available for systems in Vroonermeer, Alkmaar. For the latter systems energy yield is high as well as the performance ratio..

8. Recommendation

- If an approach is used in which test users are asked to note down the energy meter reading, one should ask them to write down the day and time of reading the meter. In this way a more accurate analysis of the performance of the system can be made.
- For such large projects, remote monitoring is advisable, in order to ensure data availability for later analysis.

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