# Evaluating the Impact of PV Module Orientation on Grid Operation

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# AGENDA

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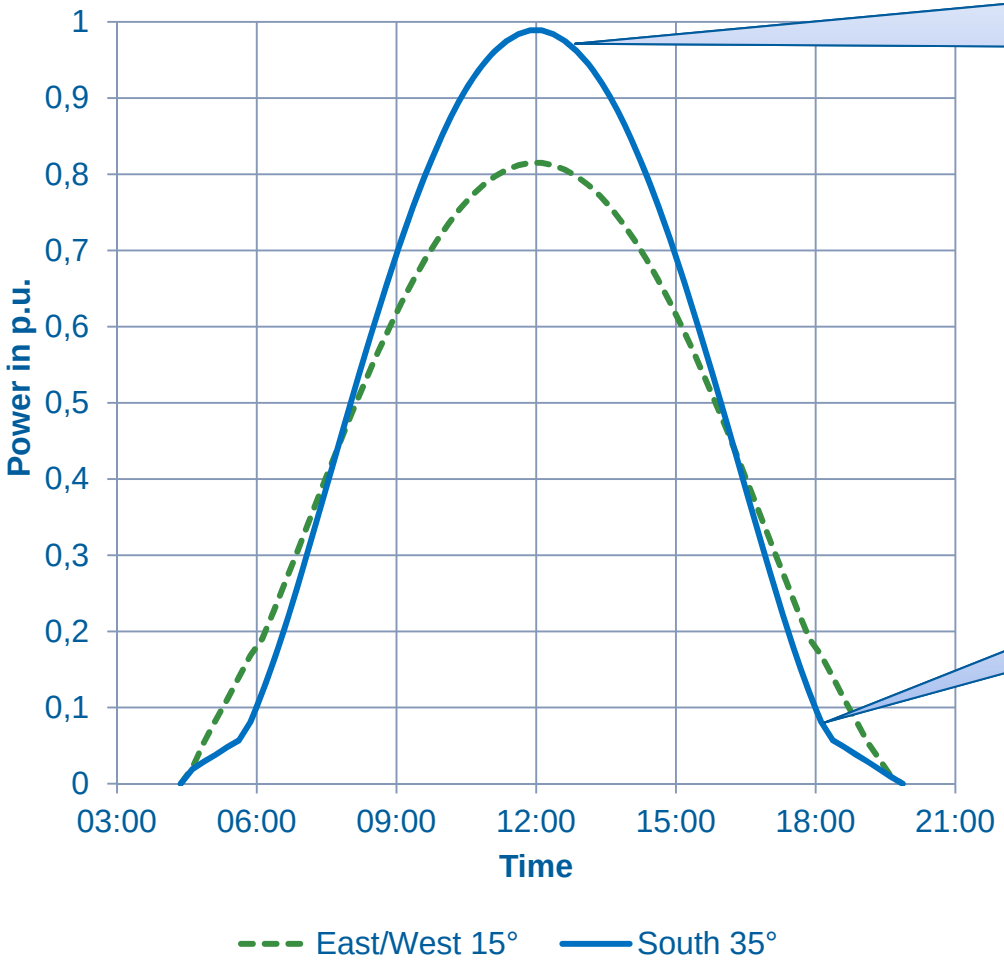
**Motivation**
**Key Characteristics**
**PV Systems**
**Results**

- Capacity Factor
- Peak power
- Power gradients
- Yield per surface area
- Correlation of production and consumption

**Summary and Conclusions**

# MOTIVATION




High peak power
➔ Overloading and voltage issues

**Solutions:**

- **Curtailment?**
- **Storage?**
- **PV orientation?**

High ramp rates

# IDENTIFIED KEY CHARACTERISTICS TO BE INVESTIGATED

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- Capacity factor (yield)
- Peak power
- Power gradients
- Yield per surface area
- Correlation of production and consumption

# PV SYSTEMS SETUPS

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**Modeled for the city of Aachen (Germany)**

| PV System No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Orientation | South | | East/West | | | | Tracking |
| Inclination | 35° | 90° | 0° | 15° | 35° | 90° | Tracking |

**1. Reference system (first choice when installing new PV modules)**

**2. Façade installation orientated to the south**

**3. Horizontal system**

Normally not installed - tend to lose their performance due to dirt.

**4. and 5. East/west configuration with different inclination angles (Half of the installed system faces east while the other half faces west)**

**6. Façade system orientated east/west**

**7. Tracking system (Indicates the maximum possible energy yield)**

# IRRADIATION DATA

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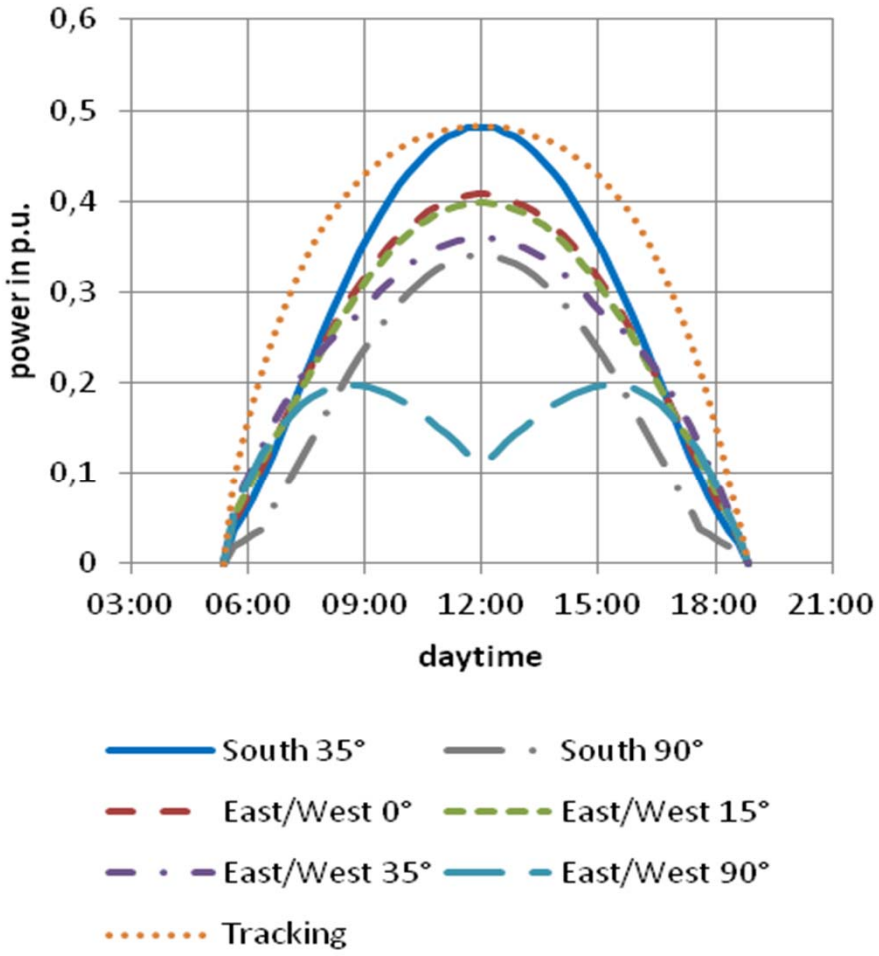
**Data source: Photovoltaic Geographical Information System (PVGIS)**

**Ramp rates and peak power**

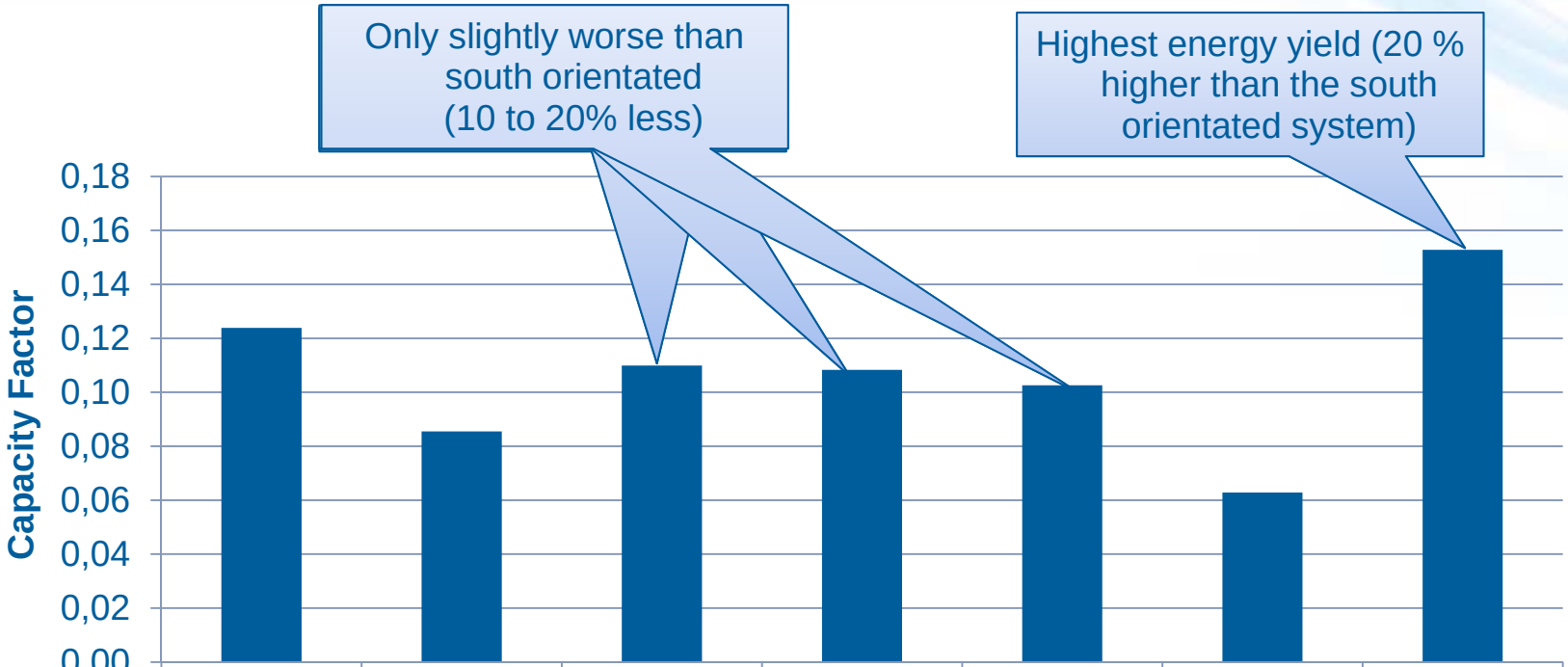
- Clear-sky irradiation

**Energy output**

- evaluation of the average irradiation

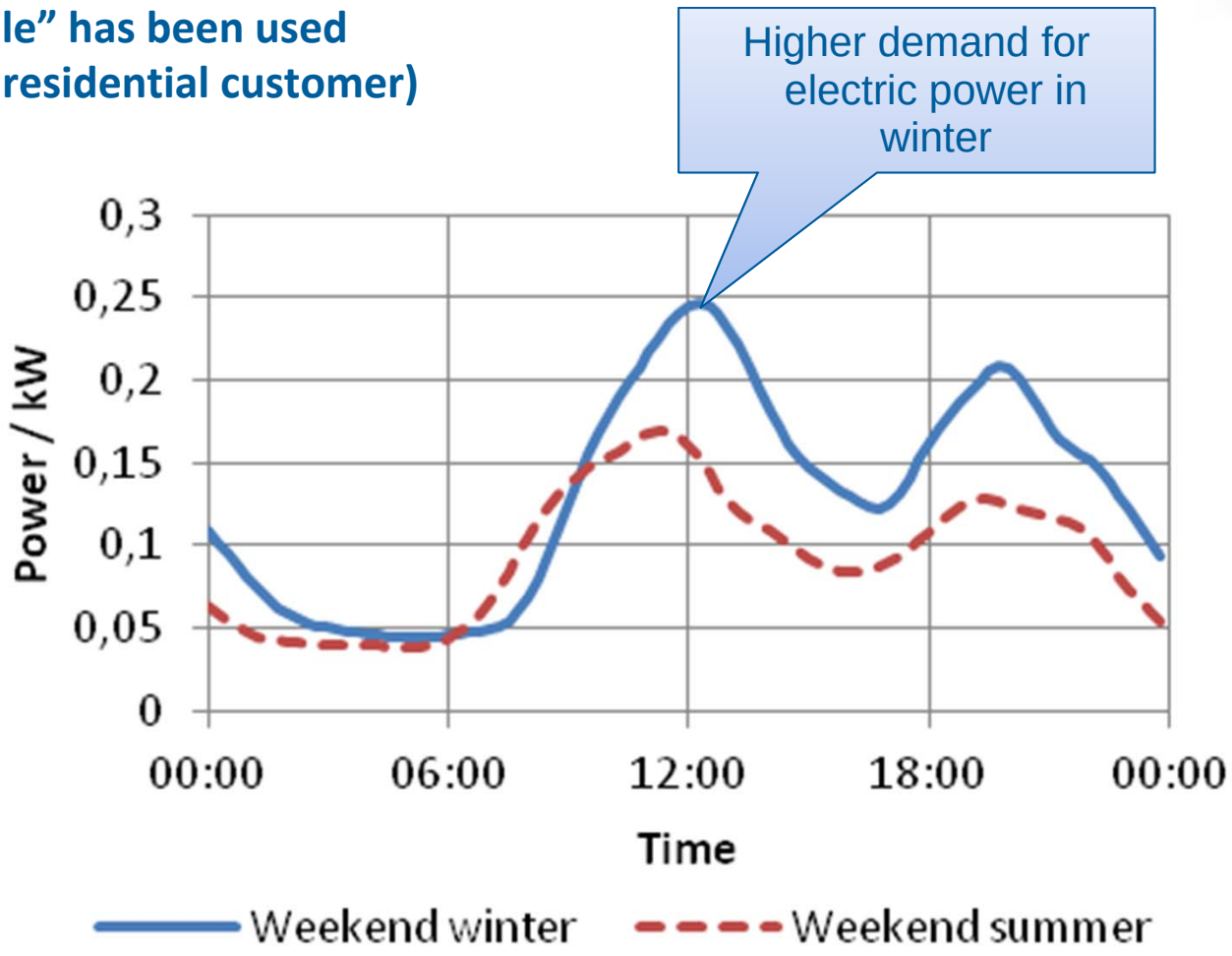


# RESULTS: CAPACITY FACTOR

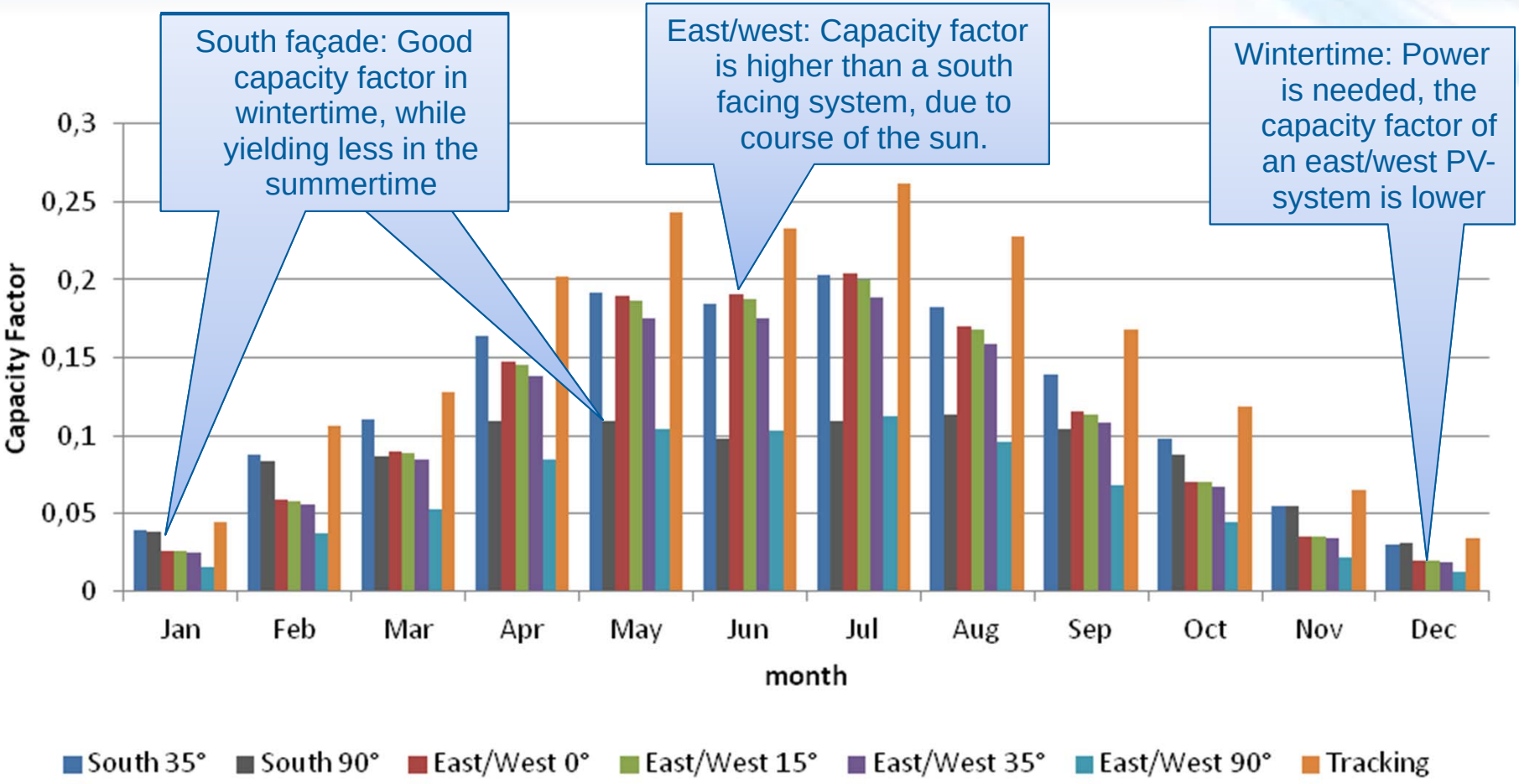


# LOAD PROFILE

**“H0-Profile” has been used (German residential customer)**



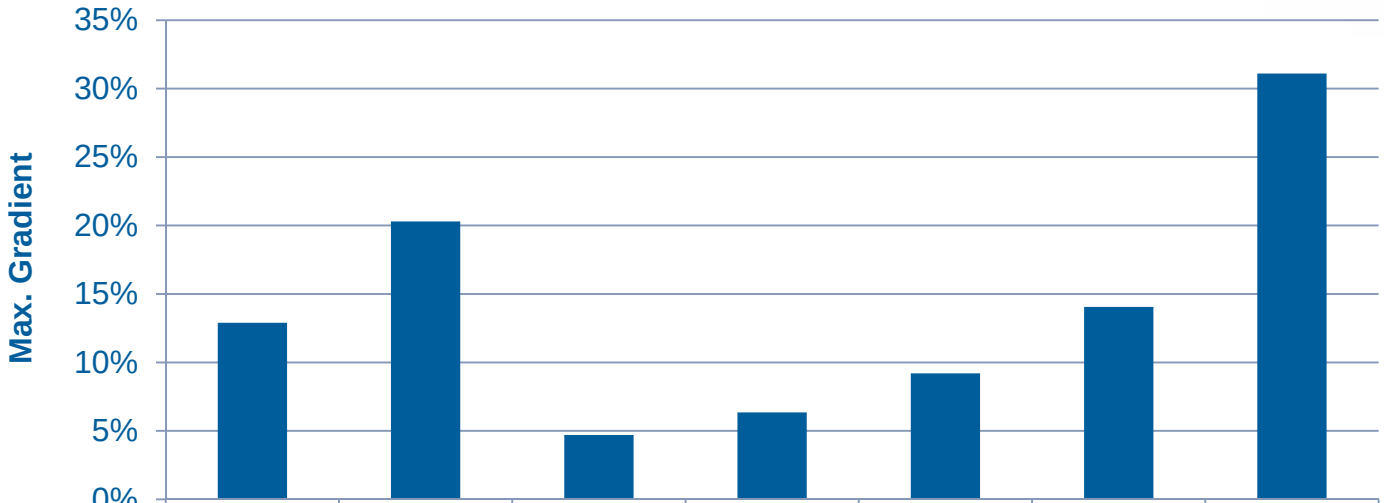
# RESULTS: CAPACITY FACTOR




➔ **The east/west orientated system is inferior to the south oriented systems.**

# RESULTS: POWER GRADIENT

- **Priority dispatch of PV in Germany ➔ Other power plants need to follow the gradients**
- **Critical event: evening hours, when the sun sets and consumption grows**
- **Maximum gradients within 15 minutes (based on the clear-sky irradiation)**




| | South 35° | South 90° | East/West 0° | East/West 15° | East/West 35° | East/West 90° | Track ing |
|---|---|---|---|---|---|---|---|
| Gradient | 12,9% | 20,3% | 4,7% | 6,4% | 9,2% | 14,1% | 31,1% |

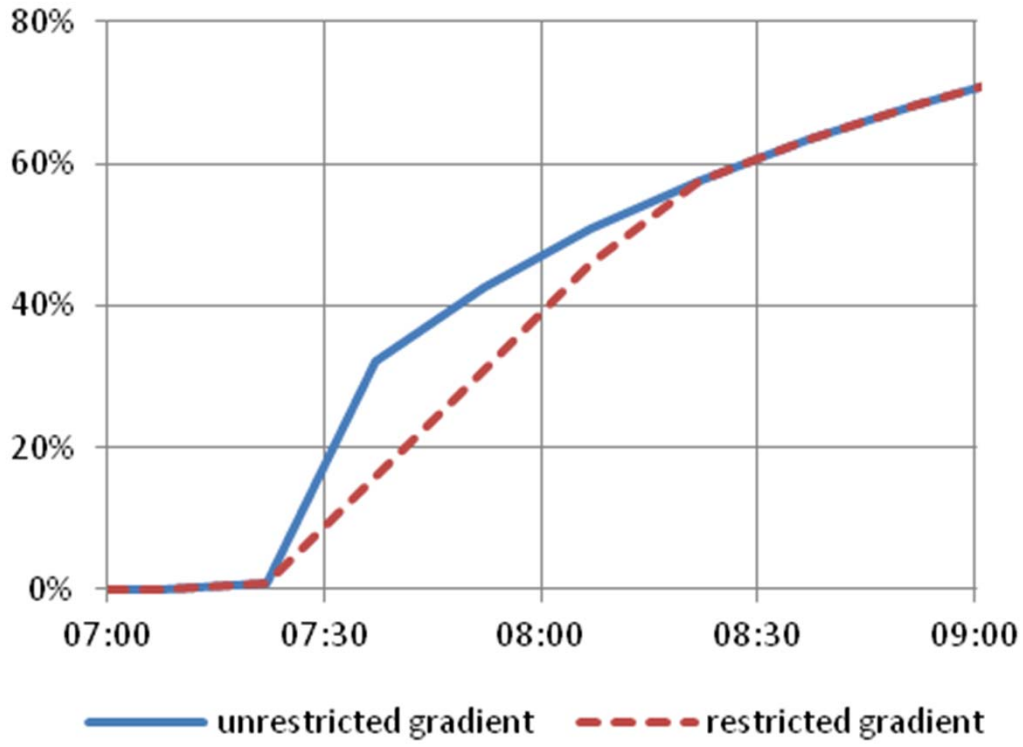
Individual ramp rates can be much higher! (e.g. cloud passing through) = stochastic nature with low correlation between wide area distributed PV systems (smoothing effect)

➔ **East/west systems are advantageous…**

# RESULTS: POWER GRADIENT

… however this is only true for unrestricted operation.

➔ In case gradients do really produce a grid operational problem, the gradients of the PV system can be limited (will also lead to reduction in yield!)

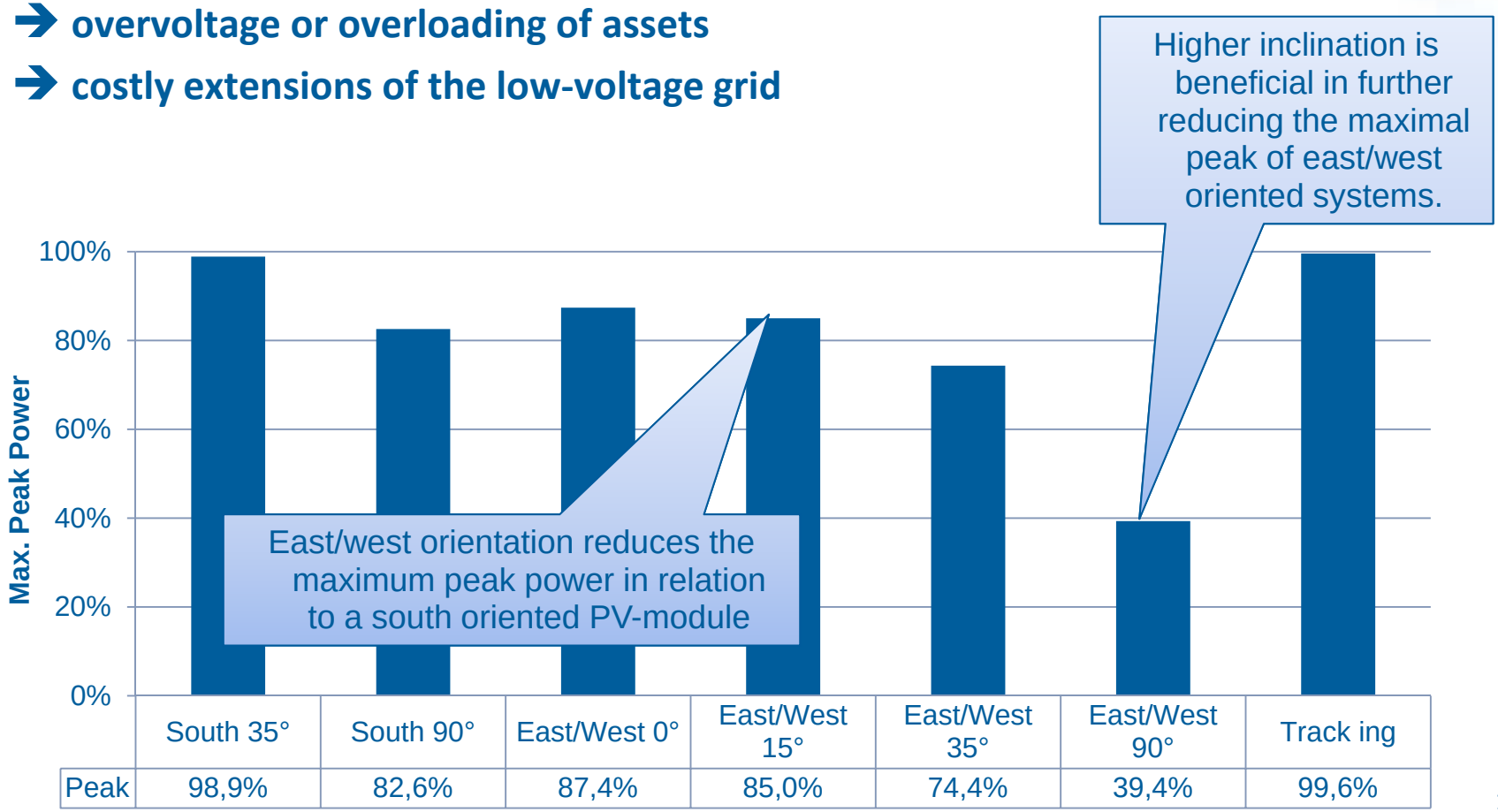


# RESULTS: PEAK POWER

**Low-voltage grid: The maximum peak power determines the voltage at the connection point and loading of transformer and cables.**

➔ **overvoltage or overloading of assets**

➔ **costly extensions of the low-voltage grid**



# RESULTS: PEAK POWER REDUCTION AND REDUCED YIELD COMPARED TO SOUTH SYSTEM

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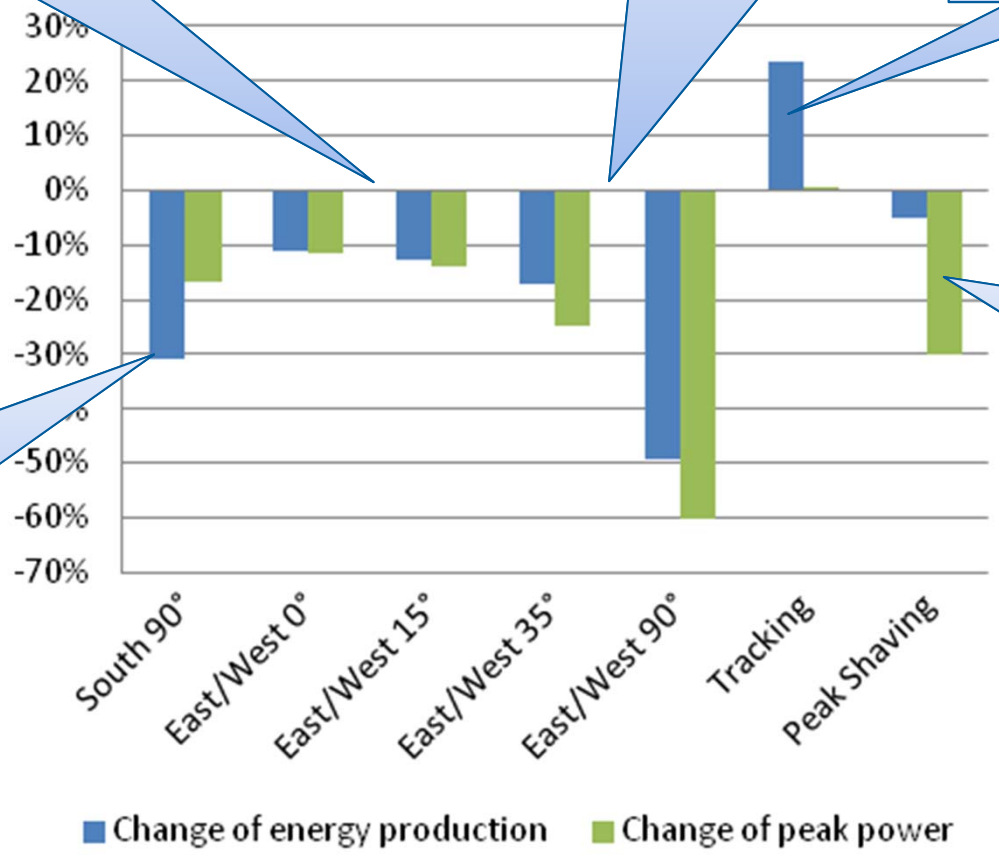
Low inclination: reduction of peak power and yield is almost equal

High inclination: individual peaks are pulled apart ➔ reduction in peak power is higher than reduction of yield

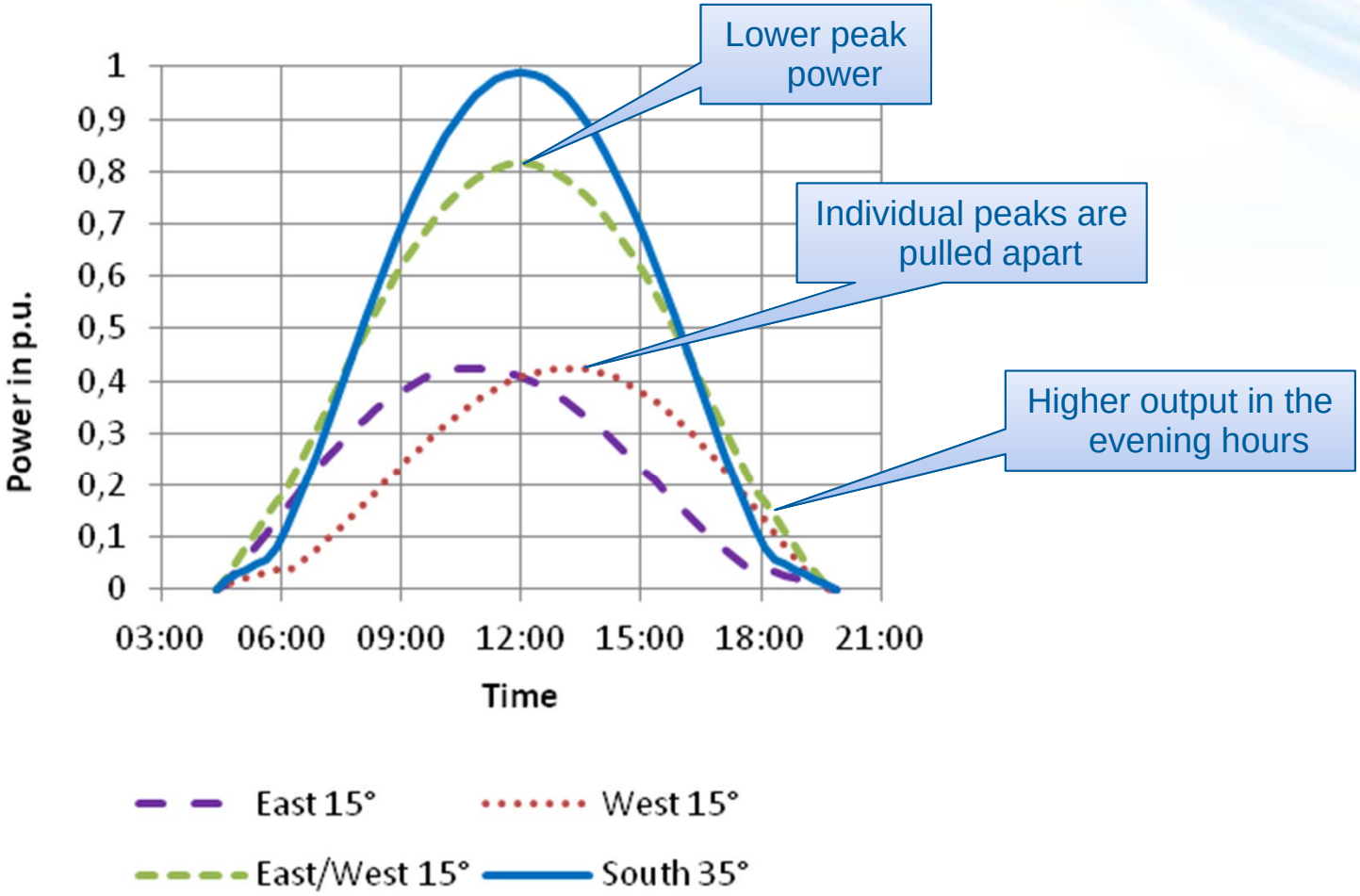
Highest yield without increase of peak power.

Very unfavorable: yield is reduced twice as high as the peak reduction

Significant reduction of peak power combined with low reduction in yield.



# RESULTS: PEAK POWER REDUCTION
# EXAMPLE: EAST/WEST VS. SOUTH



# RESULTS: YIELDS PER SURFACE AREA COMPARED TO SOUTH SYSTEM

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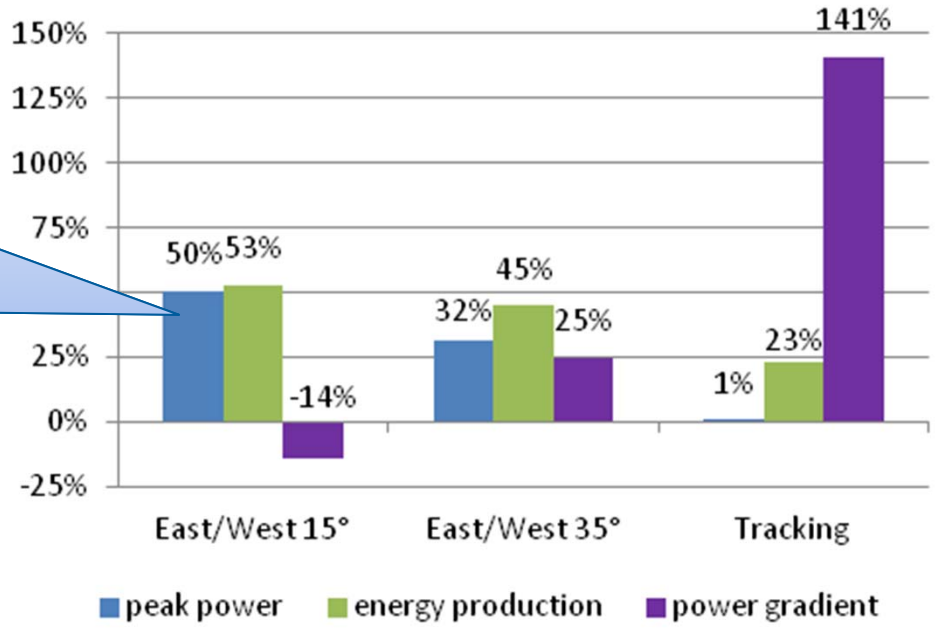
## Advantage of east/west orientation:

- Rooftops: amount of PV might be doubled using both sides of the roof
- Open field: area utilization of 70% (vs. 35-40% for south orientation due to shading)
  ➔ 75% higher installed capacity vs. south orientation

Significant increase of peak power combined with even higher increase in yield and a lower power gradient.




Since façade systems would not be feasible on an open field and horizontal systems would be difficult to keep clean they have not been considered.

# RESULTS: CORRELATION BETWEEN PRODUCTION AND CONSUMPTION

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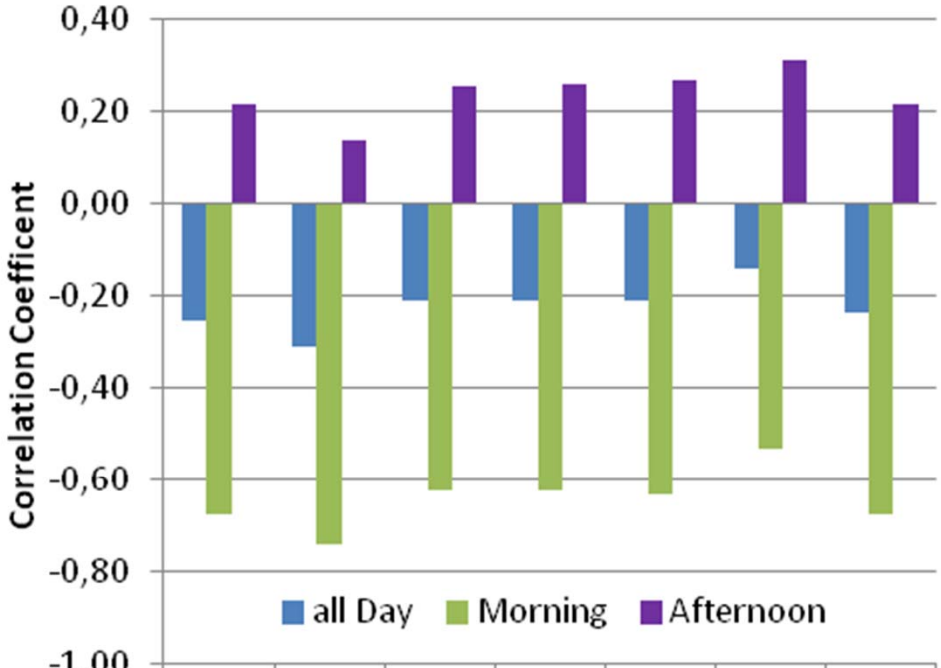
- Overall good correlation between consumption and PV production
- Correlation in the morning hours is very good
- There is an anti correlation in the afternoon hours
- East/west system is slightly worse than south
- Best correlation can be observed when using south oriented façade systems.




| | South 35° | South 90° | East/ West 0° | East/ West 15° | East/ West 35° | East/ West 90° | Tracking |
|---|---|---|---|---|---|---|---|
| all Day | -0,25 | -0,31 | -0,21 | -0,21 | -0,21 | -0,14 | -0,24 |
| Morning | -0,68 | -0,74 | -0,62 | -0,63 | -0,63 | -0,53 | -0,68 |
| Afternoon | 0,21 | 0,14 | 0,26 | 0,26 | 0,27 | 0,31 | 0,22 |

# SUMMARY AND CONCLUSIONS

- **South 35°**
  - Good energy yield (especially also in winter time)
  - High power gradients and peak power
    - By limiting the peak to 70 % and also restricting the gradients ➔ same good characteristic as the east/west orientated systems.
  - Poor energy yield on equivalent area
  - Good correlation between production and consumption
- **South façade**
  - Good energy yield during winter time
  - Good correlation with consumption
  - Bad overall yield
- **Horizontal system**
  - good in terms of power gradients
  - average correlation characteristic
  - small energy yield during winter time

# SUMMARY AND CONCLUSIONS

- **East/west orientation with a small inclination**
  - Low power gradient
  - Good usage of space ➔ Good overall energy yield but high peak power
- **East/west with a higher inclination**
  - similar to small inclination but for some criteria inferior
- **East/west façade**
  - worst system
  - fairly low power gradient
  - very low peak power
- **Tracking**
  - Can emulate all other systems
  - highest yield
  - highest power gradients and peaks (if not restricted)

➔ **No obvious optimal orientation for grid operation!**

# SUMMARY AND CONCLUSIONS

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| PV System No. | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| Orientation | | | *South* | | *East/West* | | | | *Tracking* |
| Inclination | | | *35°* | *90°* | *0°* | *15°* | | *90°* | *Tracking* |
| Equivalent rated power | Yield | overall | good | bad | o.k. | | o.k. | very bad | very good |
| | | winter | good | good | | bad | bad | very bad | very good |
| | | summer | good | | good | good | good | very bad | very good |
| | Power Gradients | | | bad | very good | very good | good | o.k. | very bad |
| | Peak Po | | bad | o.k. | o.k. | o.k. | o.k. | very good | bad |
| Equivalent | | | bad | n/a | n/a | very good | good | n/a | o.k. |
| | | winter | o.k. | n/a | n/a | good | good | n/a | good |
| | | summer | bad | n/a | n/a | very good | good | n/a | o.k. |
| | Power Gradients | | good | n/a | n/a | very good | o.k. | n/a | very bad |
| | Peak Power | | good | n/a | n/a | bad | o.k. | n/a | good |
| Correlation between production and consumption | | | good | very good | o.k. | o.k. | o.k. | bad | good |

No obvious optimal orientation for grid operation!

# OTHER LOCATIONS?

- Results have been determined for Germany.
- Further north (e.g. Sweden) the south facing system will be more advantage.
- Further south (e.g. Portugal) the advantages of East/West might be more pronounced.

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# THANK YOU FOR YOUR ATTENTION!