

Final report

1.1 Project details

Project title	Capacity credit of wave and solar energy
Project identification (program abbrev. and file)	Energinet.dk project no. 12134
Name of the programme which has funded the project	ForskVE
Project managing company/institution (name and address)	Wave Star A/S Park Allé 350E 2605 Brøndby
Project partners	Julia F. Chozas, Consulting Engineer Aalborg Universitet Dansk Energi Danfoss
CVR (central business register)	29838879
Date for submission	15-12-2015

1.2 Short description of project objective and results

The development of renewable energy has been on the agenda for many years. Many resources are devoted to lower the price per. kWh for the facilities, but few resources have been dealing with the systemic implications of renewable energy in the energy system.

In many countries the use of still operational planning systems that are based on the basic power units with fuels, such as coal, gas and uranium. They can be stored and thus scheduling stable. Renewable energy sources such as wind, sun and waves is all weather dependent, but can be predicted.

This project is opening the debate on the value of renewable energy in the operational planning for the short, medium and long term. The project has calculated Capacity Credit for three renewable energy sources, wind, solar and wave, individually and together.

1.3 Executive summary

In Europe, there will be more and more electricity generated through renewable energy sources and the share of conventional power plants will decrease. More renewable energy sources also mean that there will be more need for balance and regulating power or a way to steer consumption.

The project has developed a methodology addressing how the renewable forms of production can be included in future electricity system, including in terms of planning.

New renewable energy production methods, such as wave power and solar photovoltaic (solar PV) panels, are not represented by a capacity credit today.

The conventional power plants are aging. It is therefore essential to get the capacity credit of the new technologies calculated and utilised. The final report addresses specifically the integrated capacity credit of the renewable energy sources wind, wave and of sun. It also addresses the benefits of a combined renewable energy system with compared to a wind-

dominated renewable energy system. And the benefits of a renewable energy sources generation mix for Denmark are higher than in a wind-dominated system, due to, low correlation between solar PV production and wave or wind production, average delay between waves and winds of 1 to 4 hours and higher correlation of solar PV and onshore wind with classical electricity demand.

ENTSO-E assumes Capacity Credit of renewable energy is 0.

Based on year 2013 hourly data, the project has proved that renewable energies have a positive daily average capacity credit, which in worst periods is the following:

$$\begin{aligned} CC_{REmix} &= 3\% - 27\% \text{ in an electricity-only system} \\ CC_{REmix} &= 3\% - 70\% \text{ in an integrated energy system} \end{aligned}$$

Summary in Danish

I Europa vil mere og mere elektricitet blive produceret via vedvarende energikilder, og de konventionelle kraftværkers andel vil falde. Flere vedvarende energikilder vil også medføre, at der vil være større behov for at balancere og regulere strømproduktionen eller at regulere og styre forbruget.

Projektet har udviklet en metode, der adresserer hvordan den vedvarende produktionen kan indgå i den fremtidige el-system, herunder i form af planlægning. Nye vedvarende produktionsmetoder, såsom bølgekraft og solcelleanlæg, er ikke repræsenteret med en Capacity Credit i dag.

De konventionelle kraftværker er ved at blive gamle. Det er derfor vigtigt at få kapaciteten af de nye teknologier beregnet og udnyttet. Den endelige rapport omhandler specifikt den integrerede Capacitet Credit af vedvarende energi fra vind, bølger og sol. Den tager også fordelene ved et kombineret system af vedvarende energi med i forhold til et vinddomineret system.

Fordelene ved et mix af vedvarende energikilder i Danmark er højere end ved et vinddomineret system på grund af lav korrelation mellem solcelleproduktion og bølge- eller vindproduktion. Den gennemsnitlige forsinkelse mellem bølger og vind er på 1 til 4 timer og højere korrelation af solcelleanlæg og on shore vind med normal efterspørgsel efter el.

ENTSO-E antager Kapacitet Credit af vedvarende energi er 0.

Baseret på data fra 2013 har projektet påvist, at vedvarende energi har en positiv daglig gennemsnit Capacitet Credit, hvilket i worst case perioder er følgende:

CCREmix = 3% - 27% i et almindeligt elsystem

CCREmix = 3% - 70% i et integreret energisystem

1.4 Project objectives

The project was implemented as planned and described in the application "Capacity credit of wave and solar energy," and all work packages are completed as expected and without problems.

There has been a major delay in the project, primarily because the project had difficulty getting the right information basis for the calculations in EnergyPlan, as well as the project's main resource was engaged by the EU in the evaluation of research work.

Energinet.dk and the distribution companies may not provide data on solar cell production based on locations in Denmark, and DONG Energy can not provide wind data from their fields in the North Sea because of commercial interests. The project succeeded in raising the nec-

essary wind, wave and solar cell production data from reliable sources by ensuring the protection of sources and by limiting the number of project staff to one person who had access to the material. Likewise, all data was cleared of sensitive personal information. Official data from Metrological Institute, and data from the public tender of Horns Rev 3 was used. The project database is wished to be transferred to Aalborg University in anonymous form for the purpose of further research, since it is a unique data set. Work continues on this issue.

There have been no risks associated with the project in addition to access to databases. Aalborg University have made their Energy Plan planning software available for the project. Before project start, there was contact with Energinet.dk to investigate the possibilities of using their planning system, but this was not possible.

In project period adjustments are made on the distribution of the budget between the partners.

1.3 Project results and dissemination of results

The project has read and reviewed all the available articles on the topic Capacity Credit and Capacity Factor from international forums.

The international organization for transmission and system operators ENTSO-E, a trade association with members from 34 European countries, sets Capacity Credit for renewable energy to zero, while Europe wants a very high share of renewable energy in its energy system. The research done on the system properties of the individual renewable energy sources, and specifically the relationships between them is very small.

From reading various articles, national and international, it is perceived that when ENTSO-E still has Capacity Credit value of renewable energy sources set to the value zero, it is because there is not completed sufficient studies.

One of the reasons is that there has not been demonstrated methods of forecasting of renewable energy sources. In order to take the sun, waves and wind into the planning, it is necessary to be able to make reliable forecasts.

For this particular two studies have been used in this project. One is a study from Aalborg University about wave energy. The other is from Oldenburg University, where studies were performed in solar energy. Wind energy has been studied at Risø.

All available studies and articles have been involved in this project, and the result is that there are values on Capacity Credit concept for not only each energy resource, but also the composition of wind, waves and sun. The project has made calculations from known figures from the three renewable energy measured in 2013 and based on these calculated various scenarios until 2035.

The project provides a number of recommendations to Energinet.dk in relation to planning in the short term, days, as well as for weeks, and up to 1 year. We therefore believe that we have fulfilled the objectives of the project.

The project encourages Energinet.dk, based on the calculations performed, to begin a detailed study of renewable energy's impact on the operational planning.

The project believe that when wind, wave and solar data is available from both the Metrological Institute as from other providers in the last 100 years, the renewable energy sources with sufficient certainty can be included with the methods that have been shown in the project.

Dissemination of results

The project started with a kick-off meeting hosted by Energinet.dk with all project partners as well as three representatives from Energinet.dk (Loui Algren, Nils Ejner Helstrup Jensen and Preben Nyeng).

Since the beginning of the project regular status meetings have been held among project partners according to the project development and project needs. There are minutes of all meetings, which can be presented upon request.

As explained in the final report the project has put strong efforts in getting realistic power production data from wave and solar PV in Denmark for year 2013. These data have been made publicly available together with explanatory notes about data origin and processing. Due to the uniqueness of the data, it is expected high welcoming of the data by researchers and other interested stakeholders.

The data can be downloaded at the website: <http://www.juliafchozas.com/projects/smart-grids-capacity-credit-wave-solar/>.

Aalborg's University research portal VBN is also providing a link to the data through the site: [http://vbn.aau.dk/en/projects/capacity-credit-of-wave-and-solar-energy\(a684b42d-e79a-4e31-b43e-c18c6d51f7e9\).html](http://vbn.aau.dk/en/projects/capacity-credit-of-wave-and-solar-energy(a684b42d-e79a-4e31-b43e-c18c6d51f7e9).html)

Also, the EnergyPLAN model of Aalborg University is introducing the wave and solar PV data obtained in this project in its free distributed data files. The files and the model can be downloaded from www.energyplan.eu/

In addition, throughout project's advancement and completion, project objectives and results have been disseminated through the following communication channels. Project results have been discussed in the final Steering Committee meeting before national publication.

Event: Tuesday Lunch Meetings.

Place: Aalborg University, Copenhagen, Denmark.

Date: 12th January 2016.

Participants: The Sustainable Energy Planning Research Group and the Center for Design, Innovation and Sustainable Transition (DIST) of Aalborg University.

Publication channel: Energy Journal of Elsevier.

Submission Date: November 2015 (paper in submission process).

Publication Date: to be confirmed, in 2016.

Publication Title (journal article): "Capacity Credit and Security of Supply: the Case of Renewable Energies in Denmark".

Event: Dissemination event at Dansk Energi.

Place: Dansk Energi, Copenhagen, Denmark.

Date: 25th November 2015.

Participants: Dansk Energi (Jørgen S. Christensen), Wave Star A/S (Per Ebert), Consulting Engineer Julia F. Chozas and Ole Graabæk (independent consultant).

Event: Final Steering Committee meeting.

Place: Aalborg University, Copenhagen, Denmark.

Date: 12th November 2015.

Participants: Energinet.dk, Aalborg University, Wave Star A/S, Consulting Engineer Julia F. Chozas.

Event: 14th Wind Integration Workshop, WIW2015.

Place: Brussels, Belgium.

Date: October 2015.

Title of the paper: "Capacity Credit and System Adequacy: the Case of Wind, Wave and Solar PV in the Danish System".

Session: Modelling of wind turbines and wind power plants for system integration studies including methods of testing and verification of compliance with requirements and technologies to facilitate integration.

Event: SDEWES 2015, 10th Conference on Sustainable Development of Energy, Water and Environment Systems.

Place: Dubrovnik, Croatia.

Date: September 2015.

Title of the presentation and paper: "Capacity Credit and Security of Supply: the Case of Renewable Energies in Denmark".

Session: Smart Energy Europe: Challenges and Opportunities for a fossil and nuclear free European continent.

Event: Project status meeting with Energinet.dk.

Place: Fredericia, Denmark.

Date: September 2015.

Title of the presentation: "Capacity Credit and Security of Supply: the Case of Renewable Energies in Denmark"

Target audience: Aja Brodal and Loui Algren.

Event: Project status meeting with Energinet.dk.

Place: Fredericia, Denmark.

Date: September 2014.

Title of the presentation: "Capacity Credit and Security of Supply: the Case of Renewable Energies in Denmark".

Target audience: Loui Algren, Anders Pallesen Jensen and Preben Nyeng.

Event: 7th INORE Symposium. Organized by the International Network of Offshore Renewable Energies.

Place: Santander, Spain.

Date: May 2014.

Title of the presentation: "Towards the Development of Smart Energy Systems: wave energy, solar photovoltaic and offshore wind energy systems".

Target audience: International researchers (mostly at PhD level) on marine energies, including wave and offshore wind.

Besides the set of specific dissemination campaigns described above, project results have been disseminated in the form of a final report and papers to the following national and international stakeholders:

- Department of System Planning at Energinet.dk
- The Danish Partnership of Wave Energy (through Jens Peter Kofoed and Wavestar)
- The Danish Partnership of Solar (through Søren Kjar Bakhoj)
- Dansk Energi (through Jørgen S. Christensen)
- DONG Energy (through Anders Sørrig Mouritzen)
- The Wave Energy Research Group of Aalborg University (through Jens Peter Kofoed)
- The Sustainable Energy Planning Research Group of Aalborg University (through Brian Vad Mathiesen)
- Aarhus University (through Gorm Andresen)
- The Joint Research Centre of the European Commission (through Davide Magagna)

1.4 Utilization of project results

The project has no plans to use the results either commercially or in any kind of organization. The project report has been made available to Energinet.dk, and the members of the Steering Committee for the project can freely use the results.

There are no data, which can be used for the purpose of patents.

If the results of the project are being used in the operational planning with Energinet.dk, it will mean that renewable energy sources can be valued and thus reduce the coal-fired standby production. A value, that can be priced in millions.

There are not used any data or knowledge from the project for educational purposes.

1.5 Project conclusion and perspective

In order to meet year 2035 fossil-free goals, Denmark has set ambitious renewable energy targets, where:

- Offshore and onshore wind increases significantly
- Only small amount of solar PV are projected
- No wave power

However, based on our findings...

- The benefits of a RES generation mix for Denmark with the 4 RES are higher than in a wind-dominated system, due to:
 - Low correlation between solar PV production and wave or wind production,
 - Average delay between waves and winds of 1 to 4 hours,
 - Higher correlation of solar PV and onshore wind with classical electricity demand

We have proved RES have a positive capacity credit:

- Daily average in worst periods:
 $CC_{REmix} = 3\% - 27\%$ in an electricity-only system
- Monthly average in worst periods: $CC_{REmix} = 15\% - 30\%$

With current capacity factors, the more offshore wind and wave in the system, the higher CC_{REmix} . The opposite is true for onshore wind and solar PV.

Overall, RES technology developments will come along with higher contribution of RES to system adequacy.

Our Recommendations for TSOs

Due to the big differences between **worst periods** and **peak-demand periods**, we recommend to investigate RE production throughout **key time periods** during a year, including: *worst period, peak-demand periods, high RES periods and best periods.*

Examine RE production in different **time spans**: intraday, intraweek, intermonth and seasonally; taking into account intra-daily and daily averages in consumption. Important as peak demand hours will be shifted to hours where demand is low or RE production is high. Assess the contribution of RES in **integrated energy systems**, where the electricity, transport, heat and industry sector are merged, and not only according to classical electricity consumption.

Open up the discussion on whether the capacity credit should be related to a tariff system for RES.

Annex

All project material, including wave and solar PV production data files, the final project report and the papers published at international conferences will be uploaded at the website: <http://www.juliafchozas.com/projects/smart-grids-capacity-credit-wave-solar/>