MSc Program
Renewable Energy in Central and Eastern Europe

Performance Analysis for different String Cabling based on Monitoring Values of large PV Plants

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, **Gerhard Mütter**, hereby declare

1. that I am the sole author of the present Master Thesis,
   Performance Analysis for different String Cabling based on Monitoring Values of large PV Plants
   and
2. that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
3. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, November 21^{st}, 2015

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Signature

Abstract

Large PV plants have different relevance of construction details. The aim of this thesis is to show the different impact of well-known influence factors especially in large PV parks with more than 10 MW_p installed capacity. This thesis is based on the on PVSEC 2014 presented results of different relevance of influence factors on performance and will give full particulars on the effects of different strings cabling.
To show this two large (>20 MW_p) PV-plants located at peninsula Crimea could be used with nearly equivalent technical structure and less than 10 km distance between the locations. There it was possible to get access to monitoring values over more than 2 years. The main methodology is comparison of the parks and correction of the power production caused by local weather differences. Any additional differences and irregularities of other impact than caused by cabling are corrected and estimation of impact will be shown. Caused by the optimized park design it will be shown, that the design cabling in single row strings leads to ~ 460 000 kWh less losses during one seasons in the 31.5 MW_p park.
In addition to the result for 1 year also a recommendation the best timeframe for setting up the changes will be given on additional investigations.
The result can be used for optimizing the design of large PV plants and gives park designer also a feeling for the main influence factors.

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1 Introduction

Photovoltaic is a very clean form of producing electrical energy.
Solar panels, called “modules”, collect the sunlight and transform a part of it direct to electricity. With a connection of more modules and the electrical interface called “inverter” this electricity can be used in the public grid.
Based on this simple principle politicians all over the world forced that technology with subsidies and made it economically interesting to invest in that technology. Investments were taken from small units in private homes up to multi-MW plants with more than 100ha area of land used for one park. There are also large portfolios with a huge amount of relatively small units (<1MWp) but in summary more than 500 MWp up some GWp electrical capacity. Multi-MW plants reach up sizes of standard power plants like we have in Austria in hydro-power plants along the rivers.
Especially professionally designed and constructed parks looks very similar on the first impressions. There are some small differences in detail of construction that have different impact on production in parks of different size. In a 10 MWp unit a performance difference of 0.10 % can result in losses of 13 000 kWh/year which is similar to 3-4 Austrian households annual electricity consumption.
One of these differences is the strategy for cabling strings in a PV park. In theory it is possible to evaluate the impact during design phase with simulation software, but usual local situations especially local weather or construction details have stronger impact and so little effects like these are not considered.
This thesis confirms the impact of different string cabling on comparison of two very similar large PV-parks based on monitoring data of the whole year 2013. Obvious differences between the parks are shown and compensated.
I have to tribute credits to my family, who allowed me to do all the evaluations and studies in parallel to a full time job. Also I want to thank my current Management Michael Oberdorfer and Günter Maier, my colleagues in daily business Denis Lange and Alex Rudnichenko who helped me to keep all necessary contacts to the Ukrainian PV parks, and all the park manager and technicians in the parks. Special scientific partners are my friends from the PV department of AIT, especially Thomas Krametz, Bernhard Kubicek and Peter Steirer. They did a lot of accompanying investigations and discussed with me a lot of possible reasons for mystic effects.
And last but not least I have to thank all my teachers and colleagues in the master course, on top of them Hubert Fechner who guided me through this work.

1.1 Motivation and History

The daily job as Technical Director for Supervision of Operation and Maintenance in large PV plants with assets of more than 700MW$_p$ to observe (07/2015) gives a lot of opportunities to evaluate impact of small influence in small and medium size PV-plant but with economical relevant results on large plants or assets.

On economically interesting feedin-tariffs and Southern Europe or compatible location you can save for 250MWp on an enhancement of 1% approximately € 1Mio per year.

Table 1: Estimation of 1% enhancement in medium sized PV portfolio (own calculation)

Capacity	250 000	kW$_p$
Yield	1 300	kWh/kW$_p$/a
Tarif	0.30 €	€/kWh
Annual production	325 000 000	kWh/a
Annual turnover	97 500 000 €	€/a
1% enhancement	975 000 €	€/a

That rough figure shows that it is very interesting for large assets to think about performance enhancement of even 0.10 %.

Performance optimization is only possible with detailed monitoring and clear understanding of already known effects and their impact in large PV plants.
On PVSEC 2014 (Mütter, Voronko, Krametz, Kubicek, & Steirer, 2014) we presented rough estimations on different impacts. This thesis uses the case of different string cabling, confirms the tendency of the rough results from PVSEC2014 and gives more precise estimations and also recommendation for the time to set up correction work.

This thesis handles just one example of possible enhancements and should sensitize higher scientific activities in enhancing existing large PV portfolios. Renewable Energy especially PV will become more interesting from economical point of view if it is handled technical more professional than actual.

1.2 Core objective and core question

In large PV-parks even little effects of ~0.10 % more efficiency have significant impact on economic results. This is a reason for deeper investigations on possibilities to improve performance.

One of this is the question of the **annual balanced results on park performance of the effects on different string cabling.**

In 2014 was a first and rough check based on monitoring values and a presentation of the rough result at PVSEC 2014 (Mütter, Voronko, Krametz, Kubicek, & Steirer, 2014).

In deeper discussions of the technical team in Operation and Maintenance (further O&M) supervision of the investigated parks questions about possible impact of not considered side effects caused by other O&M activities and faults came up.

This thesis is a deeper analysis of the effects considering to filter as much as possible of side effects and to get an understanding of the distribution of the effect over the whole year.

The goal of this thesis is to investigate the effect on summarized achieved yield of 2 possible styles of cabling in large PV parks.

String Cabling Configuration 1: “C-STYLE“

1.11	1.10	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	2.11	2.10	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1
1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.20	1.21	1.22	2.12	2.13	2.14	2.15	2.16	2.17	2.18	2.19	2.20	2.21	2.22

String Cabling Configuration 2: “=-STYLE“

2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12	2.13	2.14	2.15	2.16	2.17	2.18	2.19	2.20	2.21	2.22
1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.20	1.21	1.22

Legend: x.y modul y of string x; String 2; table for modules; String 1

Figure 1: Different string cabling to investigate (Mütter, Voronko, Krametz, Kubicek, & Steirer, 2014)

The result of this Master Thesis will answer the core questions:

a) What is the impact of different string cabling in parks > 10MWp
b) Is the economic amount of the technical effect, especially the ROI (Return On Investment), enough to justify the investment of a retrofit
c) If a) and b) results positive: When will be the best time to implement this retrofit

1.3 Structure of work

The thesis first gives a rough overview about the problems and the methodology of investigation.
The differences of the 2 strategies for cabling are presented including advantages and disadvantages.
A short presentation of specific problems on investigations of effects on performance in large PV plants is followed by the basic methodology "comparison of parts that can be compared".
An overview about the steps of the investigation is the beginning of a description of an 8 steps long evaluation of the difference.
The single steps that lead to the primary result are presented in more detail including intermediate results.
The conclusion of these 8 steps is the percentage of improvement of the annual yield in given configuration.
Additional details on investigation of economic feasibility and recommendation of best time to start closes the part that is relevant for the exiting PV plants.
Based on the findings for existing parks a methodology for cabling that can combine the benefits of both cabling styles is presented to consider it for construction of future parks.

For those who are interested in more details, the relevant construction details of main components of both parks are provided in the annex as well as weather and production values of 2013 of both parks and hints to further literature on some details.

2 Problem and Methodology

On a PV site the produced energy is mainly a function of:

1) Irradiation in module plane
2) Temperature of the modules
3) Number of the used components
4) Losses of modules, combiner boxes, cables, inverters, transformer

Large PV plants do not follow the theoretical calculations of a summary of single effects based on laboratory conditions. Main reason is the size and in every timeframe different boundary conditions for local components with a great variety of interference between different effects that can cause losses. Nevertheless park performance should be enhanced or at least there should be confirmation that a park is working well in all his components.

Especially 4) is hard to estimate in simulations, because of interference of different reasons for energy losses.

Some example of influence chains

- Irradiation → higher production on module → higher temperature of module → lower production of module → lower efficiency of inverter → lower production at AC side
- Higher production → higher losses in cables
- Higher production → higher efficiency of inverter
- Higher ambient temperature →lower cooling of modules→lower production of modules
- Higher ambient temperature → higher temperature on cables → higher losses on cables

2.1 Data sources and calculations in detail

Basic data are

- hourly yield data and
- average of all temperature sensors and
- hourly sum of average of minute recording of all pyranometers

for each park.

Sensor values are filtered to reliability and values with deviations caused by service activities or faults are not considered.

Charts of the hourly values of all months of 2013 are in

ANNEX 3: Hourly yield and effect in monthly diagrams for 2013

Technical parameter are provided by the owner of the park and reduced to that values needed for these investigations. The collection is in

ANNEX 2: Investigated parks

All calculations are done in the Excel-files

- Park_Comparison
  Comparsion of the parks and all evaluations based on hourly recorded yield and weather values, as well as calculation of the position of the sun in order to set up filter for the near shadowing effect including resulting charts
- Calculations
  All calculations on monthly base (Copy of results in “Park_Comparison” is source of some calculations and single calculations including resulting charts.

2.2 String cabling configuration 1 (C-Style)

ADVANTAGE: SHORT CABLES

This configuration has the advantage of short cables in summary. The start of the string is less than 2 m near the end. This leads to cheaper installation and lower losses on DC-cabling.

DISADVANTAGE: MORE LOSSES ON NEAR SHADOWING

Large PV plants are always optimized between costs for land and maximum possible output. There is a minor impact of near shadowing accepted in the morning as well as in in the evening in order to keep the land use at low level.

There are different strategies to reduce that effect, like mounting the modules in landscape mode to use the bypass-diodes to bridge shadowed cells. Another possible construction detail is to split between lower row and upper row in string cabling.

In the configuration the modules are portrait oriented and in C-Style cabling both rows are part of the same string. That causes that in case of near shadowing the whole string will be infected by additional losses.

Shadowing effects are also handled in (Mathur, 2009) and in (Ramapraba, 2009)

2.3 String cabling configuration 2 (=-Style)

ADVANTAGE: LOWER LOSSES ON NEAR SHADOWING

This main advantage of this cabling style is lower impact of local shadowing. To get a real benefit out of this fact, the times of significant production during near shadowing effect appears should be high, but this increases overall losses..

DISADVANTAGE: LONGER CABLES

This implies higher costs on construction and additional losses on DC cabling. In our investigated configurations we are talking about 23m additional cable on every string. To reduce this effect there are 2 possible construction details useful

- Cross section of the cable
  The losses are linear reciprocal proportional to the cross section of the cable
- Cool location of cables
  The higher the temperature of a cable, the higher the resistance, the higher the losses.

Both possibilities lead to higher costs of the cabling.

Away from the different cabling following construction details near to the topic of local shadowing are feasible to reduce losses and increase production:

- Higher distance between the module tables
  That implies shorter time for near shadowing over the whole year
- Local weather situation with low irradiation during near shadowing timeframes.
  This detail is usual not known during the design phase of a PV plant. Only rough estimations based on climate model of the region is normally available. Confirmation of right design can only be done based on monitoring data of the first complete years of operation.

2.4 Challenges in large PV plants

The problematic of handling large PV plants was presented at PVSEC 2015 (Mütter, Krametz, & Steirer, Experience with a performance package for multi MW PV plants based on computations on top of monitoring, 2015).
Large PV parks are too complex to be handled with methodologies based on laboratory measurements.

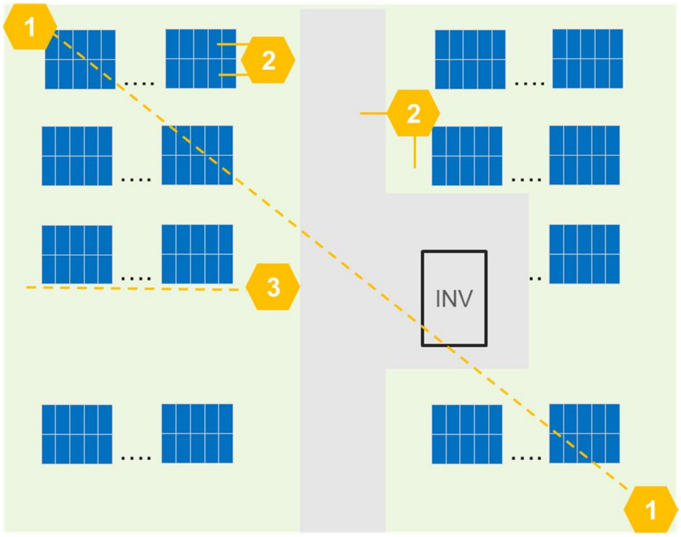

Figure 2: Differences of large PV plants against laboratory conditions (own design for PVSEC 2015)

1. Long distances between different locations, especially sensors and modules. In a 10 MW_p PV park with a size of ~400 m * 500 m clouds with 10 km/h need more than 3 minutes from one corner to the other
2. Different cooling of the modules
   upper row of modules effect of cooling by wind is higher
   ambient temperature between road and grass is different
3. Huge amount of modules
   10 MW_p consists of ~40 000 modules →20 km border (2 row installation)

These facts require different methodologies for investigations than local use of formulas under laboratory conditions.

2.5 Basic methodology: Comparison of parts

To get reliable results on investigations a comparison of parts that differ in only in one detail will lead to success. Hard to consider side effects will take place at similar dimension in both parts.

The methodology of this thesis is based on this perception and consists of:

- SELECTIONS
  Two similar parks and timeframe for valid investigation are selected.
- CHECKS
  Relevant details are checked if impact will be significant,
- ADJUSTMENTS
  If necessary the differences are compensated and
- RESULTS
  the final result is a comparison compensated by known effects

With this basic methodology only differences between situations can be evaluated. This is enough for the economic decisions to the question: “Start a retrofit or not?”

2.6 Steps of Investigation

The investigation will be done in following sequence

Table 2: Steps of Investigation (own table)

Step N°	Methodoloy	Topic	Comment
1	Selection	PV plants to compare	Selection of 2 parks with similar structure and similar location.
2	Check	GPS Locations of parks	verification if location is near enough to be handled without correction on yield values or time frames
3	Selection	usable time frames of monitoring data	selected time frames should be without significant interruptions or losses
4	Check	comparison of used modules	should be same technology (crystalline) and with similar key parameter
5	Adjustment 1	weather correction of local weather differences between both parks	hourly summary of irradiation and average of ambient temperature is taken to scale result of OMAO <-- adjusted to weather(OWL)
6	Adjustment 2	Filter on timeframes where local shadowing can occur	Only time frames where local shadowing can occur. If hour of investigation is not complete in timeframe values to compare are linear interpolated to real duration
7	Adjustment 3	Correction of different inverter efficiency	Summary of difference is scaled with respect to the difference of the inverter efficiency.
8	Adjustment 4	Losses by additional DC cables	Losses by additional DC cables should be considered. They reduce the amount of the advantage. A maximum estimation should be taken first and if value is not significant enough detailed investigation can be skipped
9	Result 1	Specific annual performance increase	percentage for possible annual yield enhancement on change of cabling
10	Result 2	Benefit on production	Additional yield in park with improvement chances
11	Check	Economical impact	estimation of costs for change of cabling and Return on Investment
12	Result 3	Return on Invest of Retrofit	Evaluation of ROI
13	Check	Best time to start retrofit	Analysis of monthly summarised distribution of the effect over a whole year and recommendation of economically most interesting time to start
14	Investigation	Alternatives for new parks?	Investigation of an alternative cabling
15	Conclusions		Overview of results

3 SELECTION: PV plants to compare

To investigate the different effects of DC cabling there are 2 parks suitable.
Both parks are very similar from structure and equipment. There is only one major difference to investigate in this thesis: Concept of string cabling.

3.1 PV plant OMAO, 20 MW_p, cabling =-Style

Omao is a 20 MW_p and part of 80 MW_p Okhotnikovo farm.
It is 8 km north east of the compared farm OWL.

Figure 3: Impressions of Okhotnikovo and OMAO (Active Solar)

OMAO is realized in parallel string cabling.

Figure 4: String cabling schema for OMAO, =-Style (own design, picture Active Solar)

The main advantage should be more optimized efficiency caused by lower losses of local shadowing.
Disadvantages are the long “back cables” to return to the beginning of the string.

3.2 PV plant OWL, 31.5 MW_p, cabling C - Style

OWL is about 1.5 times larger than OMAO and located 8 km south-east of OMAO.

Figure 5: Impressions of OWL (Active Solar)

Main advantage of this style to connect the modules of one string is the saving of at least 23 m DC string cable per string (22 m for modules and 1m for change of rows).
OWL´s 134 288 modules are connected to 6 106 strings.
That results a cable saving of approx. 140 km.
On a price of 1.50-2.00 €/m during construction of the parks the saving on construction material was ~0.25 Mio €.
This was a relevant amount to be considered for selection of the construction detail “C-Style cabling”.

The question: Would the additional yield return the costs of the additional material?

The difference to OMAO is a cable saving style of string cabling in C-Style.
The following picture should help to understand the naming.
.

Figure 6: String cabling for OWL, C - Style (own design, picture Active Solar)

3.3 Details of technical relevant Differences

OWL is about 1.5 times larger than OMAO and located 8 km south-east of OMAO.

See in the following table the main technical specifications and equipment.

Table 3: Comparison of technical details with possible relevance (own selection, numbers AES)

Basic information				
Farm		Okhotnikovo	Mityaevo	Relevance for comparison
Park		Omao	Owl	
GPS coordinates	°	45.281294N	45.236972N	no
		33.599608E	33.75972E	check: diffence sun east<->west
area of park	[m²]	395 000	600 000	no
structure of area		flat max height diff 1m/100m	flat max height diff 1m/100m	equal
lenght of fencing	[m]	2 513	4 380	no
Start of Parks		01.12.2011 - 04.12.2011	17.05.2012	check: timeframes for monitoring
Modules				check: same modules or similar values in
Capacity nom.	[Wp]	21 459 155	31 559 450	no / linear
Capacity inst.	[Wp]	21 658 888	31 923 600	no / linear
modules		93 600	134 288	no
Type		Cristalline	Cristalline	equal
tilt	[°]	25	25	equal
mounting system		2 rows modules portrait	2 rows modules portrait	equal
row distance	[m]	6.65 - 7.20	6.65 -7.20	equal
Strings				**MAIN ISSUE OF THIS INVESTIGATIONS**
N° of strings		4 362	6 106	
String Wiring		= - Style	C-Style	
N° of Combining Boxes		280	414	no
inverters				
N° of stations		40	30	no
N° of inverters		80	60	no
AEG PV Protect 250		80	2	Check: efficiency
AEG PV Protect 500			58	Check: efficiency
AC & AC wiring				
Dimension DC cables		4mm², 6mm², 70mm², 110mm²	4mm², 6mm², 70mm², 110mm²	no: distributed state of the art
extra cables for = style		4 560 m/MWp	0	Check: Additional losses

4 CHECK: GPS location of parks

The irradiation that can be used from the sun is equivalent to the sinus of the angle between the module plane and the sun. The largest slope of sinus is near 0, so the largest possible difference is when one park have sinus(0) and the other one the angle of the same time at the other location.

There we have to check the different locations in east/west direction.

The parks are located in a difference of 8 km. Both parks are in flat land near the black sea at peninsula Crimea and are only 8 km distance, that's less than the large park Okhotnikovo has in north-south dimension.

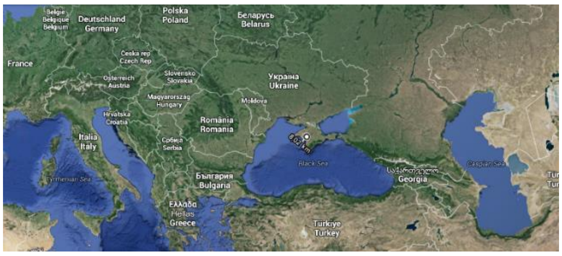

Figure 7: Location of taken PV-Parks (Google maps)

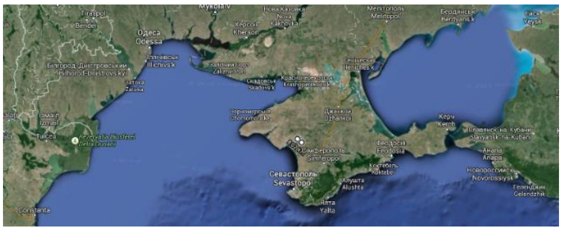

Figure 8: Location at peninsula Crimea (Google maps)

Figure 9: Google Earth detail with both parks and distance of 8km measured (Google Earth)

In the order to ensure that the angle to the sun is similar (< 1 minute), the smallest resolution of available measured values, east-west difference was double checked.

Table 4: check of time difference between locations (own selection, data AES)

OMAO	33.599608	°E
OWL	33.675972	°E
° Est-West difference of parks	0.076364	°
seconds a day	86 400	s
° earth rotation / second	0.00416667	°
seconds differenc of sunangle	18.33	s

There is a time difference of 18.33 seconds between both locations.

This is negligible, as we can only use hourly monitoring over this long time period.

There is no need to set up any correction as consequence of too far distance of GPS-Coordinates.

5 SELECTION: Usable time frames of monitoring data

To answer the main question: "Which cabling style is to prefer?" the real monitoring data of both parks could be used, including irradiation in module plane and module temperature, which should help to correct small but existing local weather differences. First investigation: Is there enough reliable monitoring data available to cover at least a whole year? Although there is currently no access to newer monitoring values but there are at least on year of valid values. For double check of the relevant winter season the values of a second winter seasons are available.

Both parks started their production in 2012.
From September 2012 both parks were running without the usual startup losses. Investigations of startup losses were published in (1) (Mütter, Krametz, & Kubicek, Analyse der Ursachen für Ertragsverluste in der Anlaufphase des Einspeisebetriebes von PV-Kraftwerken, 2014). This is the first time for a reliable comparison of both parks.

Figure 10:Yield of both parks of all available timerframes (SKYTRON)

1. January – June 2012 only OMAO was active
2. June – August 2012 Startup phase of OWL, Yield behind expectations
3. September – December 2012 both parks reliable running, similar weather, yield roughly like expected

In phase 2 (June-August 2012) there is the typical pattern of startup-losses in large parks, where technical faults of the construction time were fixed and the park goes more and more into normal production mode. To keep this phase as short as possible is very much appreciated from economical point of view. See more details in this figure:

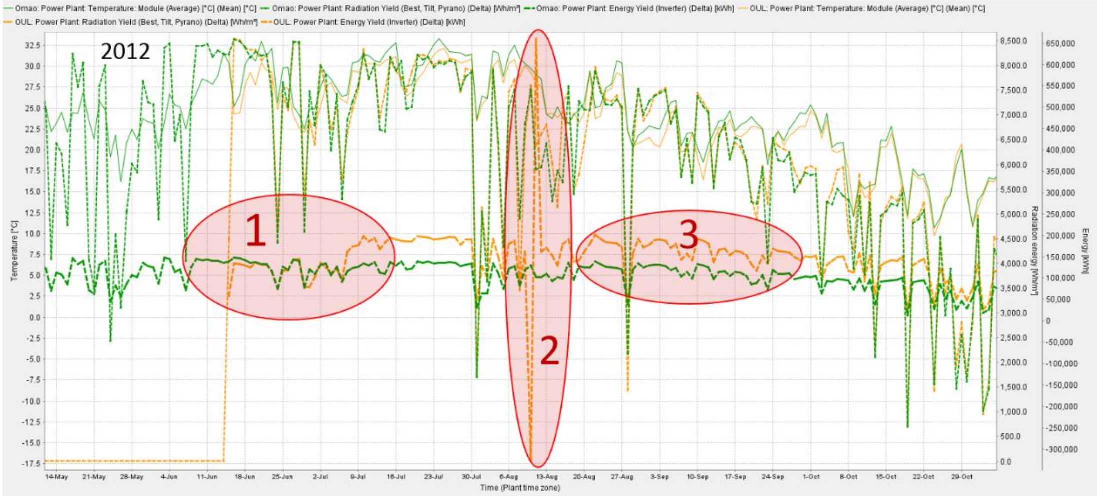

Figure 11: Details of Start-up PV plant OWL June-August 2012 (SKYTRON)

1. First start of OWL mid of June 2012, Yield about 25-30% behind expectations caused by start-up problems on grid connection (KRPZ) in the part. Technical solution June 5th -10th is visible
2. Problems with feed-in counter of OWL(orange) in August 9th and programmed compensation a day later
3. First phase of normal operation,
   August 28th was strong thunderstorm, visible in Irradiation running parallel to Yield graphs

For investigations in this master thesis **the whole year 2013 could be taken**.
It was really homogeneous with both parks running stabile in the first years of production. The political troubles in Ukraine starting end of 2013 had no immediate impact on electricity production. The daily yield sum of the whole year looks really reliable.

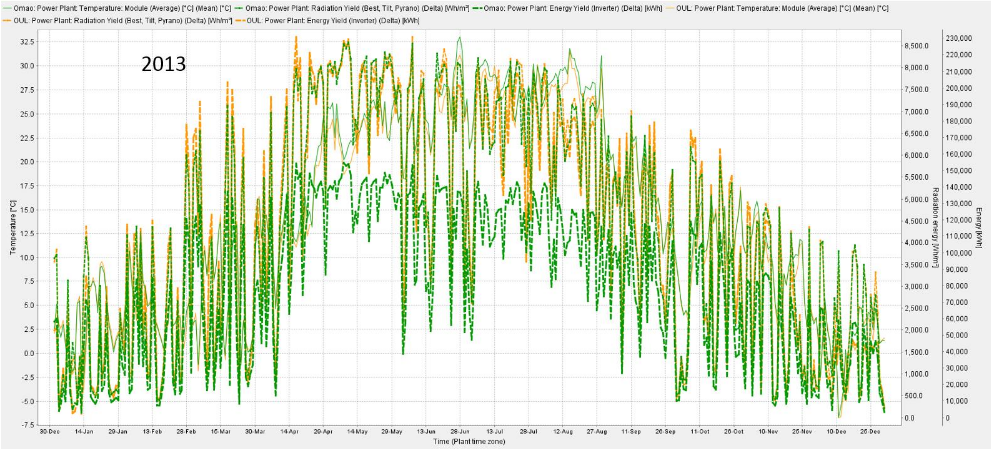

Figure 12: Yield, Irradiation and Temperature 2013, daily sums (SKYTRON)

It is easy to find out that May, July and August 2013 were good month for PV-production. There were constant high daily sums of irradiation and only single days with lower values. Both parks follow the irradiation curves in a parallel pattern. OMAO (green) is with 21.5 MW_p capacity like expected at about 2/3rd level of OWL (orange) with 31.5 MW_p installed capacity.

The parks are located on the peninsula Crimea, former Ukrainian territory.

Since the Russian occupation the political situation is not clear. Caused by the political troubles of the region the parks were shut down on daily political command, starting from April 2014. In October 2014 all Internet connections of non-Russian providers were shut down by local laws. Since this time no direct monitoring access is possible. Monitoring sums show a clear picture of this terrible situation.

Figure 13: Yield, Irradiation and Temperature 2014, daily Sums (SKYTRON)

1. First longer shut down period
   Irradiation and temperature still good but no production
2. Second longer shut down period
3. Loss of data access from Central Europe caused by shutdown of Internet provider

6 CHECK: Comparison of modules

One of the most important influence factors on yield is given by technology and quality of the modules. We have in both parks crystalline modules and most of the modules are of the same supplier. All modules are in similar capacity. A comparison of the datasheet shows similar technical parameter for all used modules.

Table 5: Used modules and relevant parameter (own table, data Active Solar)

Modules						
Park	**Modul types**	**Country of origin**	**number**	**l x b x w [mm]**	**power tolerance**	**temp.-coeff**
OMAOo	Jinko JKM 225P-60	China	23 177	1650x992x45	-3% / +3%	-0.48%/°C
	Jinko JKM 220P-60	China	6 336			
	Jinko JKM 230P-60	China	18 007			
	Solarfun SF220-30-1P230	China	24 000	1652x1000x50	-3% / +3%	-0.45%/°C
	Solarfun SF220-30-1P235	China	22 080			
			93.600			
OWL	Jinko JKM 230W	China	37 134	1650x992x45	-3% / +3%	-0.48%/°C
	Jinko JKM 235W	China	59 666			
	Jinko JKM 240W	China	37 488			
overall			**134 288**			

The table shows that modules are

- Same producer or same country of origin (China)
- Similar dimensions
- Same power tolerance
- Similar temp coefficient

All modules have the same technology “crystalline”.

The check of modules confirms that there is no need for compensation of values caused by technical significant difference of the modules.

7 ADJUSTMENT 1: Weather correction

To compare both parks a correction of OMAO weather to OWL weather should take place. For a rough approximation the two main criteria

1. Irradiation
2. Module Temperature

are used to evaluate the theoretical possible specific yield of OMAO based on OWL´s weather. The direct comparison of the weather parameter with main impact on the yield shows only smaller differences between the parks and only little timeframes with considerable differences. Nevertheless there are deviations in the weather situations.

7.1 Weather and Yield Overview October 2013

The following graphs show the hourly values in October 2013:

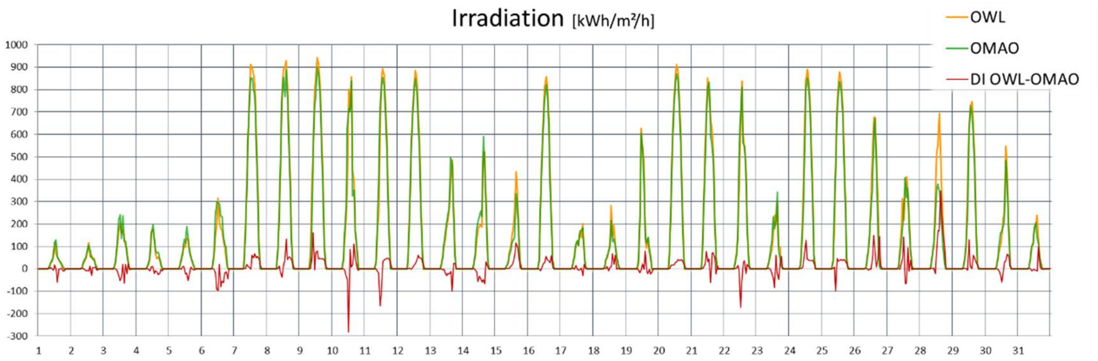

Figure 14: Irradiation in both parks in October 2013 (own chart, orig. data SKYTRON)

The second highest impact on yield is given by module temperature, because for a higher temperature of 1°C there is a loss of 0.45% to 0.48% of the production. The module temperature is influenced by factors like

- Ambient temperature
- Wind speed and direction
- Dirt and dust on modules
- Local shadowing
- Humidity of air
- Rain, snow and ice

To avoid complex simulations and assumption for the investigation the module temperature is taken for comparison. Further details that guided to the selection of the methodology are also in (Kubicek, Mütter, Voronko, & Krametz, 2014). In October 2013 the module temperature in the parks was like shown in the figure:

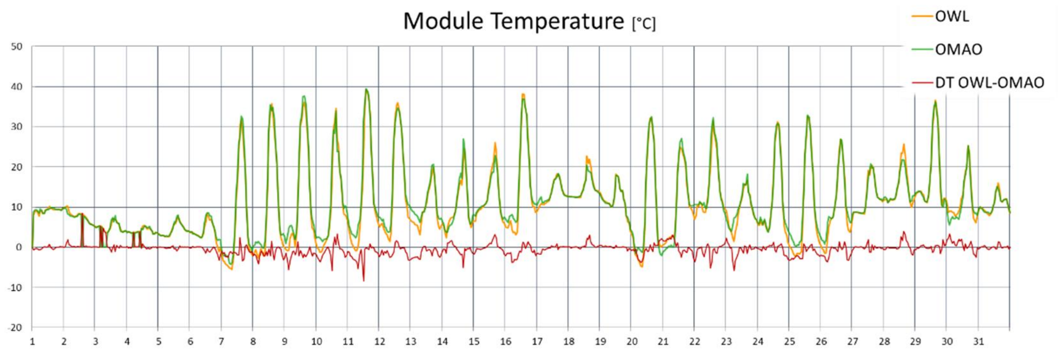

Figure 15: Module temperature, hourly average, October 2013 (own chart, orig. data SKYTRON)

Based on the relevant weather values the Yield of OMAO was corrected in order to get local weather effects filtered out. The result for October 2013 is:

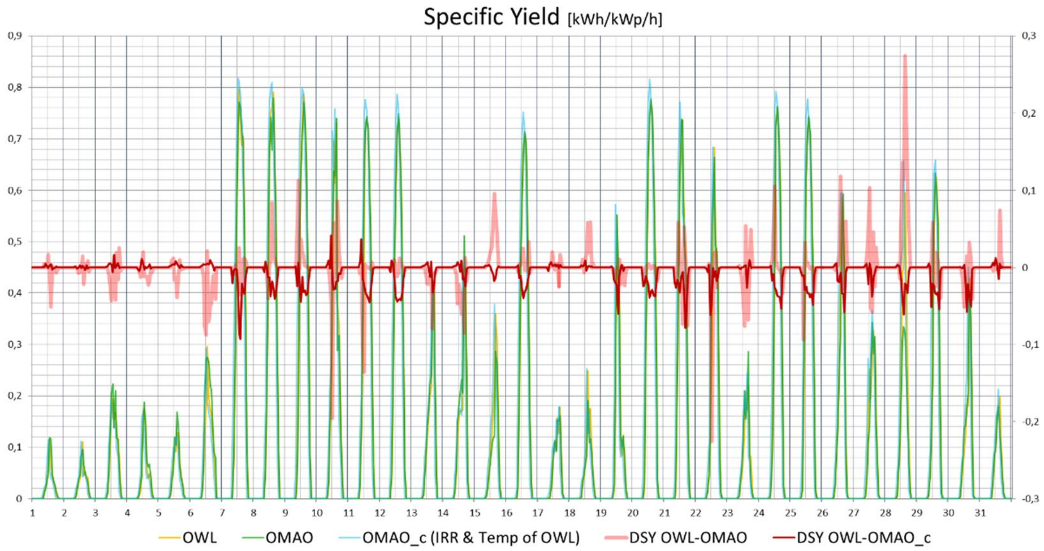

Figure 16: Specific Yield, Differences and Weather correction OMAO, October 2013 (own chart, orig. data SKYTRON)

The pink line in the centre shows the difference between the parks including aberrations caused by local weather differences.
The red line leaves the main part of the effects caused by advantages of better handling of local shadowing. Local weather differences, especially those on days with not perfect sunny weather caused by slow moving clouds are filtered out and result more reliable values for small timeframes.
The clear tendency to negative values shows that =-Style cabling is more efficient than C-Style cabling can be stated.

7.2 Detailed investigation CW43/2013, October 22nd ï 29th, 2013

To get more detailed impression of the effect, a special tool to switch between all month and in a second sheet to switch to every calendar week was designed in EXCEL. In

ANNEX 3: Hourly yield and effect in monthly diagrams for 2013

the monthly results for 2013 are shown. For calendar weeks CW43/2013 which was from October 22nd-29th, 2013 will be commented here.

This week have as well nice sunny day as cloudy days with lower irradiation.

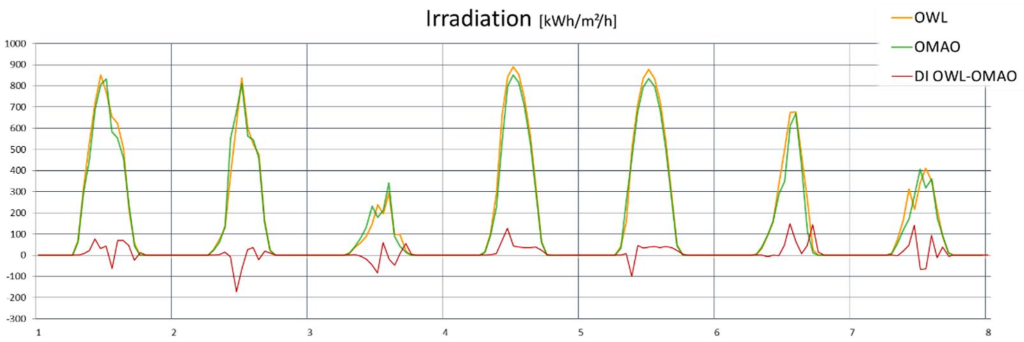

Figure 17: Irradiation in CW43/2013 (own chart, orig. data SKYTRON)

On Tuesday (3-4) and Saturday (7-8) is a time shift of irradiation to mention, combined with differences in irradiation up to +/-15%.

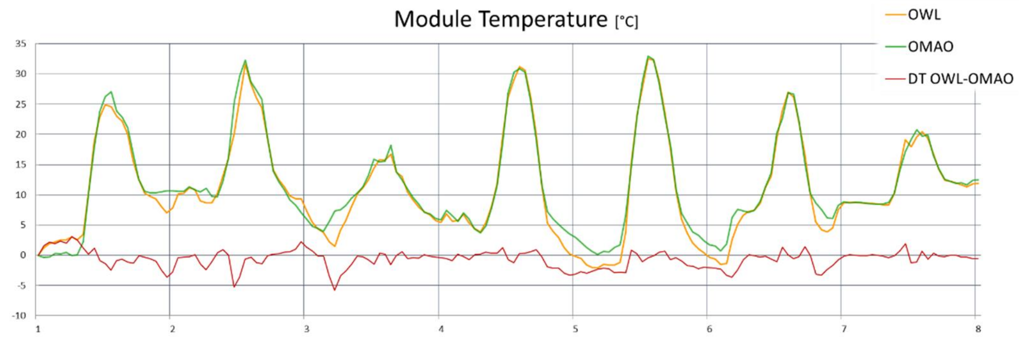

Figure 18: Module Temperature CW43/2013 (own chart, orig. data SKYTRON)

Module temperature follows the irradiation during daytime. OWL is a few kilometres more away from the coast and in October not so foggy. This enables a more intense cooling during the night, nice to see around midnight in the second half of this week. A short time after sunset the temperature difference is less than +/-2°.

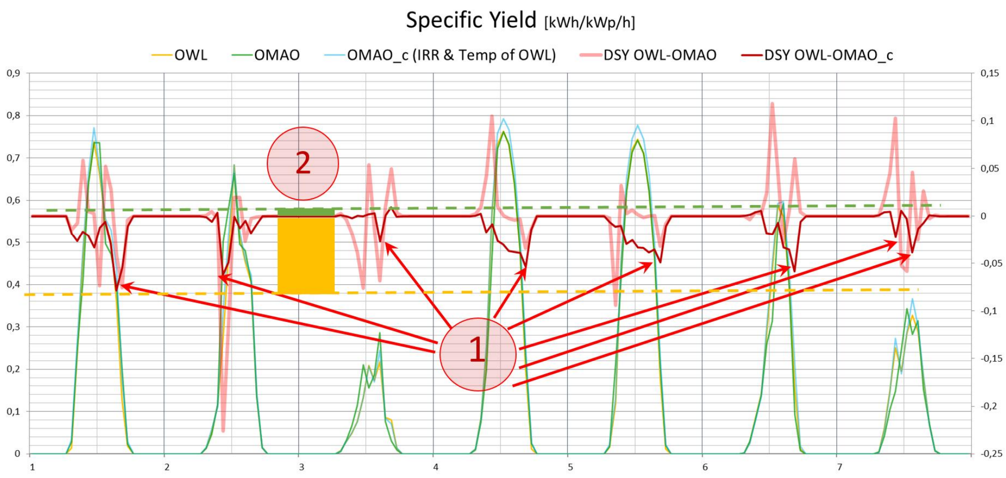

Figure 19: specific Yield, Differences and Weather correction OMAO, CW 43, 2013 (own chart, orig. data SKYTRON)

Easy to acknowledge are two main effects

1. Peaks with higher value of effect during sunrise and sundown under *8.2 Timeframes with valid effect* will follow a confirmation of this effect.
2. Significant higher positive effect for =string cabling most effects for other deviations are filtered out at this state of investigation Only constant factors like inverter efficiency under *9 ADJUSTMENT 3: Different inverter* efficiency and effects of longer back cables under *10 ADJUSTMENT 4: Losses by additional DC* cables will follow to complete the estimations.

7.3 Result ADJUSTMENT 1

Table 6: Result of ADJUSTMENT 1: weather correction (own table)

Value	Unit	OMAO	OWL	Diff OMAO-OWL	% of OWL
Specific Yield 2013 (SY13)	[kWh/kWp]	1 320.70	1 301.91	18.79	1.44%
ADJUSTMENT 1	Weather Correction				
SY13 with weather of OWL	[kWh/kWp]	1 375.33	1 301.91	73.42	5.64%

8 ADJUSTMENT 2: Filter on timeframes where local shadowing can occur

To avoid disturbance on any effects that can happen during a whole year, and to keep the amount of that as low as possible, based on the relative sun position a filter was set up. It handles:

1. Evaluation of maximum and minimum height of sun for effect
2. Isolating every hour below minimum and above maximum sun height
3. Isolating additional every hour with azimuth <90° (East) and >270° (West)

As we have only hourly measurements linear interpolation was taken to estimate the portion of effect. Usual on that timeframes the effect is more than the average of the whole hour. That implies that the result shows a minimal value of the real impact.

8.1 Evaluating minimum and maximum sun height

Based on the geometry of the tables a minimum and maximum angle was evaluated. It is based on following parameter

Table 7: Parameter for evaluation of borders (own table, N° of construction drawings Mounting Systems)

	min	max
module lenght [m]	1.60	3.20
raw distance [m]	6.65	7.20
tilt [°]	25	25

Taking these values under consideration the result is:

Table 8: Maximum and Minimum Sun Height for Effect (own calculation, based on Mermoud)

Borders for near shaodowing effect valid		
min_sun	6.707178235	°
max_sun	19.83194209	°

To evaluate the border angle

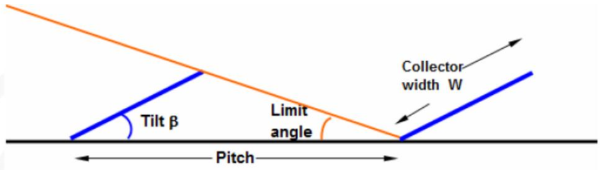

Fig 1. - Basic representation of a row arrangement.

$$\textbf{LimAngle} = \mathrm{ArcTan}\ (W \cdot \cos\beta / (P - \sin\beta))$$

Figure 19: Evaluation of border angle (Mermoud)

The methodology was taken from (Mermoud, Optimzation of Row-arrangement in PV Systems, shading loss evaluations according to module positioning and connexions , 2012)
For every start and end of an hour the sun height was evaluated for location OWL and the “factor of relevance”, a number between 0-1 calculated to estimate the minimum ratio of the effect. The following chart shows for every time during a year the time with the effect.

8.2 Timeframes with valid effect

Taking these values for every hour of the year the maximum appearance was calculated.

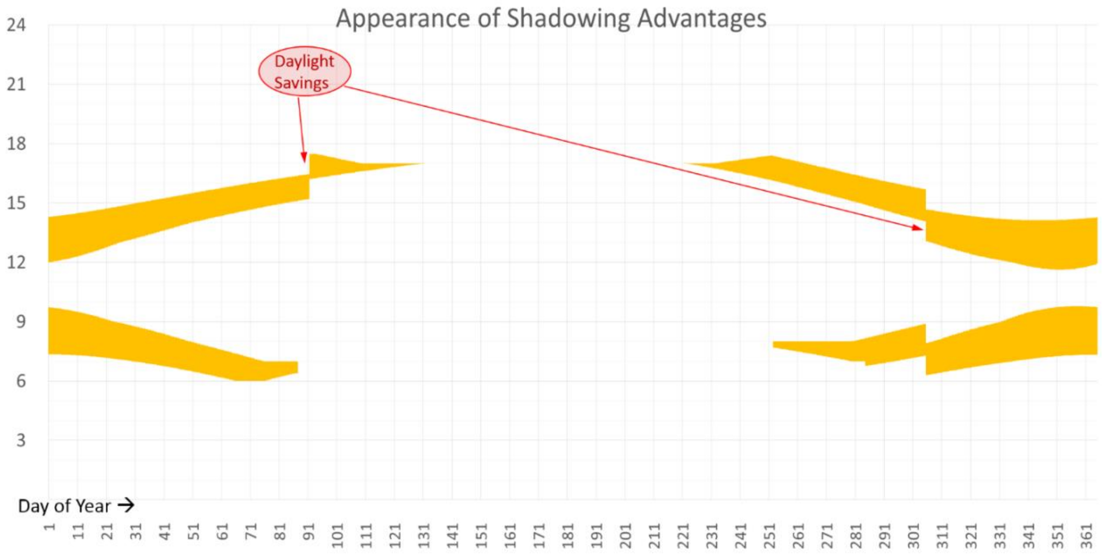

Figure 20: Times where shadowing effects give advantages (own evaluation)

On the horizontal axis the day of the year is marked.

Each day has one bar. In yellow the time with appearance is marked.

On the vertical axis there is the hour of the day. The step around 90th and 305th day is the change of the local time for daylight savings.

Between approx. 100th day and 250th day the effect of "east-west cutting" is visible. This appears when the sun is below east or after west but in relevant height for shadowing. A shadowing of the next row is not possible at these times, so it has to be skipped additionally.

The result is a clear indicator of the time when the effect really appears and gives also a confirmation of the tendency shown in *7 ADJUSTMENT 1: Weather* correction

8.3 Result ADJUSTMENT 2

Table 9: Result of ADJUSTMENT 2: Filter on times with near shadows possible (own table)

Value	Unit	OMAO	OWL	Diff OMAO-OWL	% of OWL
Specific Yield 2013 (SY13)	[kWh/kWp]	1 320.70	1 301.91	18.79	1.44%
ADJUSTMENT 1	Weather Correction				
SY13 with weather of OWL	[kWh/kWp]	1 375.33	1 301.91	73.42	5.64%
ADJUSTMENT 2	Filter on times without Effect				
SY13 in timeframes with shadowin	[kWh/kWp]	117.37	100.49	16.87	16.79%

9 ADJUSTMENT 3: Different inverter efficiency

The parks have 2 different types of inverter. Both parks are equipped with Inverters of the AEG Protect PV series, but OMAO have 250kW Capacity and OWL 500kW. This causes a slight difference on the Inverter efficiency of 0.3%. It was considered for time of appearance of the shadowing effect.

Table 10: Inverter Efficiency (AEG)

PV-250 Eff:98.5%	PV-500 Eff:98.2%

A personal phone call with AEG-Service-team, Mr. Rene Hartmann confirmed that the efficiency-curves of both inverter types are parallel with nearly constant difference between both lines.

This fact allows this simplified calculation for the impact of that effect.

9.1 Result ADJUSTMENT 3

Table 11: Result ADJUSTMENT 3 Different inverter efficiency (own table, data Active Solar)

Value	Unit	OMAO	OWL	Diff OMAO-OWL	% of OWL
Specific Yield 2013 (SY13)	[kWh/kWp]	1 320.70	1 301.91	18.79	1.44%
ADJUSTMENT 1	Weather Correction				
SY13 with weather of OWL	[kWh/kWp]	1 375.33	1 301.91	73.42	5.64%
ADJUSTMENT 2	Filter on times without Effect				
SY13 in timeframes with shadowin	[kWh/kWp]	117.37	100.49	16.87	16.79%
ADJUSTMENT 3	Different Inverter Efficiency				
Inverter in Use		PV-250 Eff:98.5%	PV-500 Eff:98.2%		
Losses Inverter Efficiency PV500			0.30		
SY13 corrected to all Inverter PV25	[kWh/kWp]	117.37	100.79	16.57	16.44%

10 ADJUSTMENT 4:

Losses by additional DC cables

After all the advantages of the lower shadowing effects the disadvantage of Ohmic losses caused by longer string cabling was calculated.

Table 12: Parameter and result for losses on additional DC cables (own table, N° AES)

	OWL	
modules per 1 MWp	4 255	
N° of strings	193	
lfm of extra cables	4 448	
	OWL	
P-Loss on extra cable	1 434.84	W/MW
	0.1435%	

The losses are calculated with an additional length of 23 m, which is based on 22 modules with 1 m width a 2 m to connect every 2nd string to the upper row.
A cable with 4 mm² will be taken, like used in both parks for similar situations.
To estimate the maximum possible losses caused by additional cables it is assumed that every time the maximum string current of 8.5 A is in the cable.
As there are lots of hours with an average of significant lower current this number is the absolute possible maximum.

On the annual specific yield of 1 301.91 kWh/kW$_p$ the maximum possible additional cable losses can be estimated with 1 868 kW/kW$_p$,
That value is only 11.7% of the benefit from the avoided losses on near shadowing effects (16.57 kWh/kW$_p$).
Even if the cable losses can be assumed as only 50-70% there is no significant change on the benefit.

11 RESULT 1: Annual specific performance plus 1.13%

As a final result of consideration of all relevant differences and filtering times where no effect occur the final table can be presented:

11.1 Possible Specific Yield Enhancement on = cabling

The following table summarizes all technical investigations

Table 13: Summary of investigations, possible specific yield enhancement (own calculations)

Value	Unit	OMAO	OWL	Diff OMAO-OWL	% of OWL
Capacity	[kWp]	21 459.16	31 559.45	- 10 100.29	-32.00%
Style of string Cabling		= Style	C - Style		
Yield 2013	[kWh]	28 341 079.03	41 087 554.01	- 12 746 474.98	-31.02%
Specific Yield 2013 (SY13)	[kWh/kWp]	1 320.70	1 301.91	18.79	1.44%
ADJUSTMENT 1	Weather Correction				
SY13 with weather of OWL	[kWh/kWp]	1 375.33	1 301.91	73.42	5.64%
ADJUSTMENT 2	Filter on times without Effect				
SY13 in timeframes with shadowin	[kWh/kWp]	117.37	100.49	16.87	16.79%
ADJUSTMENT 3	Different Inverter Efficiency				
Inverter in Use		PV-250 Eff:98.5%	PV-500 Eff:98.2%		
Losses Inverter Efficiency PV500			0.30		
SY13 corrected to all Inverter PV25	[kWh/kWp]	117.37	100.79	16.57	16.44%
ADJUSTMENT 4	Losses on additional needed Cables				
Annual cable loss additional cables	[kWh/kWp]		1.87	- 1.87	
Corrected with cable losses	[kWh/kWp]			**14.71**	**1.13%**

The result of 14.71 kWh/kW_p possible enhancement is now taken for the investigation of the relevance in OUL with 31.5MW_p.

12 RESULT 2: Additional Yield in park with 31.5 MW_p

The result would have additional yield of more than 460 MWh in a year similar to 2013 if the cabling in OWL (31,5MWp) would be changed.

That is equal to 1.13 % additional yield on simple change of cabling

Table 14: possible annual additional yield on = cabling in OMAO (own calculations)

possible benefit on change to = wiring in OWL		
Specific Yield	[kWh/kWp]	14.71
possible annual Yield 2013	[kWh/kWp]	1 316.62
		1.13%
additional Yield 2013	[kWh]	464 096.62

13 CHECK: Economic impact

To check the economic impact costs for change of cabling have to be compared to the possible benefit. For decision finding the ROI (Return on Investment) will help.

13.1 Costs for change of cabling

To find a clear decision if change of cabling is suitable first the costs for the change should be evaluated.

The cost of the additional cables can be estimated like following

First step is to evaluate the needed cables per MW_p

Table 15: m additional cable per MW_p (own table, N° AES)

	OMAO	OWL
modules per 1 MWp	4 362	4 255
N° of strings	198	193
m of extra cables	4 560	4 448

We assume that the work is prepared during daylight and the change of the plug will happen during unproductive hours when the sun is not shining on the modules. At actual market prices we can assume following costs:

Table 16: Costs per MW_p to change the cabling (own calculation, prices AES)

POSITION	AMOUNT	€ / UNIT	SUMMARY
Cable	4 448	1.50 €	6 672.00 €
Plugs (2 per String)	386	3.50 €	1 351.00 €
Cable fixing material	193	2.00 €	386.00 €
Construction work (0,1h/string, 70€/h construction team)	19.3	70.00 €	1 351.00 €
management/ preparation of work	1	500.00 €	500.00 €
			10 260.00 €

14 RESULT 3: Return on investment of retrofit

To find the decision the return on Investment based on possible feedin tariff will help in individual cases.

Table 17: ROI based on Feedin Tariff (own calculation)

Feedin Tarif	annual return	ROI [Years]
0.05 €	735.27 €	13.95
0.10 €	1 470.55 €	6.98
0.15 €	2 205.82 €	4.65
0.20 €	2 941.09 €	3.49
0.25 €	3 676.37 €	2.79
0.30 €	4 411.64 €	2.33
0.35 €	5 146.92 €	1.99
0.40 €	5 882.19 €	1.74
0.45 €	6 617.46 €	1.55
0.50 €	7 352.74 €	1.40

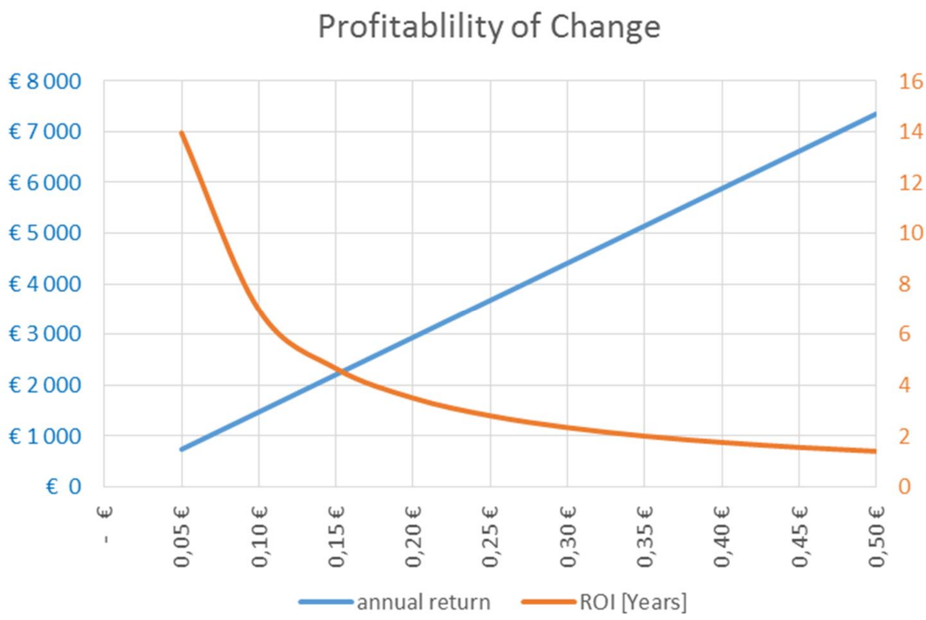

Figure 21: ROI based on Feedin Tariff (own chart)

The evaluation shows a clear recommendation for fast change on every feedin-tariff higher than 0.15 €/kWh (<5years ROI).

Even on a market price of electricity of 0.05 €/kWh a ROI below the life time of the park (20years +) is possible.

15 CHECK: Best time to start retrofit

In countries with reliable legal framework it is clear that a change of the cabling make sense. A question that comes up is:

When is the best time to change?

15.1 Monthly Yield Distribution

This can be answered on the distribution of yield and effect during the year.

Figure 22: Monthly Distribution of specific Yield and Effect [kWh/kW$_p$] (own chart)

Table 18: Monthly Distribution of specific Yield and Effect [kWh/kW$_p$] (own table)

	Yield with no Effect	Effected Yield	Benefit	Total Yield
January	19.449	11.320	3.273	34.041
February	45.605	11.233	0.850	57.688
March	86.444	10.918	0.779	98.141
April	138.970	5.849	0.392	145.211
May	198.410	0.501	0.032	198.943
June	157.377	-	-	157.377
July	167.197	-	-	167.197
August	156.292	2.025	0.167	158.484
Septembe	103.634	10.388	0.446	114.468
October	69.279	14.347	0.971	84.597
November	43.326	16.958	2.558	62.842
December	15.435	16.954	7.407	39.797

Based on this distribution the recommendation to do the works for changing will be September/October, where in case of short local interruption the losses are not so high like in summer and the months with highest benefits (November-January) are short time ahead.

15.2 Annual percentage of monthly yield and benefit

To get an idea about variation of annual yield, influenced yield and amount of benefit the evaluation of percentage during the year is useful.

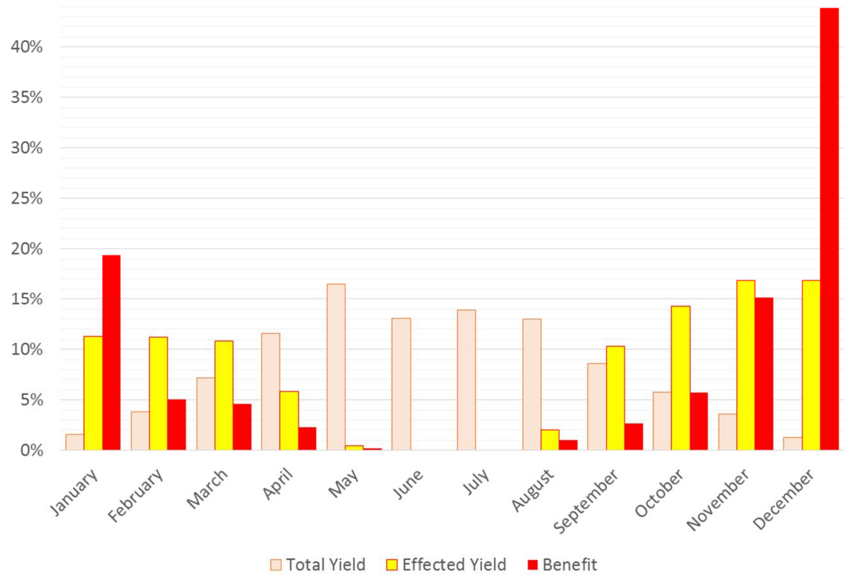

Figure 23 : Monthly percentage of annual yield and benefit (own chart)

Table 19 : Monthly percentage of annual yield and benefit (own table)

	Total Yield	Effected Yield	Benefit
January	1.619%	11.264%	19.398%
February	3.796%	11.178%	5.038%
March	7.195%	10.865%	4.615%
April	11.567%	5.820%	2.321%
May	16.515%	0.498%	0.190%
June	13.099%	0.000%	0.000%
July	13.917%	0.000%	0.000%
August	13.009%	2.015%	0.990%
Septembe	8.626%	10.337%	2.646%
October	5.766%	14.277%	5.751%
November	3.606%	16.875%	15.158%
Dezember	1.285%	16.871%	43.894%

The high effect during the partial shaded winter month is another clear indicator to recommend changes before that season.

As the benefit is only 1.11% of the annual yield, the 43.9% of December refer only to 0.48% of the total annual yield.

Nevertheless is 89.24% of the benefit in the season between October and February.

16 Alternative cabling for new parks?

The ahead presented results lead to a question if it will be possible to get the benefits of lower losses during near shadowing and short cable length to avoid costs for cables as well as Ohmic losses.

There is also additional possibility to avoid the long extra cables.

It could look like the following schema:

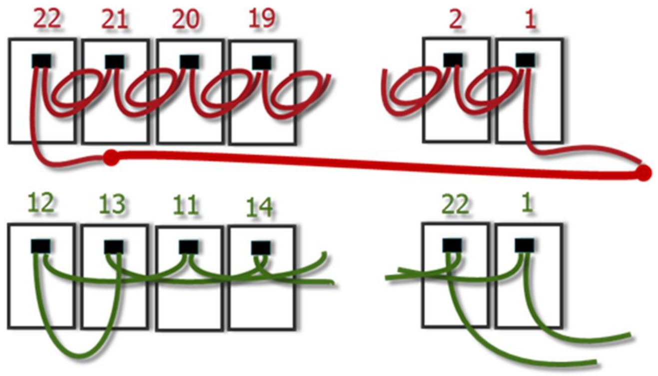

Figure 24: Schema for string cabling to avoid long back cables (own sketch)

This very effective cabling is only possible if the cable length is about 10% longer than the module width. An extra series of module have to be negotiated with the manufacturer of the modules where the connection cables of the modules are 1.1m (usual 1.0 m). With orders of more than 40 000 modules (~10MW$_p$) this should be possible to negotiate without extra costs.

This will allow another 0.15% higher performance (Table 12: Parameter and result for losses on additional DC cables (own table, N° AES)) at same installation costs!

17 Conclusions

The investigations on that special effect show that for large PV-parks the economic feasibility is far underestimated.

17.1 Return on change is given in short time

1) It is possible to earn every year additional
€ 300 000.-- per 100 MW_p of a portfolio
if strings cabling is changed to one line cabling (=Style)

ROI is shown that it is below 3 Years on a feedin-tariff of more than 0.20 € / kWh.
That feedin-tariff should be possible by most installed PV farms.
Considering that the ROI is within 3 years and the parks have feedin for 10-20 years it will be feasible in most situations.
For new parks there should be no discussion.
On only 0.20 €/kWh feedin the effects gives the chance of extra earnings of ~3 000.-- €/MW_p a year.
For a portfolio of 100MWp we are talking about € 300.000,--/year, which makes it quite interesting to consider it.

17.2 Significant rate of >80% of the effect in winter

2) Realization should be done it in a way that the work is finished short time before October 15th

In 15.2 was shown that the 89.4% of the effect takes place between October and February, which gives a clear timeframe to do the changes if possible a short time before the winter season starts.

18 Bibliography

Kubicek, B., Mütter, G., Voronko, Y., & Krametz, T. (2014). Unsing an optimized analytic predictor as an error indicator in multi MW PV-plants. *PVSEC*, (p. 5BV.1.13). Amsterdam.

Mathur, B. (2009, 10). Effect of Shading on Series and Parallel Connected Solar PV Modules. *Modern Applied Science*, p. 32ff.

Mermoud, A. (2012). Optimzation of Row-arrangement in PV Systems, shading loss evaluations according to module positioning and connexions . *PVSEC.* Frankfurt.

Mermoud, A., & Lejeune, T. (2010). Partial Shading on PV Arrays:By-Pass Diode benefits Analysis. *PVSEC*, (p. 4bv.1.81). Valencia.

Mütter, G., Krametz, T., & Kubicek, B. (2014). Analyse der Ursachen für Ertragsverluste in der Anlaufphase des Einspeisebetriebes von PV-Kraftwerken. *29. Symposium Photovolatische Solarenenergie.* Bad Staffelstein.

Mütter, G., Krametz, T., & Steirer, P. (2015). Experience with a performance package for multi MW PV plants based on computations on top of monitoring. *PVSEC.* Hamburg: PVSEC.

Mütter, G., Voronko, Y., Krametz, T., Kubicek, B., & Steirer, P. (2014). Evaluation of influence factors on park performance in large PV plants based on monitoing of up to 700 MWp over 2 years. *PVSEC* , (p. 5BV1.42). Amsterdam.

Ramapraba, R. (2009). Impact of Partial Shading on Solar PV Module containing Series Connected Cells. *International Journal of Recent Trends in Engineering*, 56ff.

Wikipedia. (2015, 10 10). *Photovoltaic effect*. Retrieved from Wikipedia, the free enziklopedia: https://en.wikipedia.org/wiki/Photovoltaic_effect

Wikipedia. (2015, 10 10). *Solar Cell efficiency*. Retrieved from Solar cell efficiency: https://en.wikipedia.org/wiki/Solar_cell_efficiency

ANNEX 1: Principles of PV, main components and their purpose

In a photovoltaic power plant there are a few components relevant for the energy production.

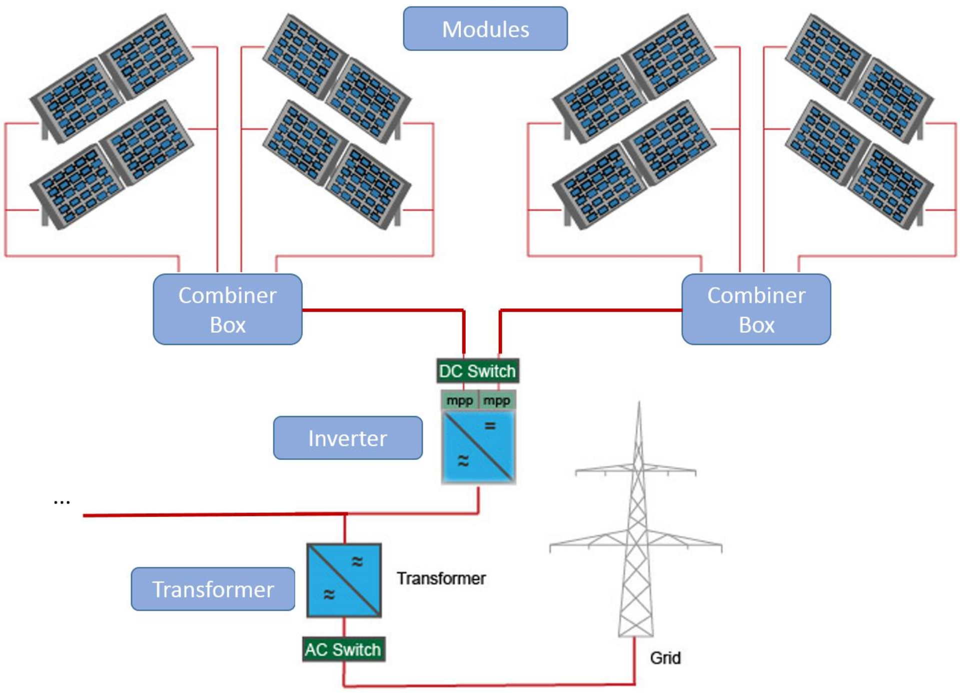

Figure 25: Structure and main components of utility scaled PV plant (own design)

Modules

Modules are necessary to collect the energy of the sun.
The principle is the photovoltaic effect, which can be referred at (Wikipedia, Photovoltaic effect, 2015)
For efficiency in power plants following details are of relevance and are taken in consideration in this document.

Solar Cell Efficiency / Module Efficiency

This is usual between 12-15% (Research cells up to-25%)
The modules in our scenarios are from the Chinese producers JINKO and SOLARFUN and have efficiency under STC of up to 15%.
STC are the standard testing conditions and represent 1kW/m² irradiation, Temperature 25°C and an Airmass AM of 1.5.
Details can be referred at (Wikipedia, Solar Cell efficiency, 2015).

Shadowing

Cells are switched in series of usual 20 -24 cells in standard crystalline modules. As soon as 1 cell of this cell-string is in significant shadow the whole module has dramatic losses. To avoid overheating By-Pass-Diodes are installed and cut the shadow infected string off, but keep the current flowing to the neighbor modules in the (module-) string. Details to this effects are given in (Mermoud, Optimzation of Row-arrangement in PV Systems, shading loss evaluations according to module positioning and connexions , 2012) and in (Mermoud & Lejeune, Partial Shading on PV Arrays:By-Pass Diode benefits Analysis, 2010).
There is predictable shadowing when modules are within a row distance that one row has shadowing impact to the next row. In the investigated park there are always 2 modules in portrait format mounted and connected in 2 different cabling styles to strings.
Effects of the so called “near shadowing” can be considered in simulation software during design of construction details.

DC Cabling

Special cables are taken for DC Cabling to connect the module-strings to the combiner boxes. Usually the copper cross section dimension is 4 mm² , on longer distances (>100m) 6mm² is recommended to avoid Ohmig -losses on DC cables.

Combiner Boxes (GCB)

In this boxes usually 3-16 strings are collected and connected with a larger dimension cable to the inverter station (usually 70m² and more)

In the combiner boxes monitoring of (module-) strings is connected and every minute the production values are transmitted to central monitoring serve in Berlin, Germany.

Inverter

Here the DC is converted to AC, synchronized to that what is needed in the grid. Electrical energy to feed in to a public grid has to be synchronized in voltage and frequency. There is a narrow bandwidth on voltage and frequency that the inverter has to deliver. Also the relation between active and reactive energy (cos PHI) can be a request of grid operator when the PV-park is of larger dimension (>1MW_p in some local grids also significant lower).
For large PV-Farms there are 2 major concepts for inverter structure

Central inverter

Here a lot of strings are connected to 1 or 2 Inverter of larger size. In our examples this concept is used with Inverter-Stations with 2x250 kW_p and 2x500 kW_p.
Advantage is primary that they can handle larger regions of the park and sometimes there is a little higher efficiency given. Also AC cabling is simplified with this concept.

String inverter

Here a small number of strings are connected to relatively tiny inverter.
Advantage is a smaller reduction of production on breakdown of one inverter, cheaper spare parts and significant lower education level for the service technicians. You are able to change a single inverter with less education than correcting even a small fault on a large central inverter. AC cabling is a bit more complex at this concept.

Grid connection point

This is the logical end of the PV-Plant.
At this point the feed-in counter is mounted in order to legalize energy put into the grid and to have records about the delivered energy.

ANNEX 2: Investigated parks

Table 20: Technical data of used modules (own table, data Active Solar)

Modules						
Park	**Modul types**	**Country of origin**	**number**	**l x b x w [mm]**	**power tolerance**	**temp.-koeff**
Omao	Jinko JKM 225P-60	China	23 177	1 650x992x45	-3% / +3%	-0.48%/°C
	Jinko JKM 220P-60	China	6 336			
	Jinko JKM 230P-60	China	18 007			
	Solarfun SF220-30-1P230	China	24 000	1652x1000x50	-3% / +3%	-0.45%/°C
	Solarfun SF220-30-1P235	China	22 080			
			93 600			
OWL	Jinko JKM 230W	China	37 134	1650x992x45	-3% / +3%	-0.48%/°C
	Jinko JKM 235W	China	59 666			
	Jinko JKM 240W	China	37 488			
overall			**134 288**			

Table 21: Main parameter of mounting structure (own table, data Active Solar)

MOUNTING STRUCTURE

Park		*Omao*	*Owl*
Capacity nom.	[Wp]	21 459 155	31 559 450
Capacity inst.	[Wp]	21 658 888	31 923 600
company		Mounting System GmbH GERMANY	Mounting System GmbH GERMANY
basic structure		2 rows portrait	2 rows portrait
module border	[m]	0.50	0.50
sum of module border	[m]	46 800	67 144
row distance	[m]	6 65	6.90 / 7.20
tilt	[°]	25	25

Table 22: Main Parameter of Combiner Boxes (own table, data Active Solar))

COMBINER BOXES

Park		*Omao*	*Owl*
Capacity nom. (DC)	[Wp]	21 459 155	31 559 450
Capacity inst. (AC)	[Wp]	21 658 888	31 923 600
AEG PV.IcX	Germany	280	414
total		280	414

Table 23: Types and distribution of installed inverter (own table, data Active Solar)

INVERTER

Park		*Omao*	*Owl*
Capacity nom.	[Wp]	21 459 155	31 559 450
Capacity inst.	[Wp]	21 658 888	31 923 600
AEG PV Protect 250	Germany	80	2
AEG PV Protect 500	Germany		58
total			**60**

Table 24: Used cables (own table, data Active Solar)

CABLES

Park		*Omao*	*Owl*
Capacity nom.	[Wp]	21 459 155	31 559 450
Capacity inst.	[Wp]	21 658 888	31 923 600
N2XS(FL)2Y 1x300 RM/25 (Schwechat, Austria)	[m]	1 395	27 000
N2XS(FL)2Y 1x120 RM/25 (Schwechat, Austria)	[m]		37 400
N2XS(FL)2Y 1x120 RM/16 (Schwechat, Austria)	[m]	27 675	
N2XSEY 3x50 RM/16 (Lappkabel, Germany)	[m]	300	5 638
NYY-O 1x95 (Lappkabel, Germany)	[m]	28 520	73 900
NYY-O 1x70 (Lappkabel, Germany)	[m]	28 480	
NYY-O 1x50 (Lappkabel, Germany)	[m]		18 300
NYY-J 4x70 (Lappkabel, Germany)	[m]		1 015
NYY-J 4x50 (Lappkabel, Germany)	[m]		2 012
NYY-J 4x35 (Lappkabel, Germany)	[m]		6 806
NYY-J 4x25 (Lappkabel, Germany)	[m]	395	
NYY-J 4x16 (Lappkabel, Germany)	[m]	4 485	
PV1-F 1x4 (Lappkabel, Germany)	[m]	247 510	270 700
total	[m]	338 760	442 771

Table 25: Used Sensors (own table, data Active Solar)

SENSORS

Park		*Omao*	*Owl*
Capacity nom. (DC)	[W_p]	21 459 155	31 559 450
Capacity inst. (AC)	[W_p]	21 658 888	31 923 600
PV.SuN		5	7
PV.PyranO		2	3
Vaisala - Weatherstation		1	1
total			11

ANNEX 3: Hourly yield and effect in monthly diagrams for 2013

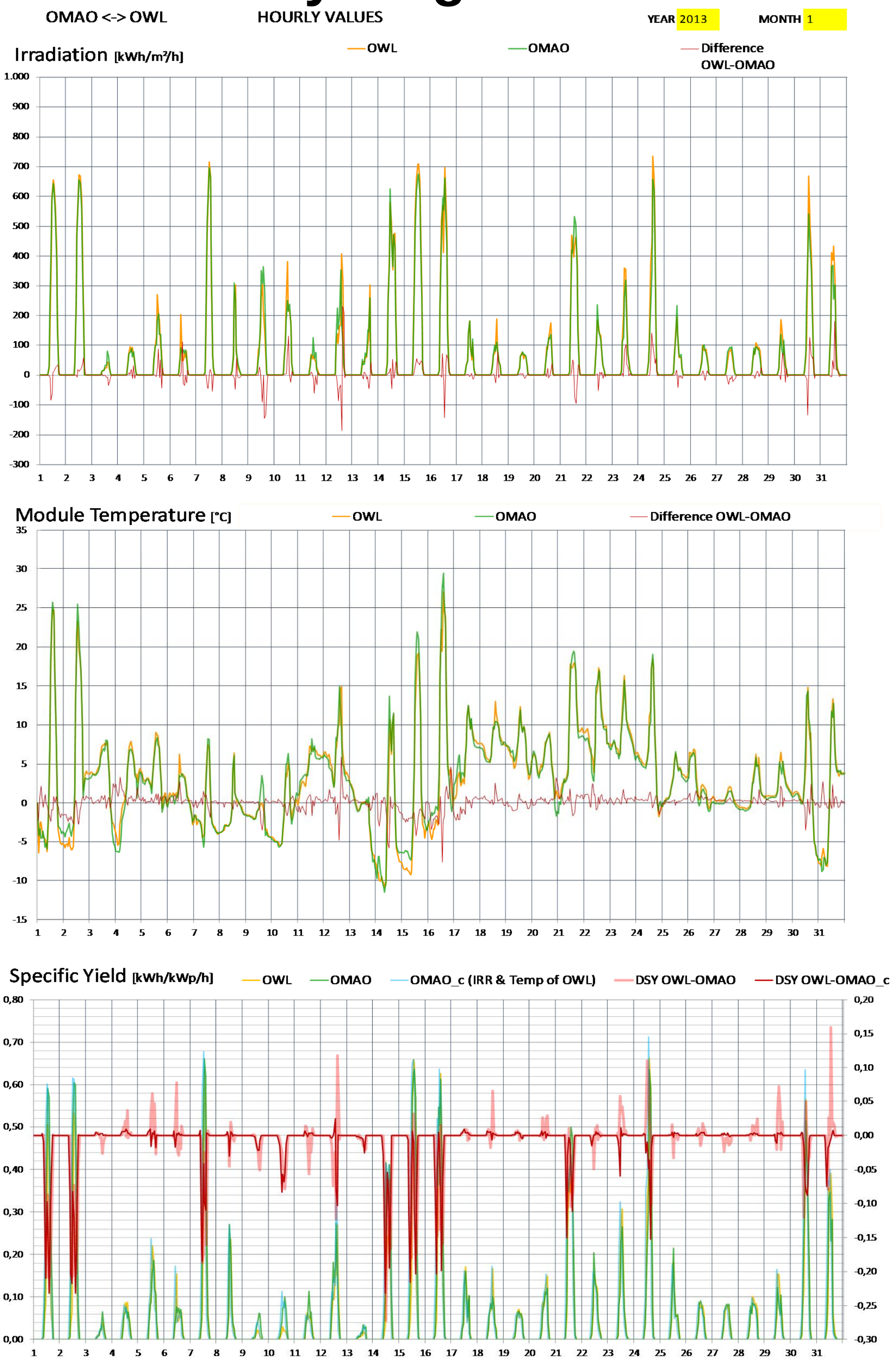

Figure 26:hourly irradiation, module temperature and yield 2013-01 (own chart, basic data SKYTRON)

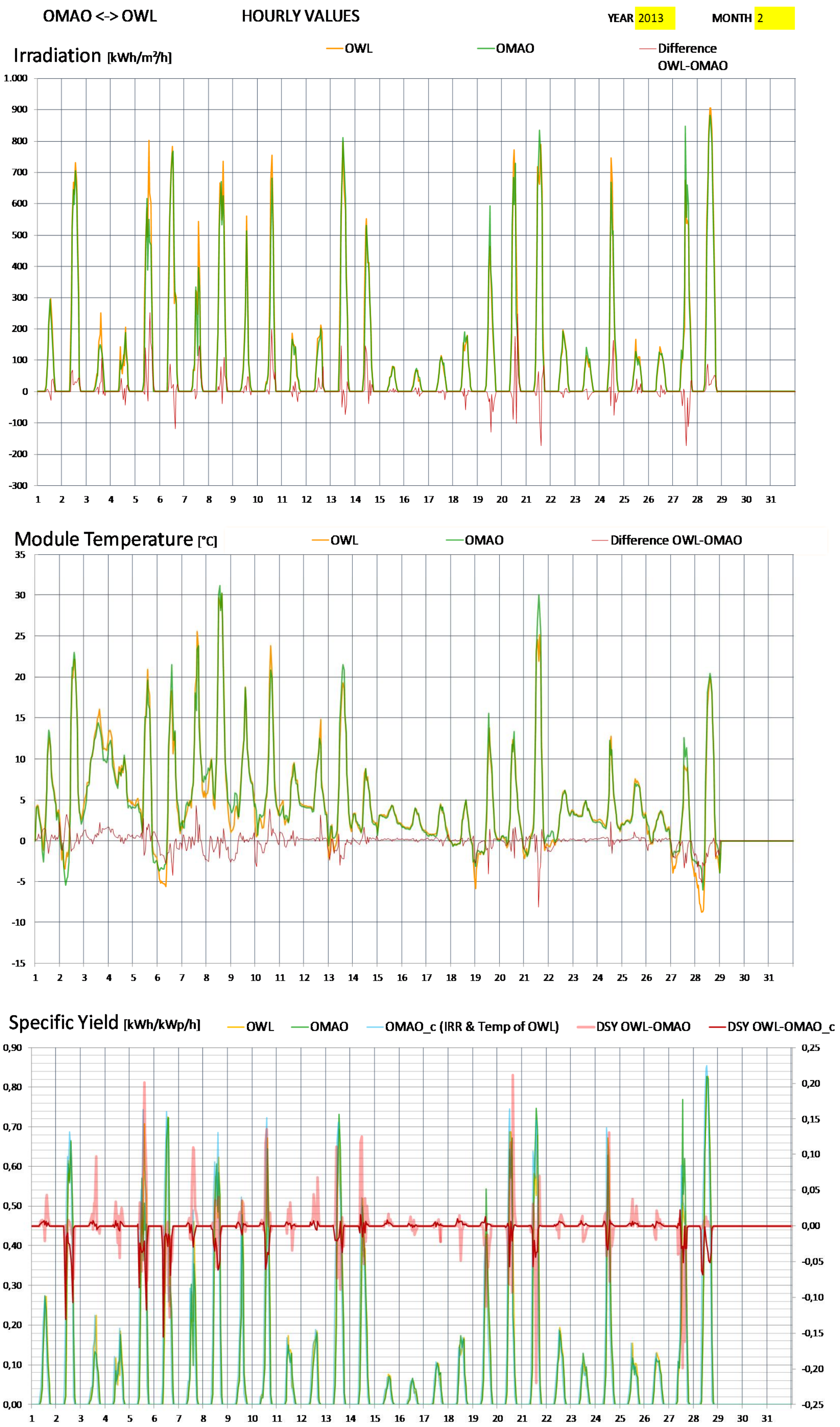

Figure 27:hourly irradiation, module temperature and yield 2013-02 (own chart, basic data SKYTRON)

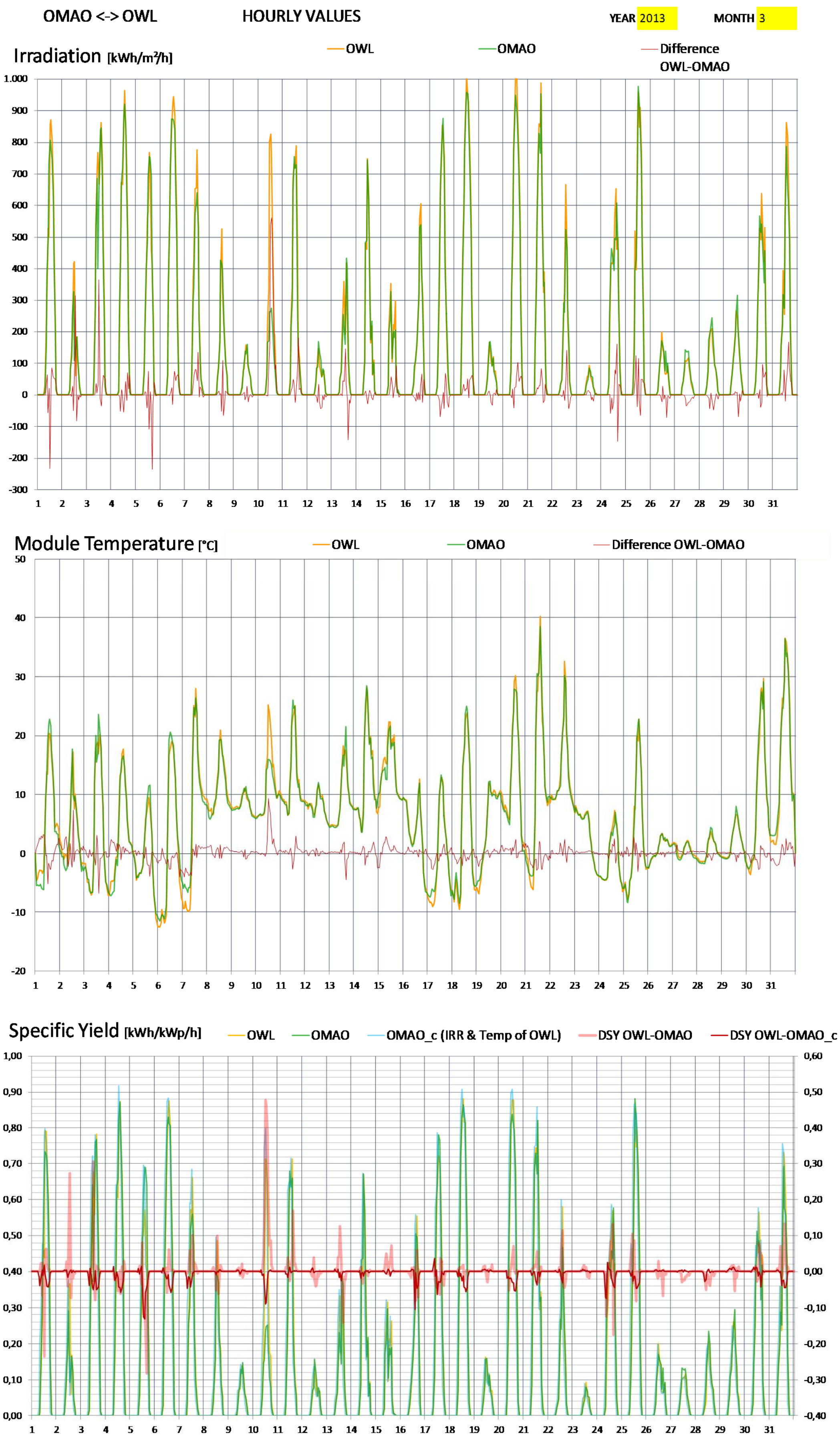

Figure 28:hourly irradiation, module temperature and yield 2013-03 (own chart, basic data SKYTRON)

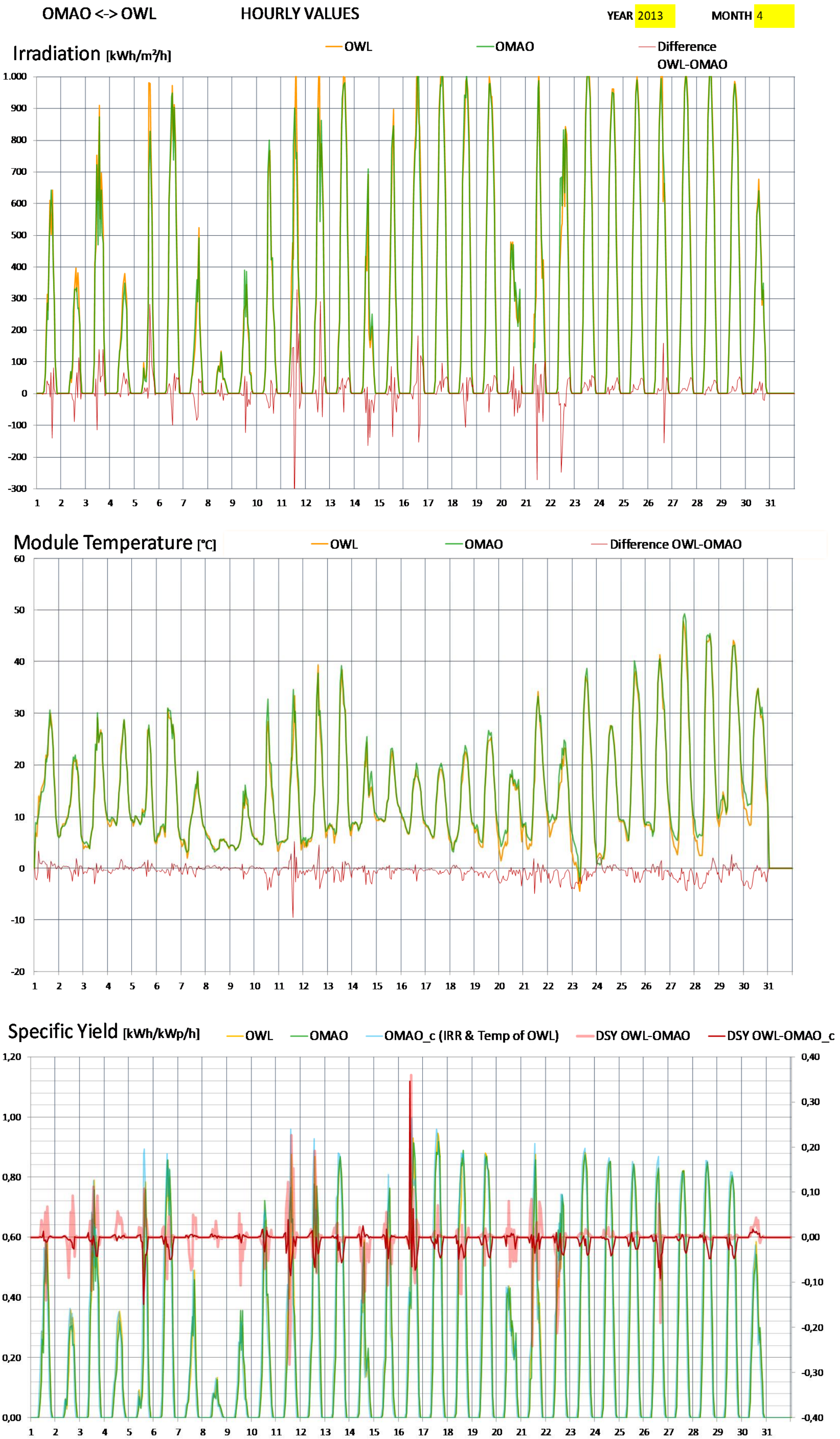

Figure 29:hourly irradiation, module temperature and yield 2013-04 (own chart, basic data SKYTRON)

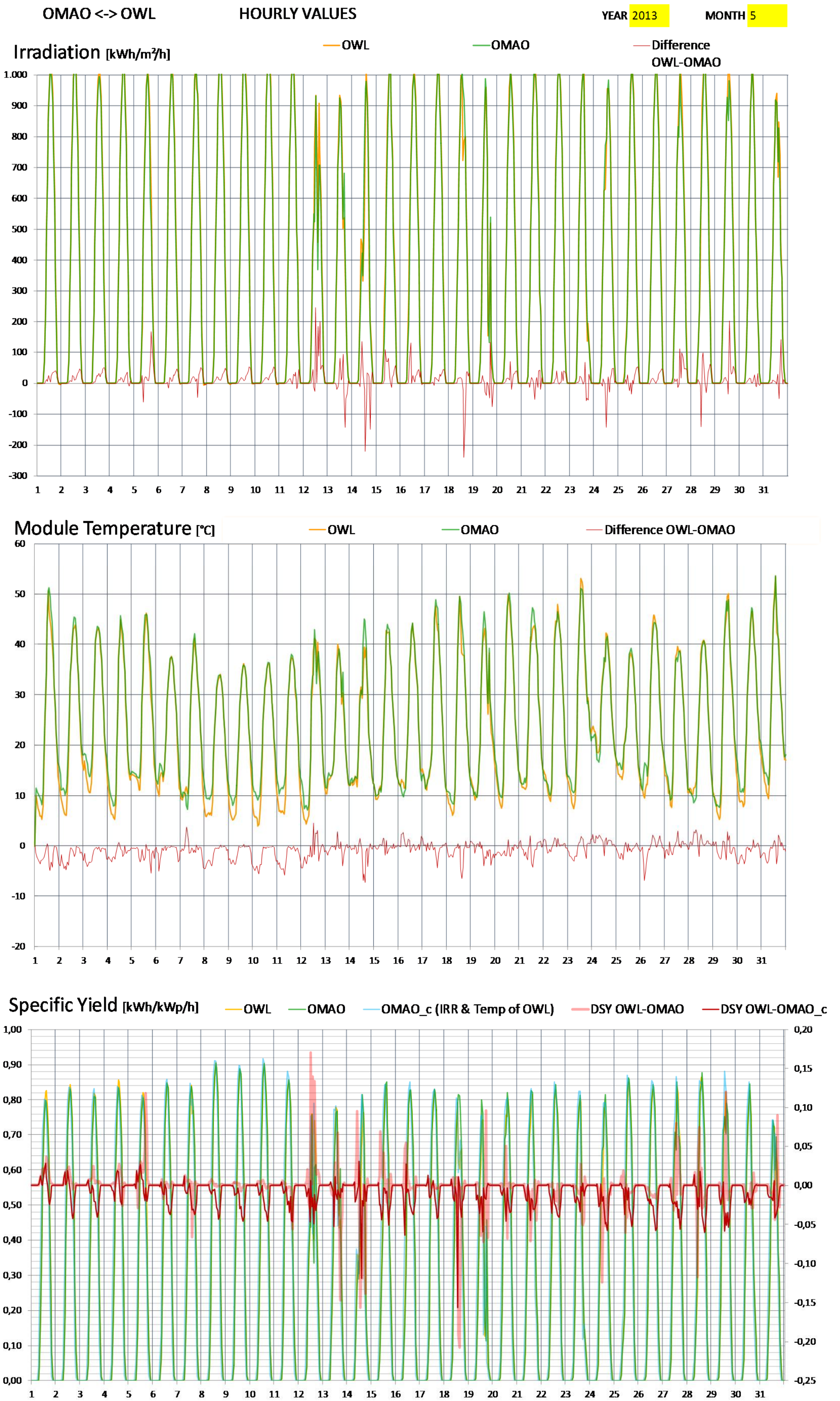

Figure 30:hourly irradiation, module temperature and yield 2013-05 (own chart, basic data SKYTRON)

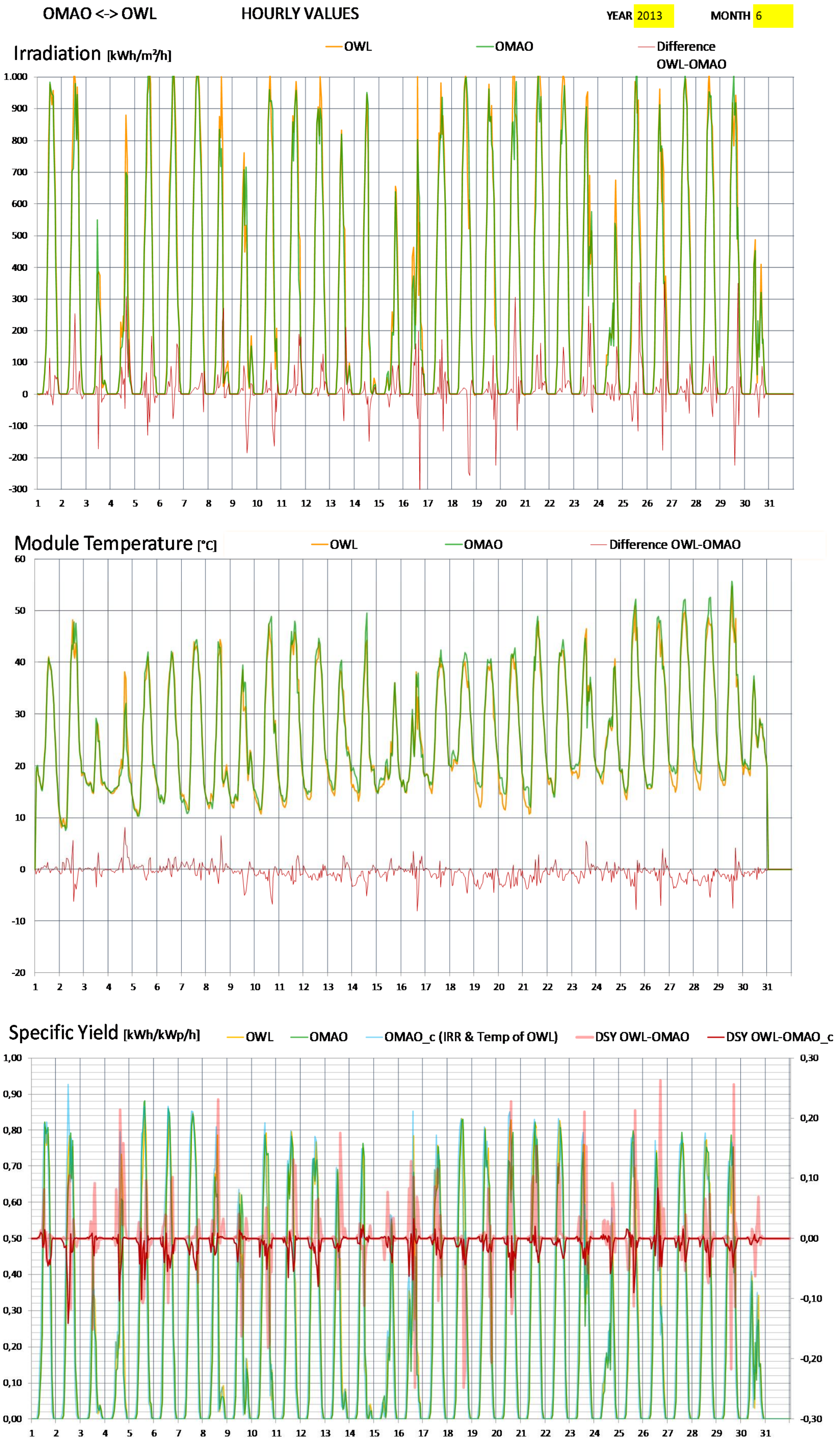

Figure 31:hourly irradiation, module temperature and yield 2013-06 (own chart, basic data SKYTRON)

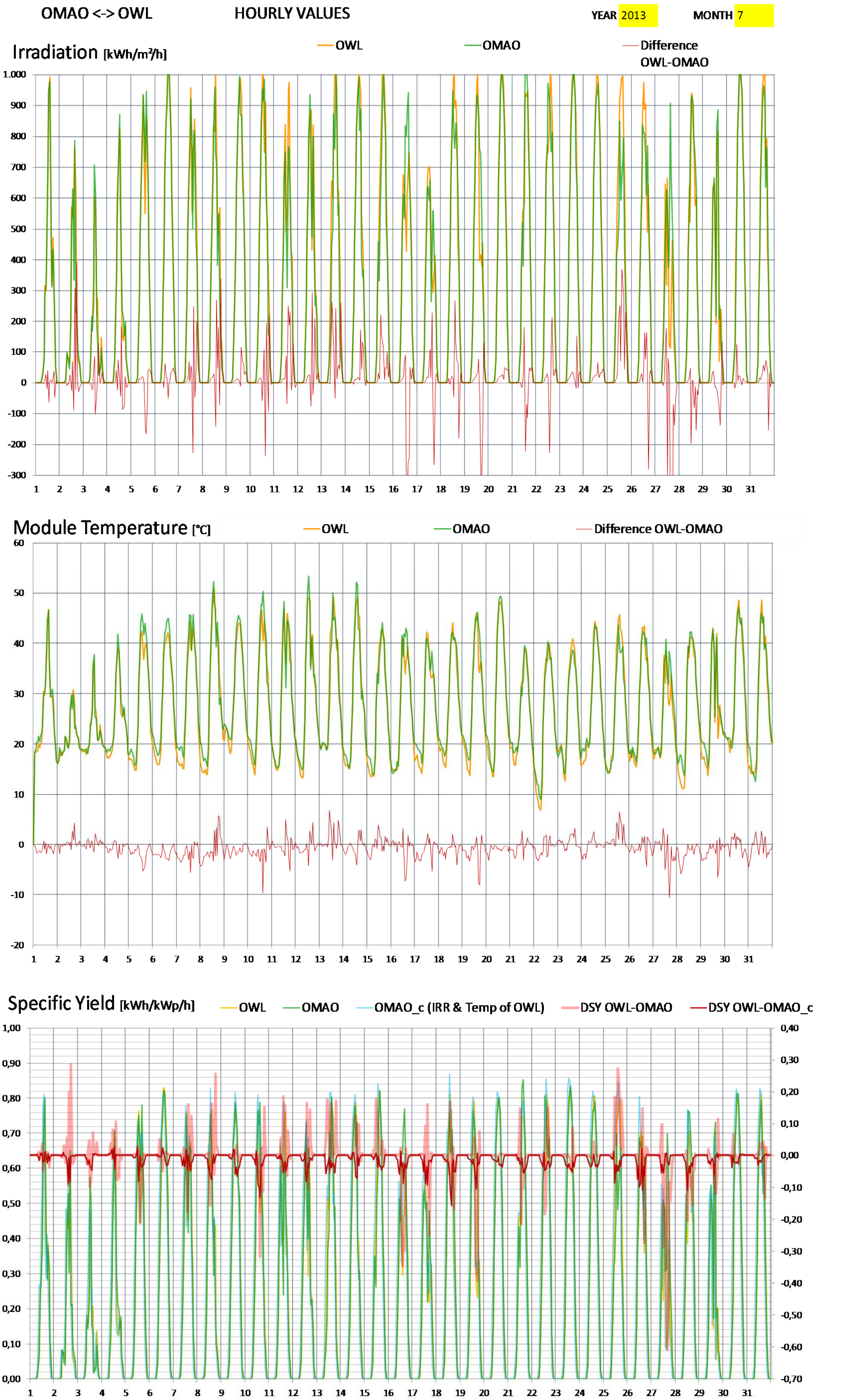

Figure 32:hourly irradiation, module temperature and yield 2013-07 (own chart, basic data SKYTRON)

Figure 33:hourly irradiation, module temperature and yield 2013-08 (own chart, basic data SKYTRON)

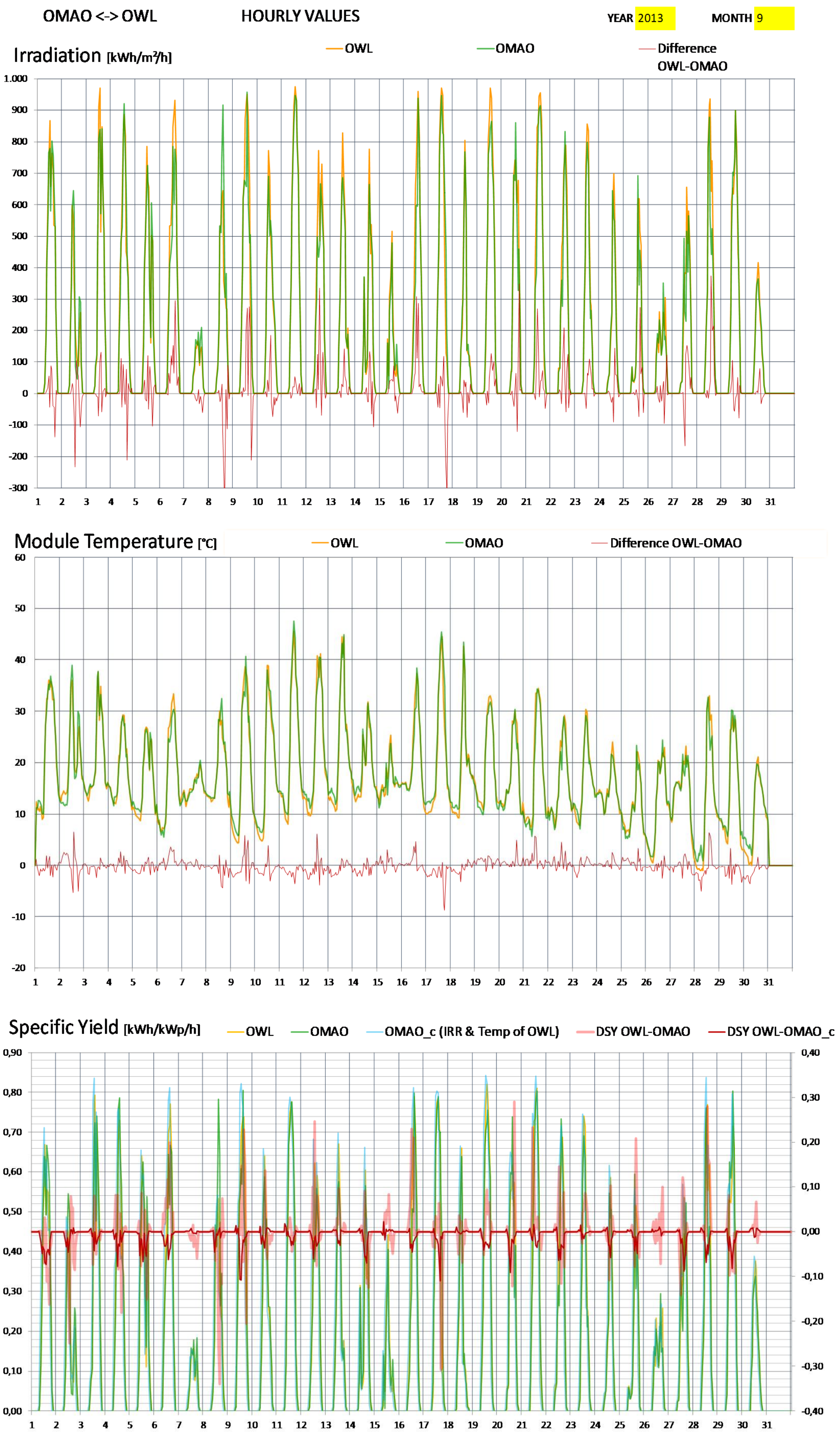

Figure 34:hourly irradiation, module temperature and yield 2013-09 (own chart, basic data SKYTRON)

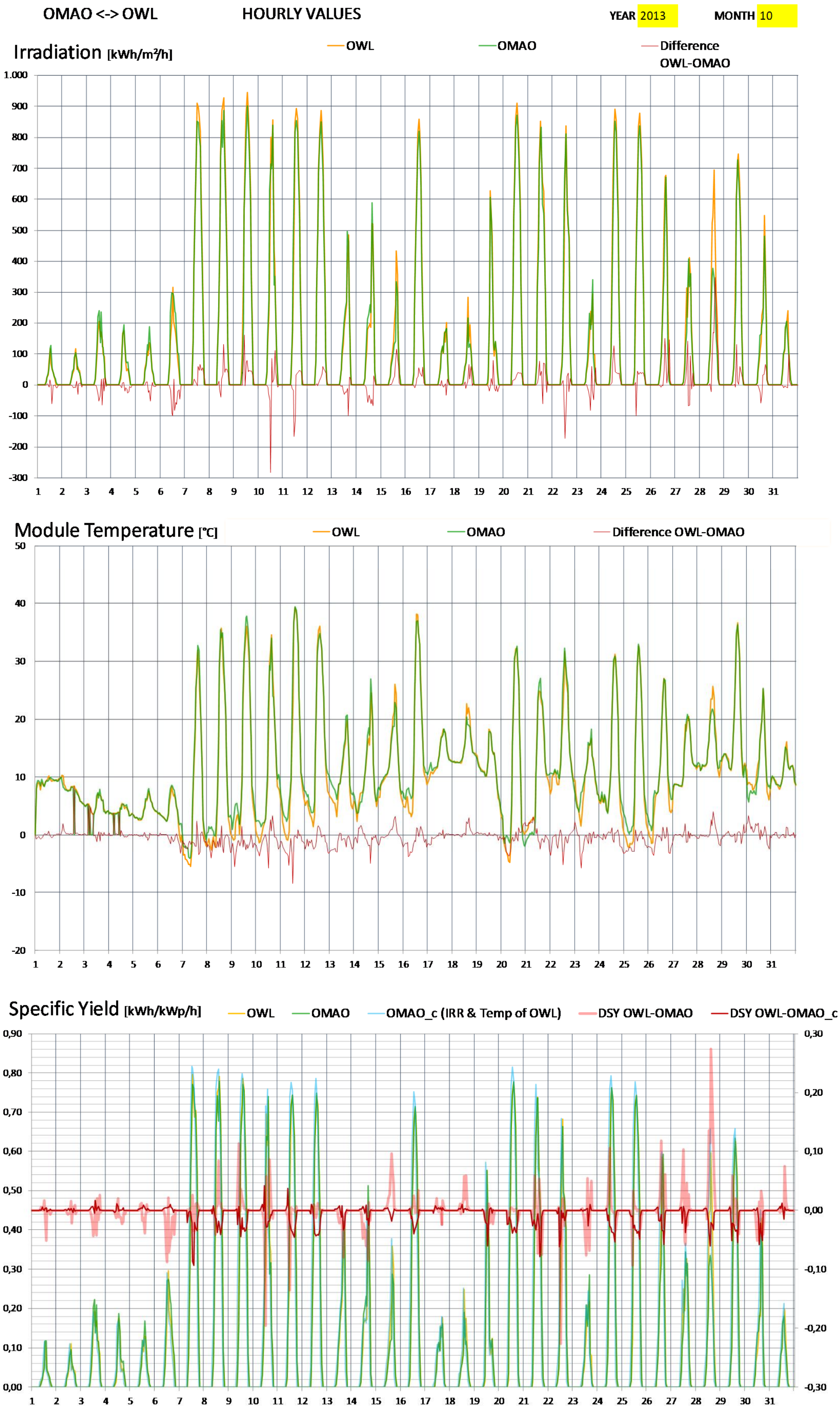

Figure 35:hourly irradiation, module temperature and yield 2013-10 (own chart, basic data SKYTRON)

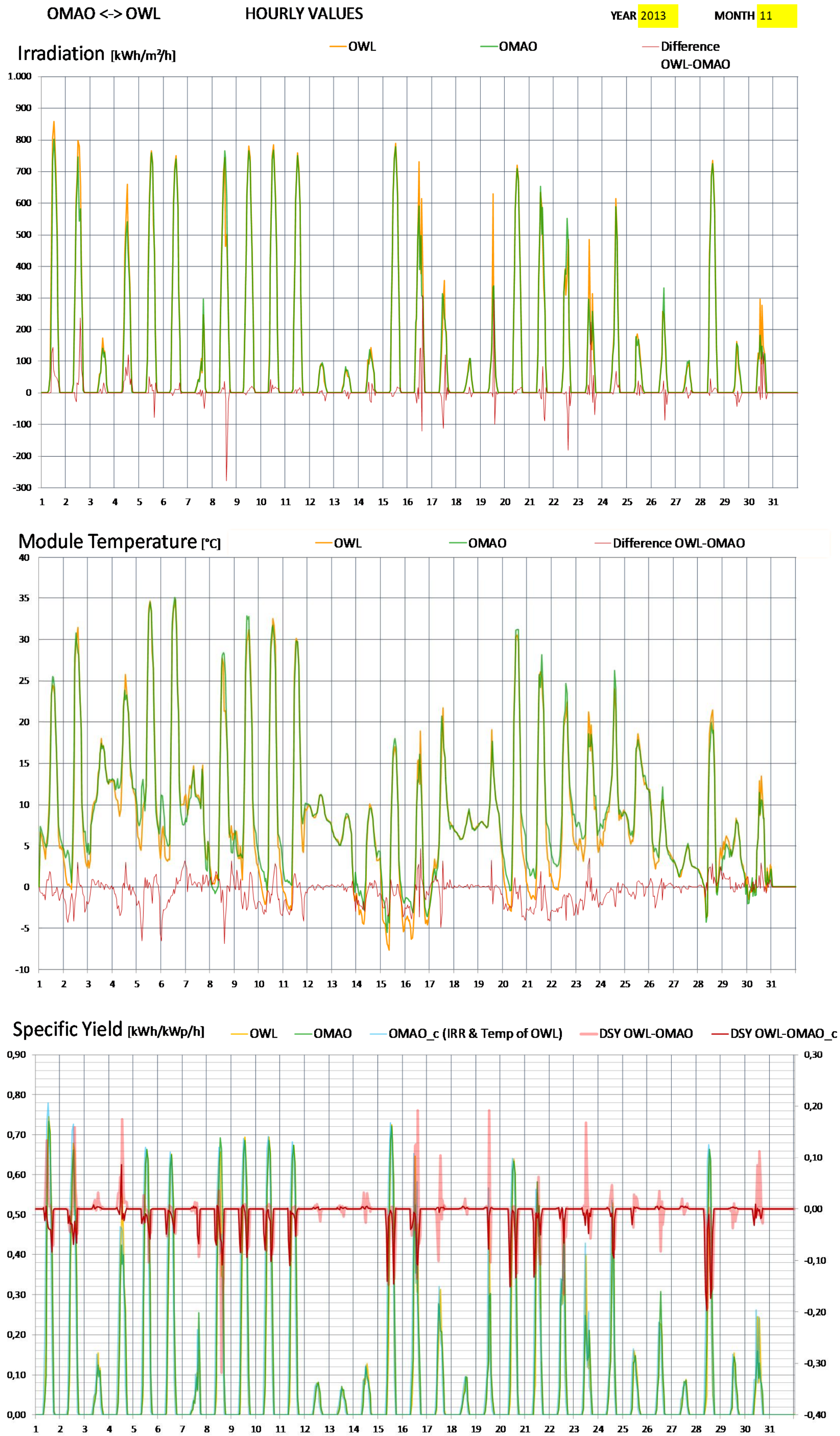

Figure 36:hourly irradiation, module temperature and yield 2013-11 (own chart, basic data SKYTRON)

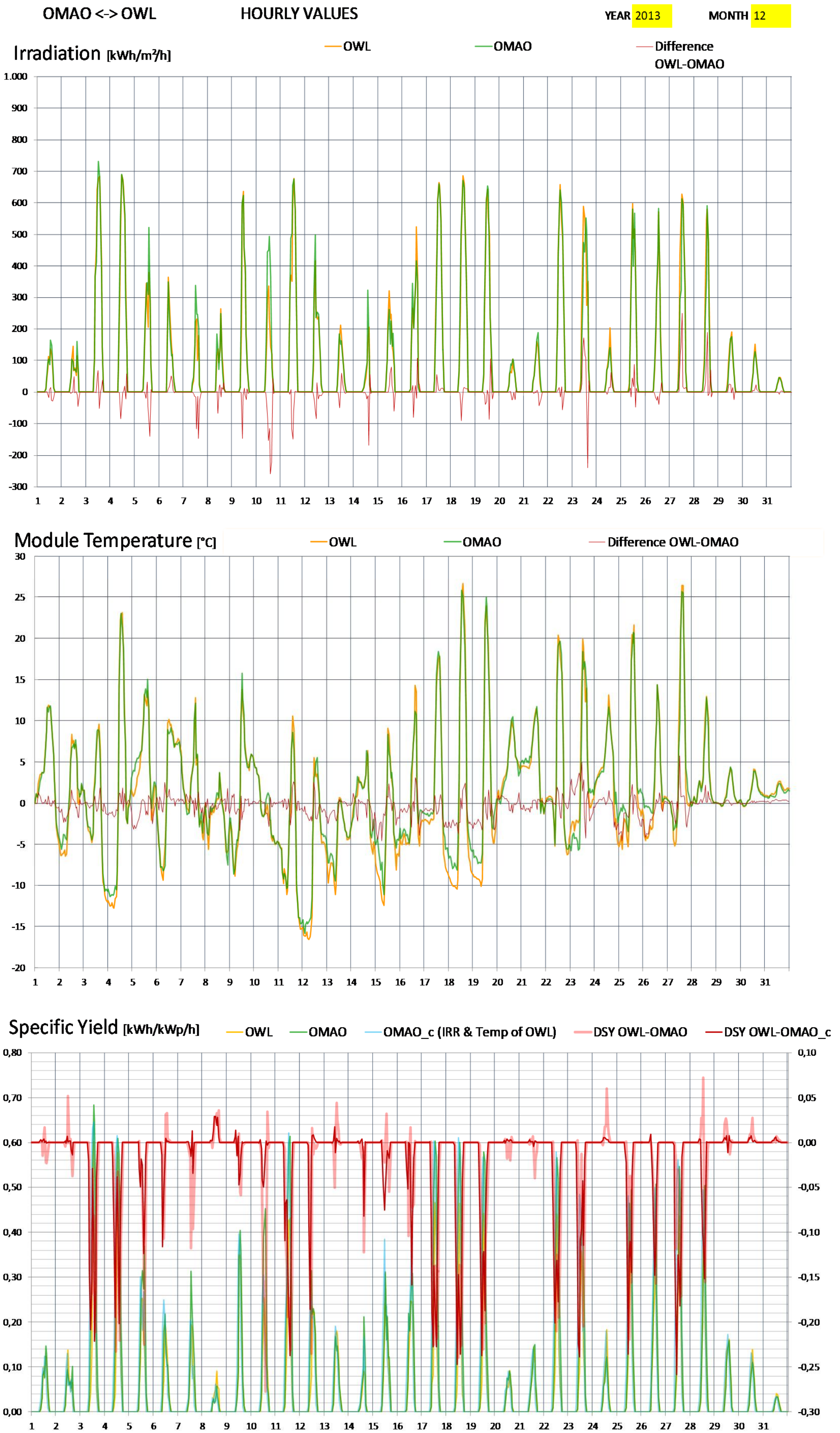

Figure 37:hourly irradiation, module temperature and yield 2013-12 (own chart, basic data SKYTRON)

ANNEX 4: Excel sheet ñPark_Comparisonò

Folder ñBasic Dataò

Table 26: Content of folder "Basic Data" in XLSX "Park_Comparison" (own table)

Column / Cell	Name	Content	Comment
		Basic Data from Monitoring System	Extracted from SKYTRON; This sheet contains the basic data used in all performance calculations. Values are extracted from monitoring system SKYTRON
A	CW	Calender Week	
B	Date	Date including hour of recorded timeframe	
C	Sequence	Sequential number of dataset	Used for shorter formulas in references
D	Year		
E	Month		
F	Day		
G	Hour		
H	Weeknum	Calender Week	Second row used for back reference
I	NrofDay	Day of the year	
J	OUL_Tmp	Average ambient Temperature in OUL [°C]	Data from Monitoring System SKYTRON
K	OMAO_Tmp	Average ambient Temperature in OMAO [°C]	Data from Monitoring System SKYTRON
L	OUL_IRR	Summary of hourly Irradiation OUL [kWh/m²/h]	Data from Monitoring System SKYTRON
M	OMAO_IRR	Summary of hourly Irradiation OMOA [kWh/m²/h]	Data from Monitoring System SKYTRON
N	Dirr	Difference of Irradiation between both parks	OUL-OMAO
O	OUL_Syield	Specific hourly yield in OUL[kWh/kW$_p$/h]	
P	OMAO_Syield	Specific hourly yield in OMAO[kWh/kW$_p$/h]	
Q	DSYield	Difference of Spec. Yield	OUL-OMAO

Folder ñParameterò

Table 27: Folder "Parameter" in XLSX "Park Comparison" (own table)

Column / Cell	Name	Content	Comment
B7:D9		GPS Coodinates of investigates parks	*GPS_lat* and *GPS_len* used in formulas for sunheight and azimut
B13:E15		Result of evaluation for max / min of sunheight	
B18:J27		Evaluation of max / min of sunheight	Maximum sunheight result of minumum row distance Minimum sunheight result of maximum row distance

Folder ñsunò

Table 28: Folder "sun" in XLSX "Park Comparison" (own table)

Column / Cell	Name	Content	Comment
			Formulas taken from **Alternative Energy Solutions GmbH** internal Library, verified with personal checks against monitoring data *Daylight_savings* simplified March 1st -October 30th
A	CW	Calender Week	
B	Date	Date including hour of recorded timeframe	
C	Sequence	Sequential number of dataset	
D	Year		
E	Month		
F	Day		
G	Hour		
H	CW		
I	NrofDay	Calender Week	Second row used for back reference
J	Dayofyear	Day of the year	
K	Declin	Declination	"=-23,45*COS(PI()*2*(Day_of_Year+10)/365)"
L	angle_h	angle_h used for evaluation of height_sun	"=15*((Hour)-(30-GPS_len)/15-12-daylight_savings +(-0,171*SIN(0,0337*Day_of_year+0,465) -0,1299*SIN(0,01787*Day_of_year-0,168)))"
M	height_sun	height of the sun at start of evaluated hour	"=ARCSIN(SIN(GPS_lat)*SIN(Deklin) +COS(GPS_lat)*COS(Deklin)*COS(angle_h))"
N	cos_azimut	Cosine of Azimut	"=(-(SIN(GPS_lat)*SIN(sun_height)-SIN(Declination))/ (COS(GPS_lat)*SIN(ARCCOS(SIN(sun_height)))))"
O	azimut	Azimut , Deviation from North-Orientation (180°=South)	
P	cos_sun_tilt	Cosine of angle between module plane and sun	Tilt of modules considered, Reference value, not needed for investigation direct
Q	low_cut	part of valid time before/after sunrise/sundown	0…no time near shadow effect possible, 1…whole hour near shadow effect possible
R	high_cut	part of valid time before/after no shadow of neighbor row	result considers already low_cut 0…no time near shadow effect possible, 1…whole hour near shadow effect possible
S	east_west_cut	part valid time when sun is after east of before west	result considers already high_cut Number gives final portion of hour where near shadow effect is possible 0…no time near shadow effect possible, 1…whole hour near shadow effect possible
T	No Effect 1	Part of hour before beginning of near shadow effect	1… 100% (not possible, value 1 only in "No Effect 2") 0….0% no near shadow effect starts in this hour
U	Effect	Part of hour with near shadow effect	0… 0% no near shadow effect in this hour 1…100% whole hour with near shaodw effect
V	No Effect 2	Part of hour after end of near shadow effect	0… 0% after near shadow effect, hour with at least starting near shadod effect 1… 100% after near shadow effect, hour with no near shadod effect

Folder ñAp_dataò

Table 29: Folder "Ap_data" in XLSX "Park Comparison" (own table)

Column / Cell	Name	Content	Comment
		Map of all hours of year with % of time with appearing near show effect in investigated location with given row distance and module arrangement	Taken for visualization in "Chart_Appearance"
A	Block	Block for data of stacked bar	Always 3 Blocks for 1 hour T...part of invalid time at start of related hour U...part of valid time of related hour (Yellow portion) V...part of invalid time at end of related hour Summary of T+U+V always 1,
B	Hour	Hour of Investigation	from (hour-1):01 to hour:00
C	Column	Column of block for investigated hour	T,U,V (see Column A)
D-ND	Day of Year	Values for Day of Year	in % of investigated hour

Folder ñChart_Appearanceò

Table 30: Folder "Chart_Appearance" in XLSX "Park Comparison" (own table)

Column / Cell	Name	Content	Comment
		Chart of all hours in the year where Near Shadowing Effect Appeas.	Yellow areas are areas of appearance, T,U,V Columns of folder "sun" are sorted in folder "Ap_data" in an order that a homogeniuos picture is presentable in EXCEL Chart.
X-Axis		Day of Year	
Y-Axis		Hour of Day	

Folder ñScope_Monthò

Table 31: Folder "Scope_Month" in XLSX "Park Comparison" (part 1 of 2) (own table)

Column / Cell	Name	Content	Comment
		Master sheet with evaluation of hourly values for whole month	Basic values are extracted from "Basic Data" compared with Values of "sun" correction of weather difference is done part of occurance for every hour is calculated values are taken in "Charts_Month_h" to visualize Values for "year" (Cell D1) and "month" (Cell D2) are taken from sheet "Charts_Month_h" in order to allow switching through the month to understand the distribution of the effect and to verify calculation steps.
D2	Month	Link to "Charts_Month_h"	for external input of key parameter
D3	Year	Link to "Charts_Month_h"	for external input of key parameter
D4	Sequence first	Index of first data set taken from "Basic_Data"	reference to row C (Sequence) in "Basic_data", Start is at first hour of month to be investigated in this sheet
D5	Sequence last	Index of last data set taken from "Basic_Data"	reference to row C (Sequence) in "Basic_data", end is at last hour of month to be investigated in this sheet
D6	Hours with Effect	Number of hour in investigated month	Summary of all hours where effect caused by local shadowing can occure. Each hour where effect can be valid, even only 1 min is counted as "hour touched". Value is taken for pre-filtering
I1:S6	Temp-Area	Temporarely values	used for verfication of results
A	Seqenz	Calender Week	
B	Day	Day of month	
C	Seq_basic	Sequential number of dataset	Reference to dataset of "Basic_Data"
D	Year	Year	
E	Month	Month	
F	Weeknum	Calender Week	Second row used for back reference
G	Hour	Hour	
H	NrofDay	Day of Year	
I	Module Temperature [°c] average of hour	OWL	Module Temperature of OWL, average of hour, taken from monitoring system
J		OMAO	Module Temperature of OMAO, average of hour, taken from monitoring system
K		Difference OWL-OMAO	Difference of the parks

Table 32: Folder "Scope_Month" of XLSX "Park Comparison"(part 2 of 2) (own table)

Column / Cell	Name	Content	Comment
L	Irradiation [kWh/m²] sum of hour	OWL	Irradiation of OWL, sum of hour, taken from monitoring system
M		OMAO	Irradiation of OMAO, sum of hour, taken from monitoring system
N		Difference OWL-OMAO	Difference of the parks
O	Specific Yield [kWh/kWp] sum of hour	OWL	Specific yield of OWL, sum of hour, from monitoring system
P		OMAO	Specific yield of OMAO, sum of hour, from monitoring system
Q		DSY OWL-OMAO	Difference of the parks
R	Spec.Yield OMAO Corrected to weather of OWL (Irradiation and Temperature) [kWh/kWp] sum of hour	OMAO_c (IRR & Temp of OWL)	Specific yield of OMAO, corrected to local weather of OWL, difference of irradiation and module temperature used for modification sum of hour
S		DSY OWL-OMAO_c	Difference of corrected OMAO to OWL
T	Location of sun at start of investigated hour	azimut [°]	Azimut of sun position
U		sun_height [°]	Height of sun
V		cos_sun_tilt	cos of sun height
W	Effect_valid	Flag if effect occurs in actual hour	0 … no near shadowing effect in hour 1 … near shadowing effect is possible
X	Filtering against borders Sun too high Sun too low Sun east-west out of relevant position	lowcut	Reduction of whole hour to part of hour with effect (1=100%) where sun is below level of possible effect
Y		highcut	Further reduction of "lowcut" to part of hour with effect (1=100%) where sun is above level of possible effect
Z		east / west cut	Further reduction of "highcut" to part of hour with effect (1=100%) where sun is east/west out of relevant position
AA		Max possible direct irradiation [kWh/m²]	Taken from "Sun" as reference for valid monitoring data
AB		effected max direct irradiation [kWh/m2]	max effected direct irradiation, part of effect evaluated based on "east/west cut " and max. possible direct irradiation
AC		effected irradiation [kWh/m²]	effected irradiation, taken from OWL, part of effected taken from "east/west cut"
AD		effected yield [kWh/kW_p]	effected yield, taken from OWL, part of effected taken from "east/west cut"
AE		effect on corrected specific yield [kWh/kW_p]	Effect of different cabling + filtered on any differences of frames where effect cannot be the reason of the difference because sun is in position where effect does not appear. + before comparison OMAO was corrected to weather of OWL (Irradiation and module temperature)

Folder ñCharts_Month_h

Table 33: Folder "Charts_Month_h" in XLSX "Park Comparison" (own table)

Column / Cell	Name	Content	Comment
		Line Charts for every hour of + Irradiation + Module temperature + Specific Yield	Comparison of parks at weather charts Difference of Spec.yield of both parks, with and without weather correction + X-axis ….. Hour of month with grid raster at every 0h + Y-axis ….. Investigated values of both parks and difference, at yield including considered weather correction
Q1	Year	Year of investigation	Trigger for data table in "Scope_Month"
S1	Month	Month where parks and differences should be shown.	Trigger for data table in "Scope_Month"

Folder ñScope_Weekò

Table 34: Folder "Scope_Week" in XLSX "Park Comparison" (part 1 of 2) (own table)

Column / Cell	Name	Content	Comment
		Master sheet with evaluation of hourly values for whole month	Basic values are extracted from "Basic Data" compared with Values of "sun" correction of weather difference is done part of occurance for every hour is calculated values are taken in "Charts_Week_h" to visualize Values for "year" (Cell D1) and "month" (Cell D2) are taken from sheet "Charts_Week_h" in order to allow switching through the month to understand the distribution of the effect and to verify calculation steps.
D2	Month	Link to "Charts_Week_h"	for external input of key parameter
D3	Year	Link to "Charts_Week_h"	for external input of key parameter
D4	Sequence first	Index of first data set taken from "Basic_Data"	reference to row C (Sequence) in "Basic_data", Start is at first hour of calendar week to be investigated in this sheet
D5	Sequence last	Index of last data set taken from "Basic_Data"	reference to row C (Sequence) in "Basic_data", end is at last hour of calender week to be investigated in this sheet
D6	Hours with Effect	Number of hour in investigated month	Summary of all hours where effect caused by local shadowing can occure. Each hour where effect can be valid, even only 1 min is counted as "hour touched". Value is taken for pre-filtering
I1:S6	Temp-Area	Temporarely values	used for verfication of results
A	Seqenz	Calender Week	
B	Day	Day of month	
C	Seq_basic	Sequential number of dataset	Reference to dataset of "Basic_Data"
D	Year	Year	
E	Month	Month	
F	Weeknum	Calender Week	Second row used for back reference
G	Hour	Hour	
H	NrofDay	Day of Year	
I	Module Temperature [°c] average of hour	OWL	Module Temperature of OWL, average of hour, taken from monitoring system
J		OMAO	Module Temperature of OMAO, average of hour, taken from monitoring system
K		Difference OWL-OMAO	Difference of the parks

Table 35: Folder "Scope_Week" in XLSX "Park Comparison"(part 2 of 2) (own table)

Column / Cell	Name	Content	Comment
L	Irradiation [kWh/m²] sum of hour	OWL	Irradiation of OWL, sum of hour, from monitoring system
M		OMAO	Irradiation of OMAO, sum of hour, from monitoring system
N		Difference OWL-OMAO	Difference of the parks
O	Specific Yield [kWh/kWp] sum of hour	OWL	Specific yield of OWL, sum of hour, from monitoring system
P		OMAO	Specific yield of OMAO, sum of hour, from monitoring system
Q		DSY OWL-OMAO	Difference of the parks
R	Spec.Yield OMAO Corrected to weather of OWL (Irradiation and Temperature) [kWh/kWp] sum of hour	OMAO_c (IRR & Temp of OWL)	Specific yield of OMAO, corrected to local weather of OWL, difference of irradiation and module temperature used for modification sum of hour
S		DSY OWL-OMAO_c	Difference of corrected OMAO to OWL
T	Location of sun at start of investigated hour	azimut [°]	Azimut of sun position
U		sun_height [°]	Height of sun
V		cos_sun_tilt	cos of sun height
W	Effect_valid	Flag if effect occurs in actual hour	0 … no near shadowing effect in hour 1 … near shadowing effect is possible
X	Filtering against borders Sun too high Sun too low Sun east-west out of relevant position	lowcut	Reduction of whole hour to part of hour with effect (1=100%) where sun is below level of possible effect
Y		highcut	Further reduction of "lowcut" to part of hour with effect (1=100%) where sun is above level of possible effect
Z		east / west cut	Further reduction of "highcut" part of hour to part of hour with effect (1=100%) where sun is east or west out of relevant position
AA		Max possible direct irradiation [kWh/m²]	Taken from "Sun" as reference for valid monitoring data
AB		effected max direct irradiation [kWh/m2]	max effected max direct irradiation, part of effect evaluated based on "east/west cut " and max. possible direct irradiation
AC		effected irradiation [kWh/m²]	effected irradiation, taken from OWL, part of effected taken from "east/west cut"
AD		effected yield [kWh/kW_p]	effected yield, taken from OWL, part of effected taken from "east/west cut"
AE		effect on corrected specific yield [kWh/kW_p]	Effect of different cabling + filtered on any differences of frames where effect cannot be the reason of the difference because sun is in position where effect does not appear. + before comparison OMAO was corrected to weather of OWL (Irradiation and module temperature)

Folder ñCharts_Week_hò

Table 36: Folder "Charts_Week_h" in XLSX "Park Comparison" (own table)

Column / Cell	Name	Content	Comment
		Line Charts for every hour of + Irradiation + Module temperature + Specific Yield	Comparison of parks with weather charts, difference of specific yield of both parks, including weather correction + X-axis ….. Hour of month with grid raster at every 0h + Y-axis ….. Investigated values of both parks and difference, at yield including weather correction. Resolution "week" useful for better understanding of effect appearence.
Q1	Year	Year of investigation	Trigger for data table in "Scope_Week"
S1	Calendar week	Calendar week where parks and differences should be shown.	Trigger for data table in "Scope_Week"

Folder ñScope_Yearò

Table 37: Folder "Scope_Year" in XLSX "Park_Comparison"(part 1 of 2) (own table)

Column / Cell	Name	Content	Comment
		Master sheet with evaluation of hourly values for whole year	Basic values are extracted from "Basic Data" compared with Values of "sun" correction of weather difference is done part of occurance for every hour is calculated. values are taken in "Sum_Year_M" to visualize
C1	Year	User input for "year"	
D2	Sequence first	Index of first data set taken from "Basic_Data"	reference to row C (Sequence) in "Basic_data", Start is at first hour of calendar week to be investigated
D3	Sequence last	Index of last data set taken from "Basic_Data"	reference to row C (Sequence) in "Basic_data", end is at last hour of calender week to be investigated
A	Seqenz	hour of investigation since start of year	
B	Day	Day of month	
C	Seq_basic	Sequential number of dataset	Reference to dataset of "Basic_Data"
D	Year	Year	
E	Month	Month	
F	Weeknum	Calender Week	Second row used for back reference
G	Hour	Hour	
H	NrofDay	Day of Year	
I	Module Temperature [°c] average of hour	OWL	Module Temperature of OWL, average of hour, taken from monitoring system
J		OMAO	Module Temperature of OMAO, average of hour, from monitoring system
K		Difference OWL-OMAO	Difference of the parks
L	Irradiation [kWh/m²] sum of hour	OWL	Irradiation of OWL, sum of hour, from monitoring system
M		OMAO	Irradiation of OMAO, sum of hour, from monitoring system
N		Difference OWL-OMAO	Difference of the parks
O	Specific Yield [kWh/kWp] sum of hour	OWL	Specific yield of OWL, sum of hour, from monitoring system
P		OMAO	Specific yield of OMAO, sum of hour, from monitoring system
Q		DSY OWL-OMAO	Difference of the parks

Table 38: Folder "Scope_Year" in XLSX "Park Comparison"(part 2 of 2) (own table)

Column / Cell	Name	Content	Comment
R	Spec.Yield OMAO corr. To weather of OWL (Irr./Temp.) [kWh/kWp] sum of hour	OMAO_c (IRR & Temp of OWL)	Specific yield of OMAO, corrected to local weather of OWL, difference of irradiation and module temperature used for modification sum of hour
S		DSY OWL-OMAO_c	Difference of corrected OMAO to OWL
T	Location of sun at start of investigated hour	azimut [°]	Azimut of sun position
U		sun_height [°]	Height of sun
V		cos_sun_tilt	cos of sun height
W	Effect_valid	Flag if effect occurs in actual hour	0 … no near shadowing effect in hour 1 … near shadowing effect is possible
X	Filtering against borders Sun too high Sun too low Sun east-west out of relevant position	lowcut	Reduction of whole hour to part of hour with effect (1=100%) where sun is below level of possible effect
Y		highcut	Further reduction of "lowcut" part of hour to part of hour with effect (1=100%) where sun is above level of possible effect
Z		east / west cut	Further reduction of "highcut" part of hour to part of hour with effect (1=100%) where sun is east or west out of relevant position
AA		Max possible direct irradiation on clear sky [kWh/m²]	Taken from "Sun" as reference for valid monitoring data
AB		effected max direct irradiation [kWh/m2]	max effected max direct irradiation, part of effect evaluated based on "east/west cut " and max. possible direct irradiation on clear sky
AC		effected irradiation [kWh/m²]	effected irradiation, taken from OWL, part of effected taken from "east/west cut"
AD		effected yield [kWh/kW_p]	effected yield, taken from OWL, part of effected taken from "east/west cut"
AE		effect on corrected specific yield [kWh/kW_p]	Effect of different cabling + filtered on any differences of frames where effect cannot be the reason of the difference because sun is in position where effect does not appear. + before comparison OMAO was corrected to weather of OWL (Irradiation and module temperature)

Folder ñSum_Year_Dò

Table 39: Folder "Sum_Year_D" in XLSX "Park Comparison" (own table)

Column / Cell	Name	Content	Comment
		Summarised effect of year + Irradiation + Module temperature + Specific Yield Collection of parts in valid time frames	Summary of each value for 1 day per line Pre-compression of hourly values to daily Summary and average taken from "Scope_Year"
A	NrofDay	NrofDay	
B	Day	Day	
C	Year	Year	
D	Month	Month	
E	Weeknum	Weeknum	
F	NrofDay	NrofDay	
G	Module Temperature [°c] average of hour	OWL	Module Temperature of OWL, average of hour, from monitoring system
H		OMAO	Module Temperature of OMAO, average of hour, from monitoring system
I		Difference OWL-OMAO	Difference of the parks
J	Irradiation [kWh/m²] sum of hour	OWL	Irradiation of OWL, sum of hour, from monitoring system
K		OMAO	Irradiation of OMAO, sum of hour, from monitoring system
L		Difference OWL-OMAO	Difference of the parks
M	Specific Yield [kWh/kWp] sum of hour	OWL	Specific yield of OWL, sum of hour, from monitoring system
N		OMAO	Specific yield of OMAO, sum of hour, from monitoring system
O		DSY OWL-OMAO	Difference of the parks
P	Spec.Yield OMAO corr. to weather of OWL (Irr./Temp.) [kWh/kWp] sum of hour	OMAO_c (IRR & Temp of OWL)	Specific yield of OMAO, corrected to local weather of OWL, difference of irradiation and module temperature used for modification sum of hour
Q		DSY OWL-OMAO_c	Difference of corrected OMAO to OWL
R	on valid time frames	OWL Syield	Specific yield of OWL, part in time frame valid for possible effect
S		Omao Yield CIRR	Specific yield of OMAO, weather correction to weather of OWL, part in time frame valid for possible effect
T		DSY OWL-OMAO_c	Effect of different cabling + filtered on any differences of frames where effect cannot be the reason of the difference because sun is in position where effect does not appear. + before comparison OMAO was corrected to weather of OWL (Irradiation and module temperature)

Folder ñSum_Year_Mò

Table 40: Folder "Sum_Year_M" of XLSX "Park Comparison" (part 1 of 2) (own table)

Column / Cell	Name	Content	Comment
		Sumarized effect of year 1 line for every day + Irradiation + Module temperature + Specific Yield Collection of parts in valid time frames	Summary of each value for 1 month per line Pre-compression of daily values to monthly Summary and Average taken from "Scope_Year"
A	Nr. of Month	Month	
B	Year	Year	
C	Nr_of_days	N° of days per month	
D	Module Temperature [°c] average of hour	OWL	Module Temperature of OWL, average of hour, from monitoring system
E		OMAO	Module Temperature of OMAO, average of hour, from monitoring system
F		Difference OWL-OMAO	Difference of the parks
G	Irradiation [kWh/m²] sum of hour	OWL	Irradiation of OWL, sum of hour, from monitoring system
H		OMAO	Irradiation of OMAO, sum of hour, from monitoring system
I		Difference OWL-OMAO	Difference of the parks
J	Specific Yield [kWh/kWp] sum of hour	OWL	Specific yield of OWL, sum of hour, from monitoring system
K		OMAO	Specific yield of OMAO, sum of hour, from monitoring system
L		DSY OWL-OMAO	Difference of the parks
M	Spec.Yield OMAO corr. to weather of OWL (Irr./Temp.) [kWh/kWp] sum of hour	OMAO_c (IRR & Temp of OWL)	Specific yield of OMAO, corrected to local weather of OWL, difference of irradiation and module temperature used for modification sum of hour
N		DSY OWL-OMAO_c	Difference of corrected OMAO to OWL

Table 41: Folder "Sum_Year_M" of XLSX "Park Comparison"(part 2 of 2) (own table)

Column / Cell	Name	Content	Comment
O	**on valid time frames**	OWL Syield	Specific yield of OWL, part in time frame valid for possible effect
P		Omao Yield CIRR	Specific yield of OMAO, weather correction to weather of OWL, part in time frame valid for possible effect
Q		DSY OWL-OMAO_c	Effect of different cabling + filtered on any differences of frames where effect cannot be the reason of the difference because sun is in position where effect does not appear. + before comparison OMAO was corrected to weather of OWL (Irradiation and module temperature)
R	**on valid time frames**	OWL Syield	% of month during valid timeframes in relation to monthly yield OWL (=O/J)
S		Omao Yield CIRR	% of month during valid timeframes in relation to monthly yield OWL (=P/J)
T		DSY OWL-OMAO_c	% of month during valid timeframes in relation to monthly yield OWL (=Q/J)

ANNEX 5: Excel Sheet ñCalculationsò

Folder ñResult Overviewò

Table 42: Folder "Result Overview" in XLSX "Calculations" (own table)

Column / Cell	Name	Content	Comment
		Final results of Master Thesis	Collection of other results to final result
B2:G25	Final Overview	Comparison of both parks	Evaluation of differences after the 4 ADJUSTMENT steps in [kWh/kWp] and in [%] of OWL
F25	specific yield 2013 benefit of = cabling	result in [kWh/kW$_p$/a]	
G25	specific yield 2013 benefit of = cabling	result in [%]	
B29:D34	possible benefit in OWL on change of cabling	estimation of possible benefit in OWL if change of cabling would happen	based on 2013 values
D34	benefit OWL in [kWh]		based on 2013 values

Folder ñshort tablesò

Table 43: Folder "short tables" in XLSX "Calculations" (own table)

Column / Cell	Name	Content	Comment
		Various short tables	collected just for better layout in Thesis
B2:C11	Estimation of 1% enhancement	Estimation of 1% enhancement in a hypothetic medium size portfolio	250MWp, 1 300kWh/kWp, 0.30€/kWh Feedin Tariff 1% enhancement --> ~ € 1 Mio
C15:G27	Estimation of losses of extra cables	Losses estimation based on OMAO Maximum losses Assumption: all time maximum current 8.5A	Calculation based on 1MW String Current 8.5A at nominal power of used modules cable cross section like standard in both parks 4mm²

Folder ñCorrection costsò

Table 44: Folder "Correction costs" in XLSX "Calculations" (own table)

Column / Cell	Name	Content	Comment
		Estimation of cost for correcting cabling in OWL	prices from dispatch center of GreenTec Energy Odessa, Ukraine, personal Interview with Alexandr Chayka Costs evaluated for 1MWp. Return on Invest estimated evaluated related to feedin-tarif.
A3:C7	Cable lenght	Evaluation of additional needed cable lenght for $1MW_p$	Extra cable lenght 23 m/string 22 m distance 2 m for connection of upper row every 2nd string
A12:D18	Costs	of 1 MW_p change of cables in Eastern Europe	
A22:H32	Table for ROI	with respect of Feedin Tarrif	
A25:	Chart for ROI	chart for table F22:H32	

Folder ñEAST_WEST_chkò

Table 45: Folder "EAST_WEST_chk" in XLSX "Calculations" (own table)

Column / Cell	Name	Content	Comment
		Check of time difference between parks	to estimate if different east/west location need additional time correction
B2:3	East location of parks	GPS values	
B4	Difference	East-West difference in ° of parks	
B7	Duration	Time difference for same sun angle	18.33 sec ~ 1/3min, ~ 1/180h 0.50% timeshift effect max possible effect on irradiation at cos(+/-90°) … near sunrise and sundown --> no relevant effect

Folder ñDistributionò

Table 46: Folder "Distribution" in XLSX "Calculations" (own table)

Column / Cell	Name	Content	Comment
		Charts and tables for distribution of effect	Monthly values taken for charts. Distribution is relevant to decide best time of the year to start correction work. Correction should be ready short time before highest benefit of correction
A4:T14	Table of monthly results	copy of values from "Sum_Year_M"	In XLSX "Park Comparison"
C21:G34	table for chart on yield distribution	Yield with no Effect Effected Yield Benefit Total Yield	specific values per MWp
C35:	Chart for distribution of yield and benefits	Values taken from C21:G34	
C66:F78	table for chart on yield distribution in %	Effected Yield Benefit Total Yield	
C82:-->	Chart for distribution of yield and benefits in % of whole year	Values taken from C66:F78	