SAARLAND UNIVERSITY
COMPUTER SCIENCE

Short-term solar energy forecasting for network stability

Holger Hermanns
Dependable Systems and Software
Saarland University
Germany

What is this talk about?

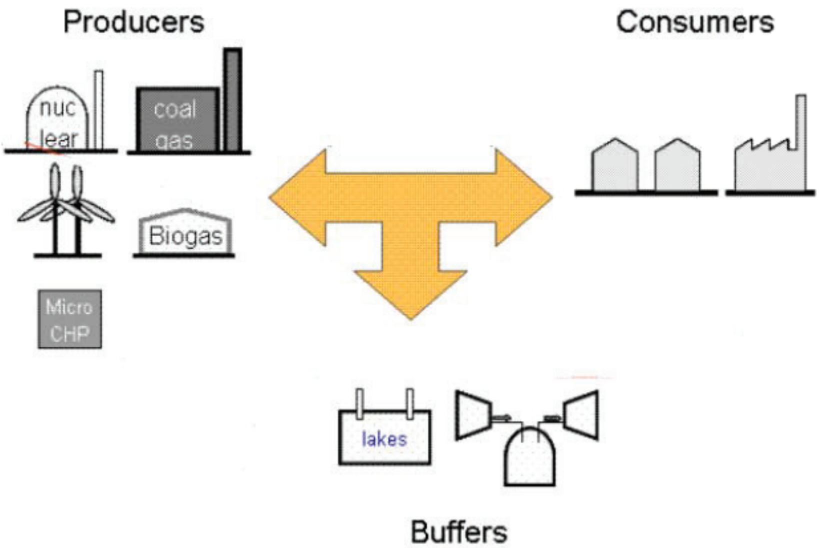
Photovoltaic energy production is an important part of the future global energy market. Especially in Germany, small scale solar production is growing massively, owed to financial incentives by the governement. A crucial feature of renewable energy sources is its unreliable and partly uncontrollable behaviour. This problem is amplified by specifics of solar producers operating in close geographic vicinity: They have a very high coincidence factor meaning that their production may change rapidly and almost synchronously owed to changes in cloud coverage. This makes the stable operation of a local area power network especially vulnerable to short term changes. To predict critical conditions, we are developing forecasting techniques for photovoltaic energy production based on precise local information and short-term weather predictions.

Background

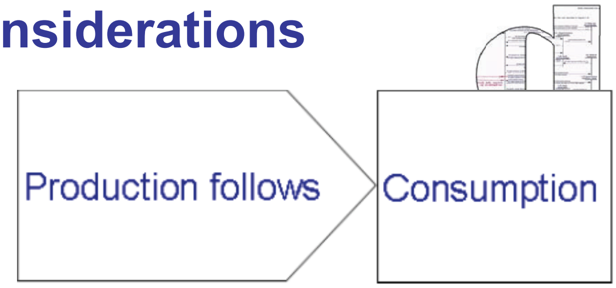
Principal Electricity Market Participants

Producers
- thermal:
  nuclear,
  gas,
  coal
  cogeneration of
  heat/power

- renewable:
  wind, solar, biogas, water
  geothermal



Principal Electricity Market Considerations



Production follows Consumption

Base assumptions:

- the electricity demand never exceeds the potential offer

- the producing entities are fully controllable

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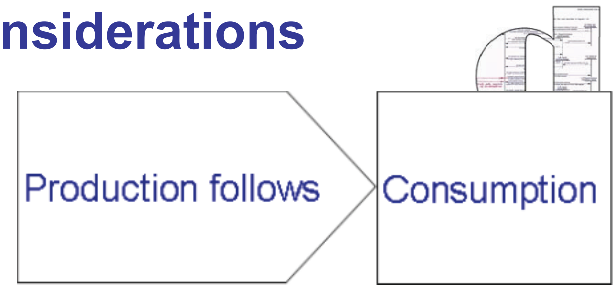

Production follows Consumption

Base assumptions:

- the electricity demand never exceeds the potential offer

- the producing entities are fully controllable

Features:

- barely any regulation on the consumer side

- producers are structured and coordinated in such a way that they satisfy the fluctuations in demand.

- consumers are charged for the costs incurred by the energy they consume

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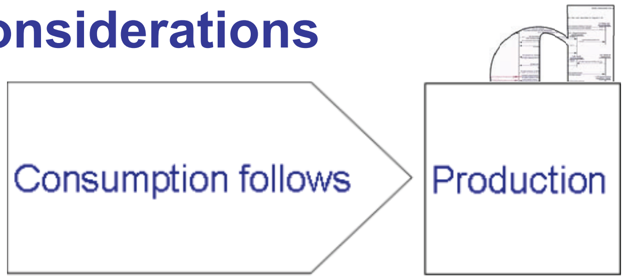

Consumption follows Production

Base Assumptions:

- electricity can only be consumed if it is available

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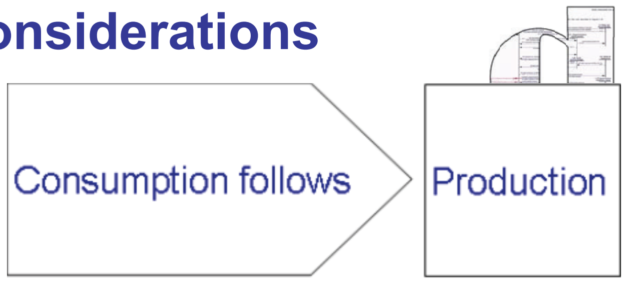

Consumption follows Production

Base Assumptions:

- electricity can only be consumed if it is available

Features:

- production entities are hardly controllable
- frequent interruptions of energy availability on the consumer side
- often comes with the allocation of electricity quotas to consumer
- mechanisms to control the consumer side characteristics

Principal Electricity Market Considerations

Production follows → Consumption

How?

Example: Germany

- currently divided into 4 so **control areas.**

Inside a control area, traders and network users form so-called **accounting grids**.

Each consumption and production unit belongs to a single accounting grid.

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How?

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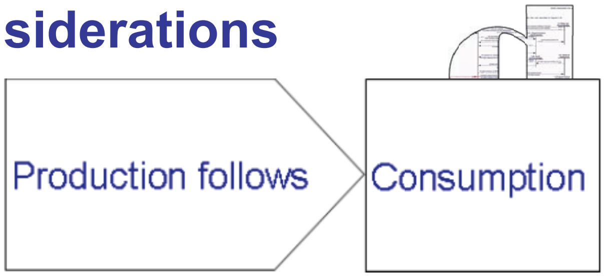
Inside a control area, traders and network users form so-called **accounting grids**.

Each consumption and production unit belongs to a single accounting grid.

Each grid has a responsible **grid coordinator** who interfaces traders and users.
Prime responsibility: maintain the electricity flow inside the grid in balance.
Deviations need to be corrected within pre-specified time bounds

Accounting grids are tightly interwoven by physical entities (cables, transformers) so they form a virtual structure on top of the electricity network.

Principal Electricity Market Considerations



How does the grid coordinator act?

- based on daily load schedules that each grid coordinator has to announce (at 14:30 the latest for the following day)

- load schedules can be adjusted on an hourly basis with a 3 hours deferral period, unless network bottlenecks result.

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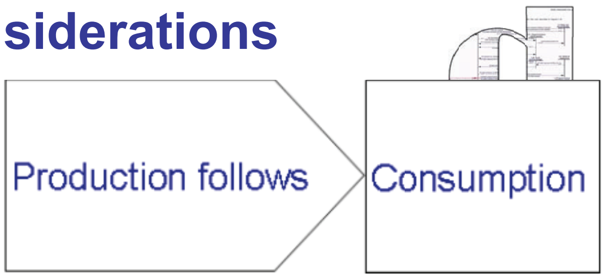

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  - needs to forecast the aggregated expected consumptions in his grid,
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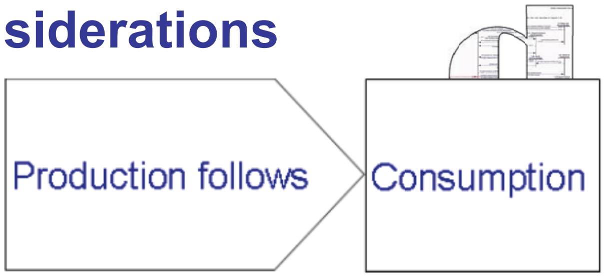

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This balance is essential for stable and reliable network operation:

Overprovisioning (or underconsumption) results in frequency drops,
underprovisioning results in frequency jumps.

Too excessive frequency deviations : malfunctioning on consumer side.
chain reactions may lead to network collapse ('blackout').

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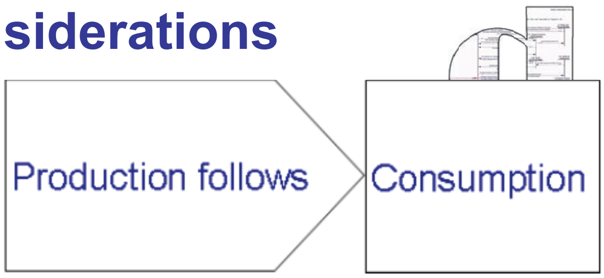

How does the grid coordinator act on short term?

- use of the concept of **control energy**.

  - electrical power that can be added to or substracted from a grid
by the grid controller almost instantaneously.

Technically often realised with the help of pump-storage plants
subtraction amounts to pumping up water
addition turns water downflow into electrical power

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about 10% of peak consumption.

Control energy can be traded across grids,
this is a characteristic feature to maintain stability.

Notably, there is a considerable energy loss because of ineffectiveness of pump-storage.

So, what's the challenge?

The integration of renewable energy.

Renewable energy production has a drastically higher volatility and this volatility is uncontrollable.

This asks for increased efforts related to network stabilization.

The drastic increase in volatility may exceed the available control energy.

This has happened for instance on September 6, 2010.

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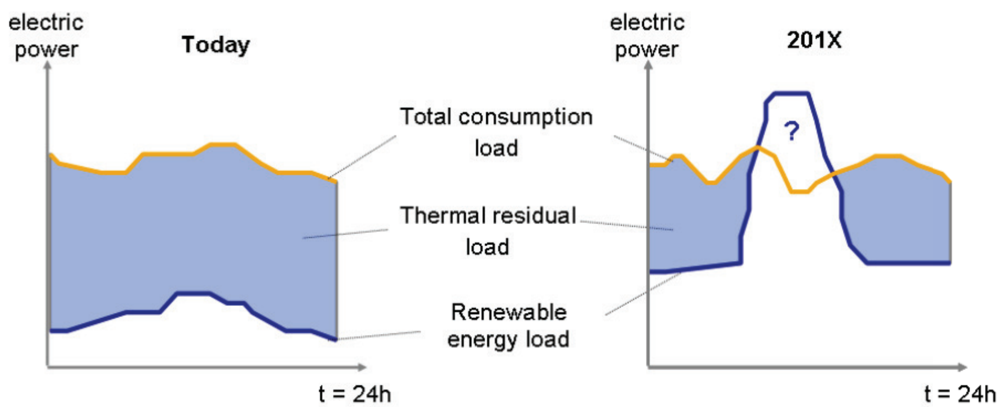
This has happened for instance on September 6, 2010.

- What happened:
  - drastically more solar power in the net than announced the day before
  - Germany @ lunchtime: surplus of 7000 MW
  - Complete negative control energy exhausted (- 4300 MW)
  - Emergency reserve imported from neighbouring countries (- 2800 MW)

Challenges for Economic Energy Usage?

Increase in renewable energy induces
- volatility effects on the stock market pricing for short term electricity,
- change in workload characteristics of traditional, thermal power plants.

Load Changes of Demand and Generation



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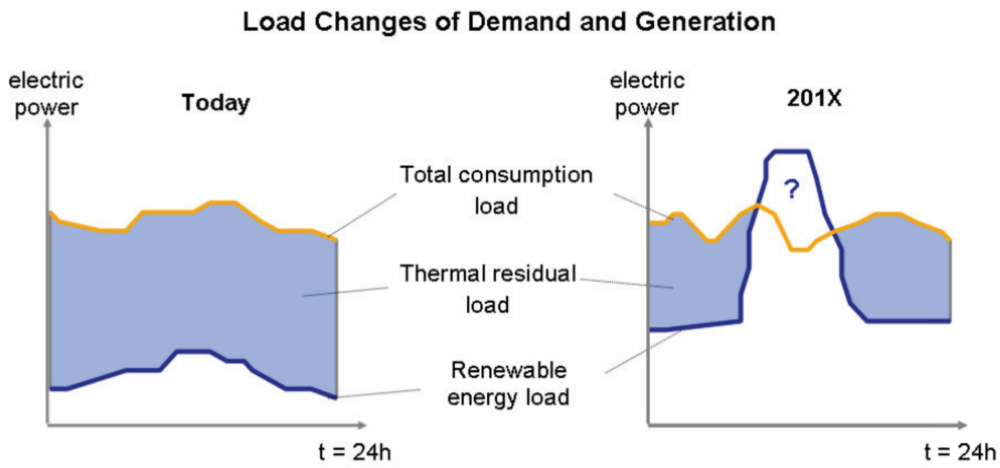

So far: base load power plants have low marginal costs
should operate most suitable all the time (running river, nuclear or lignite fired).

Concerns:
- What happens in situations when renewable energy production is higher than total consumption?

- What production entities are needed,
if all the base consumption load is covered by renewable energy?

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Economical and ecological reasons will dictate a **shift away** from the

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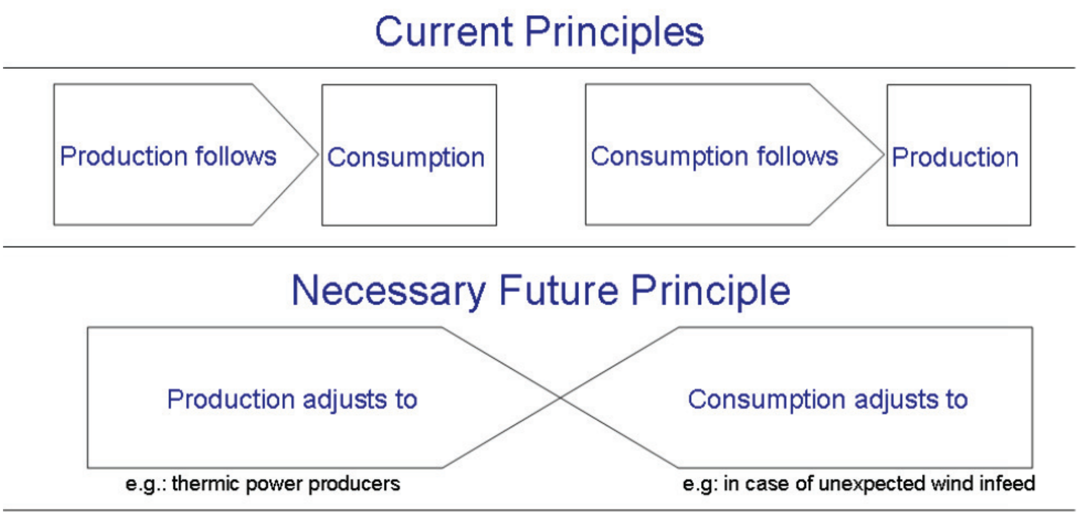


Balancing the volatility in production (partly) on the consumer side

What to Control on the Consumer side?

Light bulbs?

Ironing?

PC?

TV?

Electrical water warming?

Climate control?

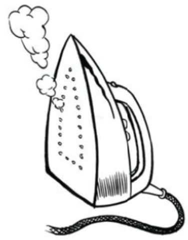
Cooling control?

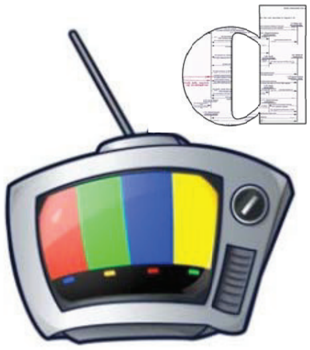
Air pressure applications?

Off-peak storage heating?

Geothermal heating?

Electrical and hybrid electrical vehicles?

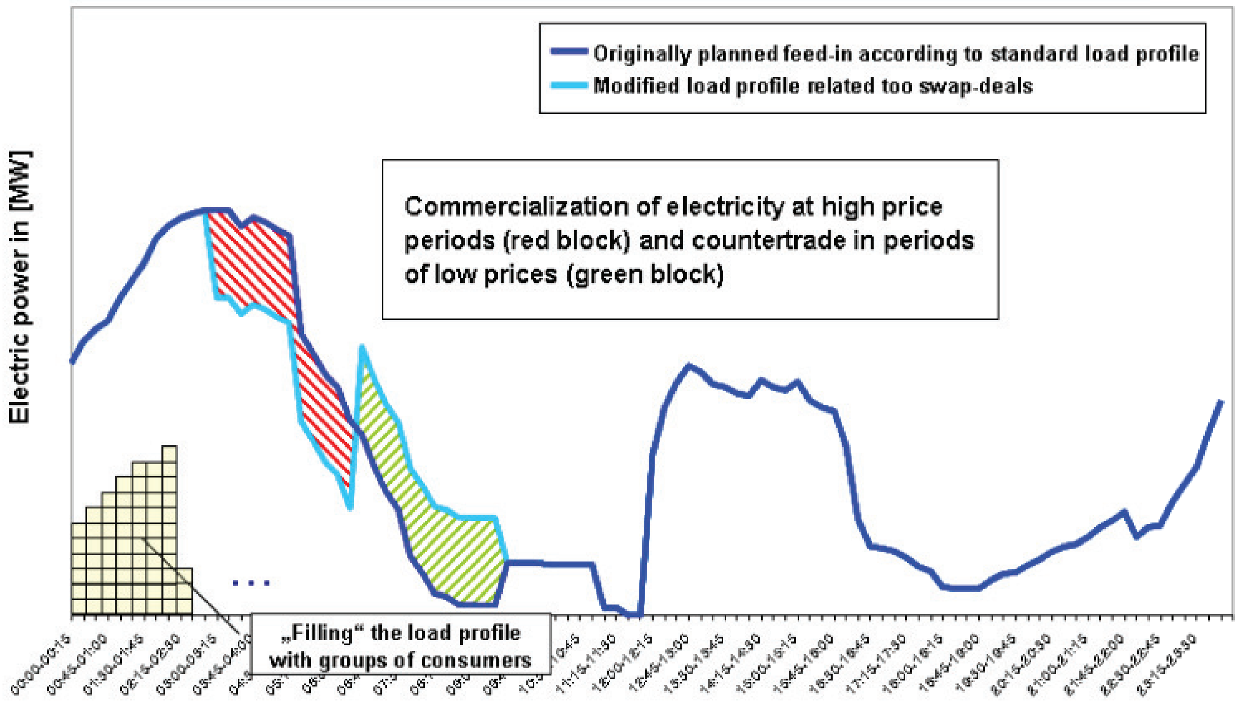




The segment of 'schedulable' consumers in Germany is in the order of a few ten thousands of MW.

How to make profit from this?
And stabilize the network ?

The Principle of electrical Swap-Deals (schematic account)



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Short term prediction of photovoltaic energy production

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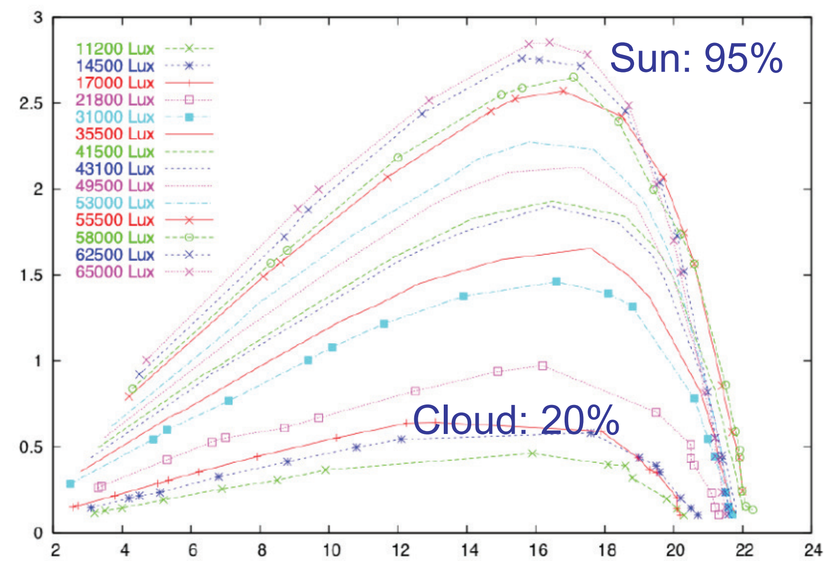
Result: Overestimation on rainy days (and in nights)
Underestimation on sunny days (and at daytime)

Another particularity

Specifics of solar producers in close geographic vicinity:

very high coincidence factor



Pai H. Chou, Dexin Li and Sungjun Kim
Maximizing Efficiency of Solar-Powered Systems by Load Matching.
ISLPED, August 9–11, 2004.

Voltage vs. power @ various sunlight intensity

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This means:

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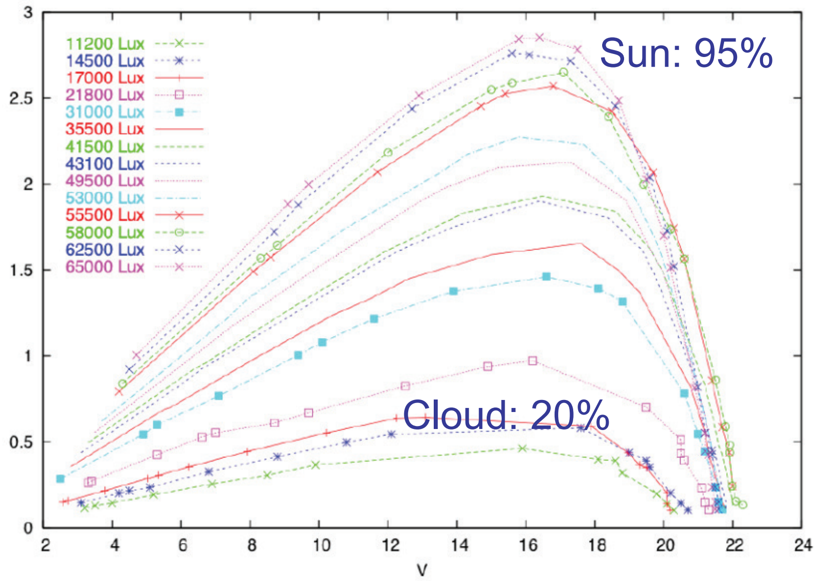

Voltage vs. power @ various sunlight intensity

Problem Statement

Given:

1) a set of solar energy production facilities (panels)
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Goal:

Estimate the net solar power production for each relevant time point.

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Solar panels

- geographical position (all in the same area)
- orientation of panel surface in 3D
- nominal power production profile
  function of light intensity, orientation towards sun, etc

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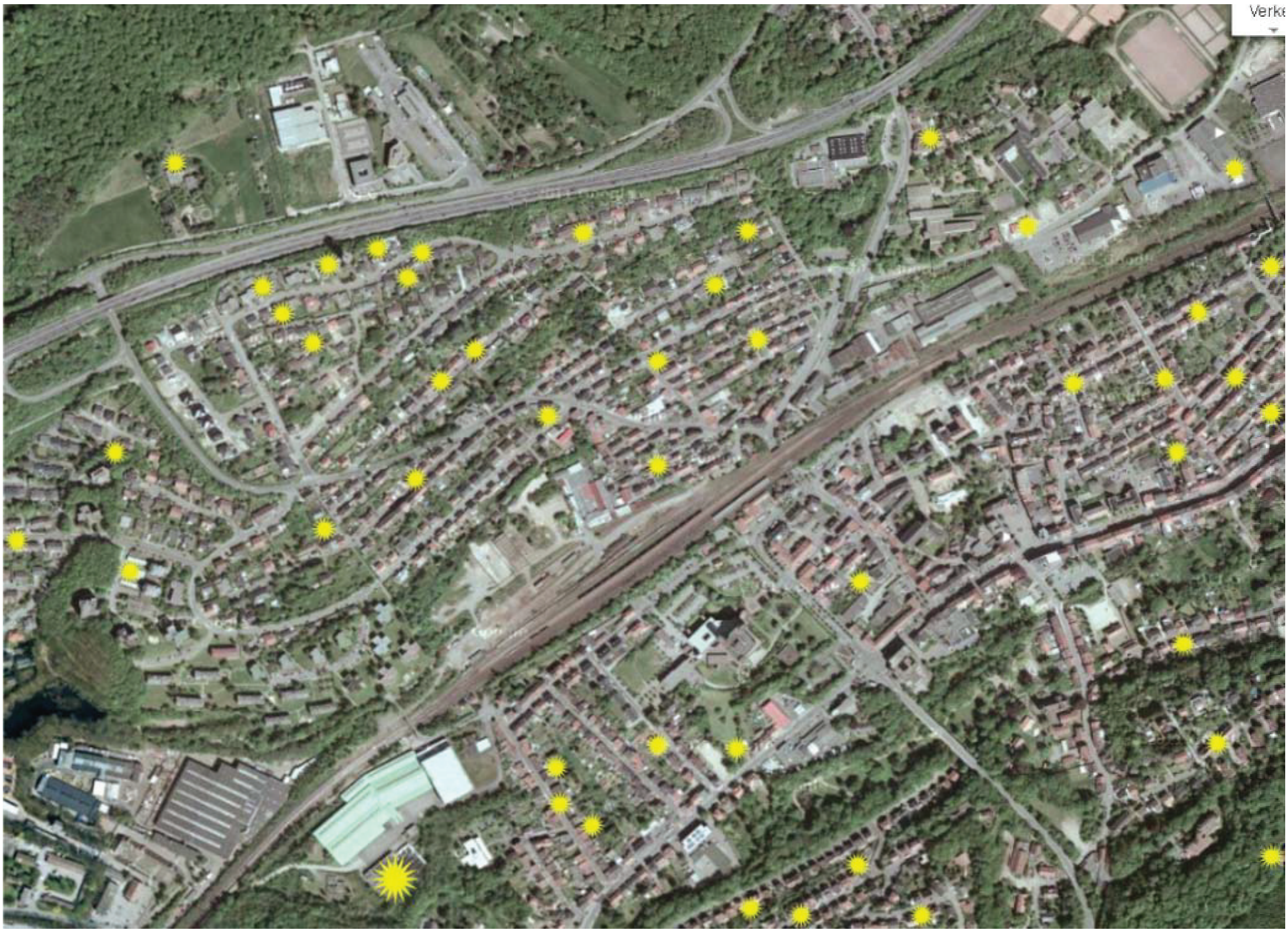
Weather forecast:

- cloud cover
- light intensity
- diffusion
  - at high, middle, low altitude

  with
  - fine time granularity (1 hr)
  - spatial resolution as fine as possible (3.8 km)



Solution

Requires calculations
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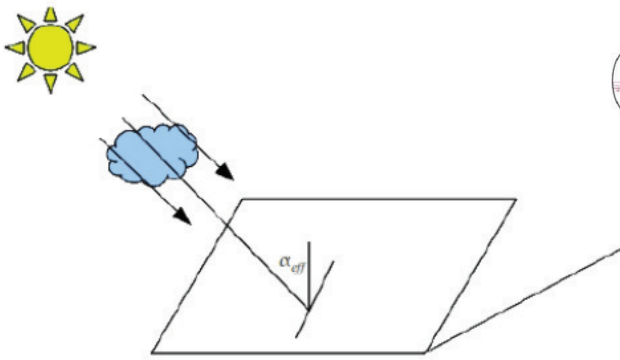
- sun position
- spehric model of earth
- discretisation
- interpolation



Effective angle between sun light and surface of solar panel

$$\phi_{ij} = f(sun\,angle, weather) * \phi_{max}$$

ϕ_{max} is a constant and equals $\approx 1300 W/m^2$.

$$\alpha_{ij}^{eff} = f(sun\,angle(t), \gamma_{ij}, \theta_{ij})$$

Discretization of power production:

$$w_{ij} = \sum_{t=t1}^{t2} P_{ij}(\phi_{ij}(t), \alpha_{ij}^{eff})\Delta t$$

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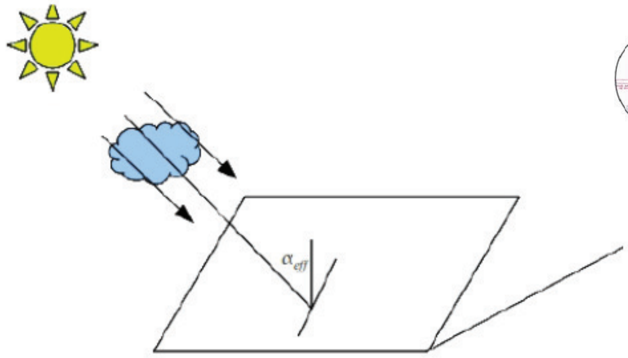

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Put into practice for a local distribution grid
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- Stadtwerke Sulzbach
  provided data about solar panels
- Luxea GmbH
  provided expertise in long-term behaviour of photovoltaic installations

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I mow the lawn at 3 pm,
since the sun will shine on the house of my neighbour then.