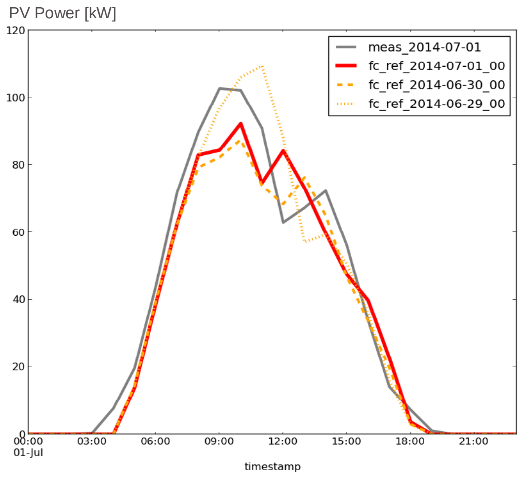
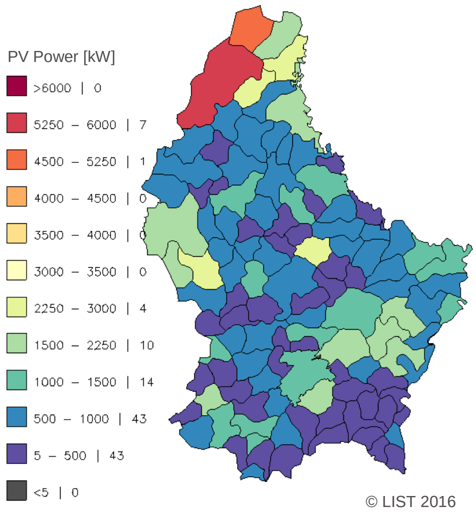
PV-FORECAST





A FINAL REPORT FOR NON-EXPERTS

FORECASTING PHOTOVOLTAIC POWER FOR LUXEMBOURG

PHOTOVOLTAIK-LEISTUNGSVORHERSAGE FÜR LUXEMBURG

PRÉVISION DE LA PUISSANCE PHOTOVOLTAÏQUE POUR LE LUXEMBOURG

A project co-financed by

FONDATION ENOVOS

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Summary

In times of transition of our energy supply towards renewable energy sources, the reliable management of our electricity supply and power grids as well as the guaranty of stable energy prices, will depend on the ability to handle fluctuating renewable sources, such as wind and solar. The trustworthy forecasting of the expected photovoltaic (PV) power production is therefore crucial for the integration of high shares of PV into our energy system.
Within the *PV-Forecast* project, the Luxembourg Institute of Science and Technology (LIST) developed a forecasting model for Luxembourg, able to predict the expected regional PV power up to 72 hours ahead. The model works with hourly solar irradiance forecasts, which are updated twice a day and cover a forecast horizon of 72 hours.
Using a set of physical and technical models, the algorithm is able to predict the expected hourly power production for all PV systems in Luxembourg, as well as for a chosen set of 23 PV-systems which are used as reference systems. Comparing the calculated forecasts for the 23 reference systems to their measured power over a period of 2 years revealed a good performance of the forecast. The mean deviation (bias) of the forecast was 1.1 % of the nominal power (low bias is an indicator of low systematic error). More pertinent is the so-called “root mean square error” (RMSE), an indicator of the performance on hourly basis, which gives higher weighting to larger deviations from the real value and is considered a suitable indicator in power forecasts. The average RMSE lies around 7.4% - a good value for single site forecasts.
LIST further tested two approaches to adapt the short-term forecast, based on the present forecast deviations for the reference systems. Thereby it was possible to improve the very short term forecast, specifically the remaining bias, mainly on the very short term time horizon of 1-3 hours ahead.

Zusammenfassung

In Zeiten der Energiewende hin zu erneuerbaren Energiequellen hängt die verlässliche Energieversorgung, der sichere Betrieb unserer Stromnetze und die Preisstabilität maßgeblich davon ab, ob es uns gelingen wird schwankende erneuerbare Energiequellen wie Wind und Sonne zu integrieren. Eine belastbare Prognose der zu erwartenden Photovoltaikleistung ist daher eine essentielle Voraussetzung für die Integration hoher Anteile an „Sonnenstrom“ in unser Energiesystem.
Im *PV-Forecast* Projekt wurde daher am Luxembourg Institute of Science and Technology (LIST) ein Modell entwickelt, welches es ermöglicht die regional zu erwartende Leistung aus Photovoltaik (PV), über einen Zeitraum von 72 Stunden vorherzusagen. Das Modell arbeitet daher mit stündlichen Solarstrahlungs-Vorhersagen, welche zweimal am Tag aktualisiert werden und 72 Stunden abdecken.
Basierend auf verschiedenen physikalischen und technischen Modellen, kann der Algorithmus die zu erwartende stündliche Leistung aller PV-Anlagen in Luxemburg vorhersagen, sowie eine spezialisierte Prognose für eine Auswahl von 23 PV-Referenzsystemen generieren. Der Vergleich der Prognosen mit den Messwerten der 23 Referenz–Systeme über 2 Jahre konnte eine gute Vorhersagequalität nachweisen. Die durchschnittliche Abweichung (bias) der Prognose betrug 1.1 % der Nennleistung (ein niedriger “bias” ist ein Indikator für einen nur kleinen systematischen Fehler). Aussagekräftiger ist der so genannte „root mean square error” (RMSE) der größeren Abweichungen eine stärkere Gewichtung gibt und somit als geeigneter Indikator der Qualität für Vorhersagen im Energiesektor gilt. Der durchschnittliche RMSE lag um 7.4% - ein guter Wert für die Prognosegenauigkeit für einzelne Systeme.
Das LIST hat außerdem zwei Ansätze getestet, um auf Basis der aktuellen Abweichungen der Prognose für die Referenzsysteme die kurzfristige Leistungsvorhersage anzupassen. Dadurch war es möglich, die sehr kurzfristige Vorhersage zu verbessern, insbesondere den „bias“, hauptsächlich in einem sehr kurzen Zeithorizont von 1-3 Stunden.

Sommaire

En période de transition énergétique vers des sources d'énergie renouvelables, la fiabilité de l'approvisionnement énergétique, l'exploitation sûre de nos réseaux électriques et la stabilité des prix dépend significativement de la façon dont nous sommes en mesure d'intégrer la fluctuation des sources d'énergie renouvelables, comme le vent et l'énergie solaire. Une prévision fiable de la puissance photovoltaïque escomptée est donc une condition essentielle pour l'intégration de fortes quotes-parts « d'énergie solaire » dans notre système énergétique.
Dans le projet « PV-Forecast », le Luxembourg Institute of Science and Technology (LIST) a mis au point un modèle qui permet de prédire la production régionale d’énergie verte des systèmes photovoltaïques pour les 72 heures (3 jours) à venir. Voilà pourquoi le modèle du LIST fonctionne avec des prévisions météorologiques horaires aussi bien du rayonnement solaire que de la température ambiante que le LIST reçoit deux fois par jour pour les 72 heures suivantes.
Sur la base de différents modèles physiques et techniques, l'algorithme du LIST peut prédire la puissance électrique horaire de toutes les centrales photovoltaïques (PV) au Luxembourg ainsi que de générer une prévision spécialisée pour une sélection de 23 installations PV dites « systèmes de référence ». La comparaison des prévisions avec les mesures de ces 23 systèmes de référence sur une période de plus de 2 ans a pu démontrer une bonne qualité des prévisions calculées. L'écart moyen (« bias ») sur la prévision de la puissance électrique était de 1.1% de la puissance nominale (un «bias» bas est un indicateur pour une petite erreur systématique). Plus concluante est la soi-disant "erreur quadratique moyenne" (« root mean square error » - RMSE) qui donne plus de poids aux écarts plus importants et est ainsi considérée dans le secteur de l'énergie comme un indicateur reconnu pour la qualité des prévisions. Le RMSE moyen était de 7.4% - une bonne valeur pour l’exactitude des prévisions pour les systèmes individuels.
Le LIST a également testé deux approches pour ajuster la prédiction de la puissance électrique générée à court terme en fonction des écarts actuels de la prévision pour les systèmes de référence. Ceci a permis d'améliorer les prévisions à très court terme, en particulier le «bias», surtout dans un horizon de temps très court de 1-3 heures.

PV Forecast - Forecasting Photovoltaic power for Luxembourg

In the following report for non-experts, the Luxembourg Institute of Science and Technology (LIST) presents its work done and results achieved in the Project *PV-Forecast*. The Project was financed by the Fondation Enovos, a non-profit foundation set up in 2010 by Enovos Luxembourg S.A., under the aegis of Fondation de Luxembourg. Fondation Enovos supported the project in its mission to promote research in the fields of environmental studies and sustainable development, particularly concerning renewable energy.

Why is solar power forecasting an important aspect of the future energy system?

In view of European and national climate protection objectives and the depletion of fossil energy resources, the shares of electricity from decentralized, renewable energy sources are rising. Fluctuating energy sources, such as wind power and photovoltaics (PV), will become a major part of the future energy mix. The reliable management of our electricity supply and power grids as well as the containment of increasing price volatility on the electricity market, will depend on the ability to handle fluctuating renewable sources, such as wind and solar. The forecasting of photovoltaic power production is therefore crucial for the integration of high shares of photovoltaics into our energy system and market.
The focus for prediction models that serve this purpose is the challenge to give a precise prediction of the dynamics of the energy production of the whole set of PV systems in an area, thus the temporal feed-in profile from PV within a specified region (e.g. a balancing group, a city, a region).

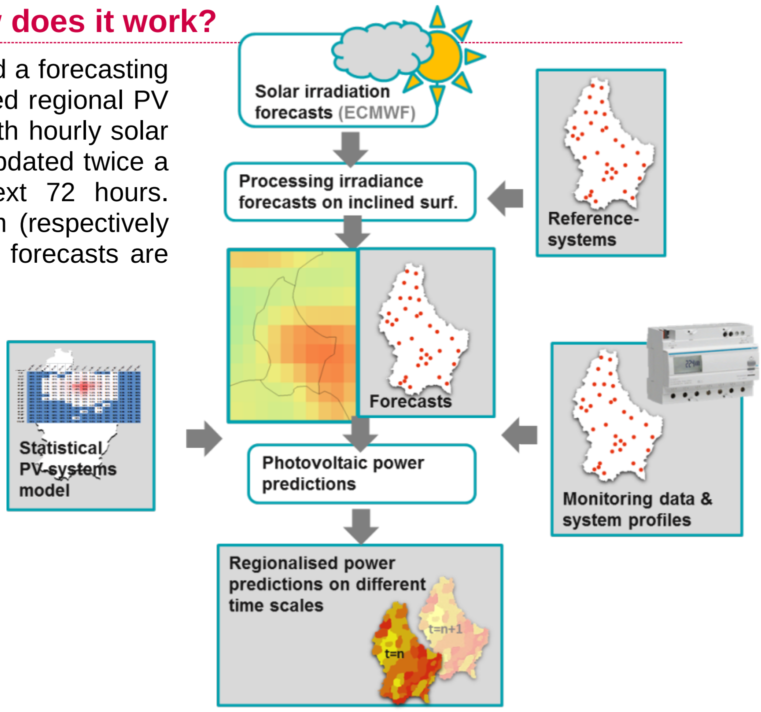
Future applications of this type of forecasting models are manifold:

- In the future, larger scale solar energy producers will need to deliver their electricity to a market or a direct consumer and need to provide a provisional time table for their production.
- Energy suppliers buy electricity from different sources (or produce it on their own) and supply their customers via the electricity grid. They need to forecast the demand of their customers and need to assure that they have at disposal the amount of electricity needed at each moment in time. Deviations between their forecast and the energy they bought can become very costly.
- Grid operators need to balance out the voltage level (and frequency) in the electricity grid. At each moment in time, the amount of electricity consumed in the grid needs to be feed-in. The more electricity is being produced by PV within the grids, the more important an exact PV power forecasting becomes for them.
- The future “smart grid” will have different technical options to balance out supply and demand e.g. by storage of electricity or partially controlling the demand in the grid by switching on or off electrical loads. In order to use these options in an optimal, anticipatory way, good forecasts for supply and demand are essential.

What is the *PV-Forecast* model and how does it work?

Within the *PV-Forecast* project, the LIST developed a forecasting model for Luxembourg, able to predict the expected regional PV power up to 72 hours ahead. The model works with hourly solar irradiance and temperature forecasts, which are updated twice a day and cover the forecast horizon of the next 72 hours. Luxembourg is split into grid cells of 9km x 12km (respectively 0.125° x 0.125°) for which specific meteorological forecasts are provided.

The irradiance forecast data on horizontal surface is further processed in order to obtain the irradiance in plane of the PV modules. A statistical model of the spatially distributed PV installations in the whole country, representing their nominal power, orientation and inclination, is then used in order to model the generated power for three days ahead over the whole region. A set of mathematical equations using standardized parameters simulate the behavior of the PV systems, taking into account effects such as e.g. the variability of efficiencies of PV modules and inverters, reflection losses, thermal behavior and cabling losses.

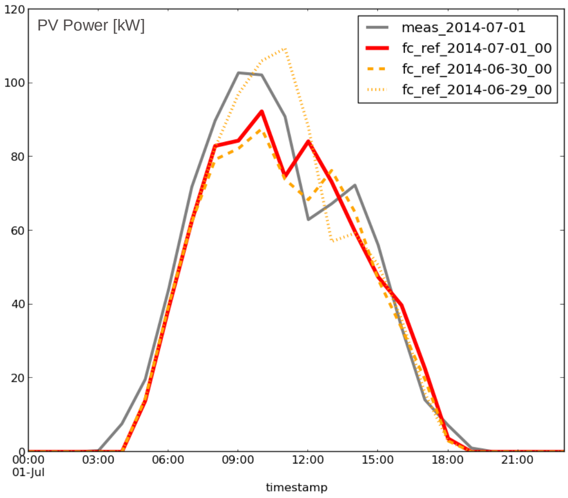


Scheme of the forecasting approach, combining modeling (left side) with a feed-back loop from PV reference systems (right side)

This simulation is also done in an even more detailed manner, for a number of known PV systems, serving as references. The reference PV systems, of which measured PV power in a temporal resolution of 15 minutes is available, are distributed over the whole country of Luxembourg. Based on individual system profiles for each reference system representing their technical characteristics, an individual power forecast is being generated. The predicted power of the reference systems is compared to their measured power, with the aim to set up a feed-back loop that enables the adaptation of the short term forecasts for the whole forecasting area, based on prediction errors of previous time steps.
Above explained forecasts for the expected hourly power of all PV systems in the country can finally be summed up for the different communes, for example. Depending on the degree of detail on the PV systems, the power could also be summed up per street or transformer station in the distribution grid, if necessary.

What are the main results of the *PV-Forecast* project?

Measurements of the power production for the 23 PV reference systems are available in 15 minutes time steps over a period of the last 2 years. To evaluate the accuracy of the forecasts, the predictions have been compared to the measured power for all three forecast horizons: 0-24 hours ahead, 24-48 hours ahead and 48-72 hours ahead (see picture below).



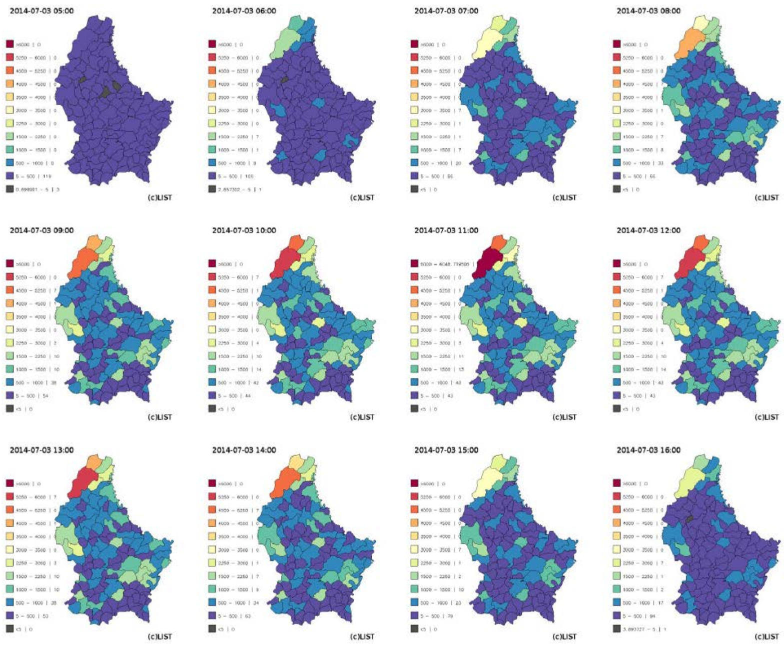
Forecasts for one day, as compared to measurements

The graph shows the measured production curve of a PV system (in grey) as compared to the so called "intra-day" forecast (0-24h in red), and the two longer-term forecasts (24-48h in orange dashed line / 48-72h yellow dotted line). Generally, the forecasting works very well for sunny days, whereas for cloudy days (such as the one shown in the graph) the hourly values deviate stronger from the actual production. The analysis of the model´s performance, over 2 years for all 23 reference systems, revealed a good performance: The mean deviation (bias) of the forecast was 1.1 % of the nominal power (low bias is an indicator of low systematic error). More pertinent is the so called "root mean square error" (RMSE) as an indicator of the performance on hourly basis, which gives higher weighting to larger deviations from the real value and is considered a suitable indicator in the energy sector. The average RMSE lies around 7.4% - a good value for single site forecasts.

The reference systems are not only used to evaluate the performance of the model, but also to test if the short-term forecasts could be improved by "learning" from the current deviations of the measured value from the most recent forecast. After testing two different approaches, it was possible to substantially reduce the mean deviation (bias) of the forecasts for an individual PV-system, for the coming hours ahead. The improvements for the above mentioned RMSE were limited to the very short term time range of 1 hour ahead, only. It became clear, that measurement based forecast adaptations might improve the forecasts in a very short forecast horizon only, but the results also revealed improvement potentials of the approach.

As a last step, the model forecasts the expected power of all PV systems in the whole country, knowing their nominal power and location. Thereby, the power can be summed up for an arbitrary regional unit, for example per commune (see picture series on the right and front cover). But, depending on the application and the available information, the power could be summed up per street or transformer station in the grid.

Finally, the developed model does show good performance for power predictions of the reference systems. As the model is able to upscale these predictions to the national level, hourly expected PV power productions can be delivered. LIST is now looking forward to bring the model into application, to contribute to the shift towards renewable electricity supply for the future.



Time series of hourly forecasts for one day, per commune in Luxembourg