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Capacity Credit of Wind, Wave and Solar Photovoltaic

Executive Summary

<Variable renewable energies and long-term system planning:
The contribution of renewable energy sources to security of supply and system adequacy>

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Executive Summary

Project Background and Scope

The remaining amount of global resources, especially oil, coal and natural gas is setting up the agenda for climate and energy policy in the years ahead. With the rapid growth in world population and social development, especially in the parts of the world that do not have a standard of living as the European, there is a need to development and use of other energy sources such as wind, solar and wave energy.

Not only climate issues are pushing for such a development, but also the fact that Europe is a net fuel importer with 50% coal, 85% oil and 60% gas. This also means that there is a need for renewable energy in order to ensure economic development and security of supply.

In this context, EU energy policies and those of its member states focus on three main objectives: increasing the use of renewable energy, enhancing security of supply and reducing climate impact, with targets of 20% of RES in the total electricity production by 2020, and 27% by 2030. This is also the case of Denmark, which has set ambitious goals in the energy sector, and aims to be independent of fossil fuels in the long run.

Under this scenario, renewable energy will have a prominent role in the production portfolio.

The integration of variable renewable energies in traditional energy systems poses new challenges. Whilst variable renewable energies are not dispatchable and vary by the whim of nature, the electricity system has to maintain the balance of supply and demand at each hour of operation.

Accordingly, the aim of this project is to evaluate the contribution that variable renewable energy generation can have to the security of supply of the Danish electricity system. System planning is the process that assures security of supply and system adequacy; it assures the ability for the system to meet peak demand even under the most extreme condition. As such, system adequacy forecasts evaluate the ability of generation units to operate when most needed by the system. Traditionally, this analysis has been based on the capacity credit parameter, which is calculated on a yearly basis and evaluates the amount of power a generation unit can reliably be expected to produce at the times when demand for electricity is highest.

In Denmark wind power plays an important role to the current electricity system; however, in long-term planning it is assumed that the contribution of wind energy to system reliability is zero. Solar photovoltaic (solar PV) has the potential to become more and more relevant in the Danish system; and generation from wave energy converters can also be expected to happen in future years.

Therefore, there is a need to examine whether new renewable energy forms of production, such as wave power and solar PV, along with wind power, can be included in the planning of future energy systems. This assessment is done in the present project, first from a qualitative point of view and secondly in measurable terms.

The analysis is based on historical hourly data from offshore wind, onshore wind, wave and solar PV power production and is done over a year. Year 2013 is the study year, and Denmark is the reference system of the analysis. Certainly, the datasets of wave and solar PV power production for year 2013 and the hour by hour analysis add unique value to the project. Also, the fact that the analysis takes into account an electricity-only and an integrated energy system, as well as flexible and inflexible electricity demand, contributes to the novelty of the project. Moreover, the analysis goes beyond the wind-dominated system of today, towards a wind-wave-solar PV system based on Denmark's potential, investigating the potential of two very important RES.

Project's Conclusions

Two major conclusions arise from this project. The first one is related to the renewable energy mix that Denmark has chosen for coming years, and the second one relates to the capacity credit of RES.

Denmark has set ambitious goals in the energy sector and by 2035 it aims to be independent of fossil fuels in the heat and electricity sector. In order to achieve 2035 goals, offshore and onshore wind generation are meant to increase significantly, and only small amounts of solar PV and almost none wave power are envisioned in the renewable energy mix. Therefore, Denmark has chosen a wind-dominated renewable energy system for the future.

This study has investigated the benefits of a combined wind-wave-solar PV mix compared to a wind-dominated system, based on the wave and solar PV potential of Denmark, and the clear advantages in combining the three RES together instead of harnessing only one of them. For example, wave energy is less variable than wind energy, waves are more predictable than winds and waves are normally some hours delayed with regards to the winds that have created them –which allow wave energy converters to cover the gaps in production from wind turbines–. Solar PV does not follow the variations of production of wind nor of wave energy, and thus, it can complement the power production of the other two.

Other positive effects among the three RES are the following. The three are seasonal resources that complement each other; wind and waves are stronger in the winter period, when electricity demand is highest, and solar PV production is correlated to daily consumption patterns. Solar PV and, to a large extent, onshore wind can act as decentralised generation, which reduces transmission losses, and the three RES are available locally, regionally or nationally, which increases nations' security of supply. In addition, the following synergies arise when combining offshore wind and wave: they can share part of the supply chain, the electrical and marine infrastructures, skills and offshore O&M facilities.

In particular, the project has explored the relationships among the three renewable energy sources and what they individually and in synergy can provide to the electricity system. For this, the correlation between RE production and demand, the correlation between wind, waves and solar PV, and the number of hours per year of null-, minimum- and full-production of different RE mixes, have been examined.

Results of the project show the following findings:

i) Onshore wind and solar PV are the RES higher correlated to the classical electricity demand, with a cross-correlation factor of 0.14 and 0.13, respectively.

ii) Among the scenarios studied including offshore and onshore wind, the highest cross-correlation factor between RE production and demand is achieved by combining offshore wind, onshore wind, wave and solar PV; and the cross-correlation factor is of 0.17. These numbers can be compared with the cross-correlation factor of RE production and demand in year 2013, of 0.13.

iii) There is high correlation between wind and wave power production, which is explained by the fact that waves are created by winds; cross-correlation factors are between 0.6 and 0.7 for a zero-hour time lag. However, and interesting property is that there is also an average delay between wind and wave production, which lies in between 1 to 2 hours for offshore wind production, and 1 to 4 hours for onshore wind production.

iv) Solar PV is low correlated with offshore wind, onshore wind or wave production, presenting a low negative correlation.

v) Among the scenarios analysed, the renewable energy mix that combines offshore wind, onshore wind, wave and solar PV is the one that reduces to a minimum the number of hours per year with a production below 1% of total production, and the number of hours per year with a production below 5% of total production, with numbers of 190 h/y and 2070 h/y, respectively. The combined offshore and onshore wind energy system presents numbers of 519 h/y and 2786 h/y, respectively.

vi) An interesting finding, which relates to the second set of conclusions to be presented below, is that the number of hours per year with no production from RES is as low as 0 h/y in most of all the RES scenarios analysed including the four RES of the study.

As a result, the first set of findings of the project highlight that there are stronger benefits in a Danish diversified renewable energy mix based on wind, wave and solar PV, than in the wind-dominated renewable energy system that Denmark is aiming for.

The second set of conclusions is related to the capacity credit of RES in the Danish system, and the contribution that RES can provide to security of supply.

In system adequacy assessments the contribution that RES can make to security of supply is evaluated by the capacity credit parameter. However, the traditional general assumption in adequacy forecasts is that variable renewable generation cannot contribute to system adequacy, and thus, that the capacity credit of RES is equal to zero. This project has aimed to go beyond this assumption and has investigated different methods to evaluate the contribution that RES can provide to the Danish system.

Accordingly, the capacity credits of different future 2030 Danish scenarios including offshore wind, onshore wind, wave and solar PV have been examined. Results of the project have proved that RES do have a positive capacity credit, with a value above zero.

Results obtained in the project based on a new approach show that the contribution to security of supply that can be expected from RES averaged over a month in the worst month and in the peak-demand month of the year is in the range of 15% to 30% of RES's installed capacity. The interval 15% to 30% depends on the scenario, as the more offshore wind and wave installed in the system, the higher the capacity credit of the RES mix. The opposite is true for onshore wind and solar PV, being solar PV the RES that presents lower capacity credits.

According to the scenarios analysed, a capacity credit of 15%-30% indicates that in a monthly average between 2000 MW and 3000 MW are available in the worst month (February in this analysis) and in the peak-demand month (January in this analysis) to cover the electricity demand. This finding applies both when considering an electricity-only system and an integrated energy system. And again, the intervals depend on the scenario considered.

If the daily averages are considered instead, the average capacity credit of the RE mix in the worst day of the year (when demand is maximum and RES production is minimum) is of 3%-4% of RES installed capacity. This corresponds to 300MW-400MW, and applies both when considering an electricity-only system and an integrated energy system.

By contrast, the average capacity credit of the RE mix in the peak-demand day of the year (when demand is maximum) changes significantly when considering an electricity-only or an integrated energy system. In the former system, the capacity credit varies in the range 16% to 27% (around 2500 MW), whereas in the latter system it presents a value of 50% to 70% of the RES installed capacity (between 5500 MW and 7000 MW). This shows the positive effects towards integrating RES of integrated energy systems, where the electricity, heating and transport sectors are merged, and of flexible electricity demand.

In addition, the Danish TSO and the Danish Energy Authority project an improvement of wind and wave harnessing technologies, and accordingly, their capacity factors are expected to increase significantly. This is especially true for wave technologies, which in some scenarios are projected to have capacity factors higher than offshore wind. These improvements provide a different scenario as the one analysed in this project, with the result that the aggregated capacity credit of RES will change positively.

Overall, this project has proved that RES can contribute to security of supply in the periods of more risk to the system, i.e. in worst periods and in the peak-demand periods. And as RE technology developments happen, RES will be capable of contributing more to system adequacy.

Recommendations for TSOs

Finally, the conclusions and results of this project aim towards the improvement of existing rules and methods in system planning, and towards the development of integrated energy systems with high penetrations of renewable energies. A set of recommendations have been made, which TSOs shall consider to implement as part of a new methodology to calculate the contribution of variable RES to security of supply.

These recommendations aim to go beyond the traditional approach used in adequacy forecasts to meet security of supply. The methodology traditionally used by TSOs, the ENTSO-E and the IEA to calculate the capacity credit of RES analyses the production of the RE mix of focus during the 10th to 100th highest consumption hours during a year. This approach is not suitable when RES are part of the electricity generation mix.

Accordingly, this project has developed a methodology that looks into the capacity credit of a RES mix in a new way. It investigates the capacity credit of a mix of RES at different time spans (intraday, intraweek, intermonth and seasonally), at key time periods during a year (in worst periods, in peak-demand periods, in high RES periods and in best periods), and considering two very different energy systems (an electricity-only system and an integrated energy system), and demand responses (flexible and inflexible electricity demand).

The following recommendations shall be taken as part of a new methodology:

- Investigate RES production throughout key time periods during a year, and not only during a given number of highest consumption hours of a year. This study has examined RES power production in periods of peak-demand, in periods where RES production is minimum and demand is maximum, in periods where RES production is maximum, and in periods where RES production is maximum and demand is minimum. Each of the four periods analysed present its own challenges, and therefore it is relevant to address all of them from a system perspective. In some periods RES production can only cover one eight of the electricity demand, and in others RES production is twice the electricity demand.

- Also, two very different periods should be distinguished and analysed: *worst periods (*where RES production is minimum and peak demand is maximum*)* and *peak-demand periods (*where peak demand is maximum*)*. Traditional system adequacy analyses investigate RES production in peak-demand hours; however, results from this analysis indicate that *worst periods* are the ones that pose a challenge to the system, rather than *peak-demand periods*. An analysis on *worst periods* is needed in order to study how the whole system can meet security of supply with minimum amounts of RES.

- Examine RES production throughout different time spans taking into account intra-daily and daily average changes in consumption. This is especially important as the pattern of the electricity demand will change in the future, and therefore peak-demand hours will be shifted to hours in the day where demand is low and RES production is high, or viceversa.

- In addition, the time span analysis looking into different intra-day scales (i.e. 1-hour, 3-hour, 6-hour, 12-hour, etc) shows what the challenges with RES production in the different time spans analysed are. These conclusions, which go well beyond the purpose of this study, are of great benefit to the current discussion on the storage capacity and flexibility that is needed in the Danish system.

- Evaluate RES production from an integrated energy system approach, with flexible electricity demand, and not only based on classical and inflexible electricity consumption. As decisions in 20 and 30 years time are happening now, it is important that this decision's processes take into account changes in demand patterns, as well as changes on how the electricity and the other energy sectors (transport, heat and industry) will interact. This is addressed in this study by implementing an electricity-only system (which is based on classical and inflexible electricity demand) and an integrated energy system (where the electricity, heat, transport and industrial sector interact, and electricity demand is flexible). Major fifferences of using one and the other have been shown.

- In today's Danish electricity market there is no capacity market for RES. After the research carried out in this project, the question on whether a positive capacity credit can be related to a capacity payment arises. Can a capacity credit above zero be related to any money scheme for the RES of focus? This would indeed allow companies and individuals who invest in RES to have an energy payment and a capacity payment. If the Danish goal is to be a fossil free nation in 2050, it might not be too early to discuss such a tariff system. The discussion could also address whether capacity payments should be part of long-term system planning or of system operation.

The report that follows this Executive Summary provides a comprehensive overview of the objectives, background, methodology and approach, and results achieved throughout the project.