Grid-Based Calculation Of Tilt Factors For An Optimal Orientation Of Photovoltaic Systems In Europe

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Introduction

Some useful information for solar energy applications cannot be obtained easily because they require large amounts of data and computational power. One example are the tilt factors indicating at which inclination a photovoltaic system at a given site generates the maximum power out- put. The underlying methods to calculate these factors have been known for over 30 years. However, due to hardware limitations, these methods could not have been explored for large areas and in great detail. Today's grid computing promises rapid evaluation of large data sets. This poster describes our early experiences with the technology based on a tilt factors computation case study.

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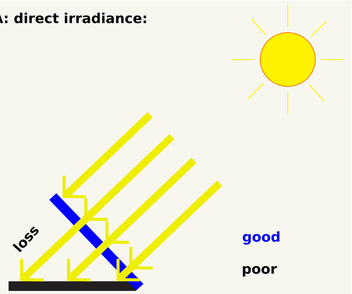
Description of the case study

The energy yield of a photovoltaic (PV) system on the northern hemisphere usually is highest for a southward directed system. Generally, the optimum inclination angle depends on the sun elevation and therefore on the latitude. At higher latitudes a PV system needs to be steeply tilted to catch the direct irradiance from the sun.

A: direct irradiance:

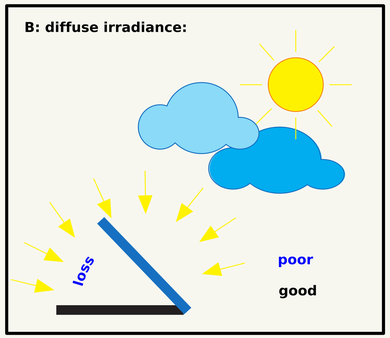


But direct irradiance is scattered on its way through the atmosphere by clouds and atmospheric constituents. In climates with high cloud cover, the fraction of diffuse irradiance dominates the incoming global irradiance.
In contrast to direct irradiance, diffuse light irradiates onto the module from all directions of the hemisphere. Therefore, to also exploit the diffuse fraction, the module plane has to be inclined at a smaller angle. To find the optimum inclination angle that balances well between both fractions of irradiance, long time series of solar irradiation data have to be evaluated to account for the mean direct and mean diffuse irradiance. To derive this information for large areas, data of the geostationary meteorological METEOSAT satellites are used. The global irradiance on the horizontal plane at ground level is derived by applying the HELIOSAT method to image data of the broadband channel.

The global irradiance is then split up into direct and diffuse fraction which enter the anisotropic all-sky model of Klucher. It considers the diffuse sky as a superposition of an isotropic diffuse background, a circumsolar disc, and horizontal brightening.

T.M.Klucher: Evaluation of models to predict insolation on tilted surfaces. Solar Energy Vol. 23, pp. 111-114, 1979

B: diffuse irradiance:



Using METEOSAT data:

* data for 1996 - 2005 (METEOSAT-5 ...-7)
* images in the visible spectrum:
  broadband channel (450nm ... 1µm)
* spatial resolution:
  3km X 3km at nadir
* temporal resolution:
  30 minutes
* region:
  Europe. 1280 X 768 Pixels

The satellite images were already converted indo cloudindex images by applying an algorithm that subtracts the ground albedo from the raw images and determines the cloud cover for each pixel based on its reflectance. These values were then stored as cloudindex maps.

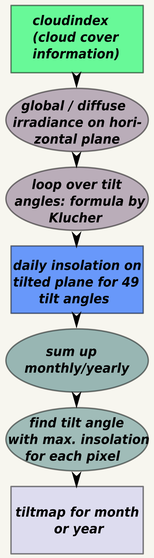
Utilizing the grid

Computing demands:
* loops over inclination angle, line, column, and hour: 6 minutes on 2.2 GHz
* daily sum of insolation on tilted plane for 49 angles: 184 MB
* cloudindex images: 27 MB per day
* additional time and space requirements for monthly and yearly sums

=> More than 500 GB of data and over 365 Hours CPU time

As a member community of the German Grid (D-Grid) we used several D-Grid compute clusters and a large storage cluster as interim archive.
Almost all computations were done within one week!

C: flow diagram



Grid jobs with Condor-GT4

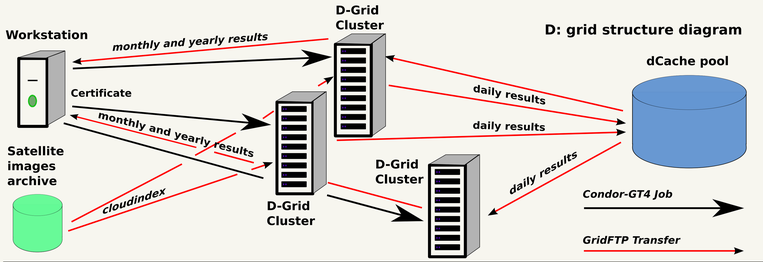
Usually, Condor is used to manage a Pool of local resources (receive jobs and start them on idle machines). But it can also pass jobs to grid resources:
* A valid user certificate is needed
* Globus Toolkit is needed partially
* Special parameters have to be provided in the command file
* Condor submits the job to the grid resource and logs the progress
* All necessary transfers are done with Globus GridFTP

Further information:
wisent.d-grid.de/tiki-index.php?page=Condor-GT4

Problems and bottlenecks

* Different grid-middlewares: Some computing clusters are not accessible via Globus
* Not all clusters set up a suitable environment
* Condor-GT4 cannot handle too many concurrent jobs
* Condor reports jobs as "running" even if the cluster is down
* Transfers to and from the archive are slow
* Tape archiving at the archive is slow and sometimes causes outages

D: grid structure diagram



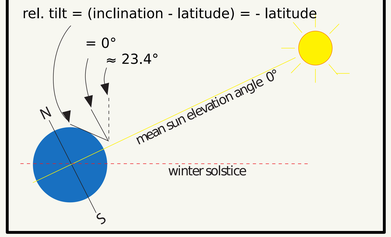
Grid computing significantly speeds up otherwise tedious computations!

Grid storage is not yet suitable for storing temporary data!

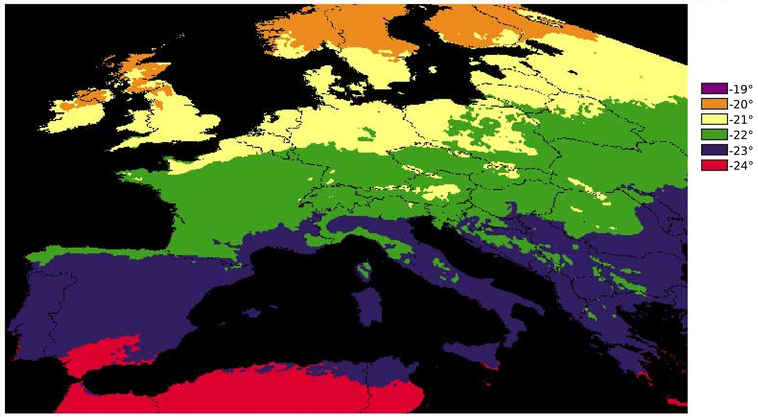
Preliminary results

Our preliminary evaluation processed the data for 1996 and led to the following map of relative tilt factors for Europe. Each pixel's color indicates for which inclination the annual accumulated insolation was maximal.
The map shows that PV systems located at higher latitudes should be inclined more steeply towards the sun than those at low latitudes.
But also smaller structures can be seen on the map. They mark regions where the cloud cover variation over the year significantly influences the optimal insolation angle.

E: relative tilt angle: inclination towards south relative to mean solar elevation



F: optimal relative tilt angles for Europe, 1996



Conclusion and outlook

In general, grid computing enables a much faster execution of tasks with large computing time or storage space needs. In the presented case study, the computing task could easily be parallelized, allowing a considerable speedup.
To use the distant archive as an interim data storage was not convincing. It came clear that the data transfers as well as the archive performance sometimes completely block the workflow.

After the present study will be carried out, it would be interesting to perform a similar analysis with other formulas for the insolation on tilted planes in order to examine the differences and agreements on a sufficiently large data base.
Also, a comparison with performance data of real PV systems would help to provide an accurate source for optimizing solar energy applications in Europe.

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