# Capacity Credit of Wind, Wave and Solar Photovoltaic

Final Project Presentation

**Julia Fernández Chozas**

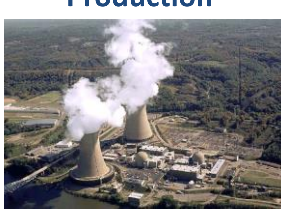
December 2015

JULIA F. CHOZAS
CONSULTING ENGINEER

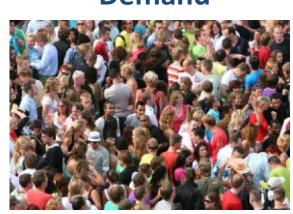
# Security of Supply

System planning is the process that assures security of supply: **ability for the system to meet peak demand even under the most extreme condition.**

**Production**



**Demand**



In adequacy forecasts each power plant is assigned **a capacity credit.**

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# Security of Supply

System planning is the process that assures security of supply: **ability for the system to meet peak demand even under the most extreme condition.**

**Production**

**Demand**

In adequacy forecasts each power plant is assigned **a capacity credit.**



# Capacity Credit

- It evaluates the contribution that a generation unit can make to system reliability.
- It is calculated as the "*amount of power renewable energies can reliably be expected to produce at the times when* ***demand for electricity is highest***" [IEA], usually, during the 10 to 100 highest consumption hours during a year.
- It is expressed as a % of the installed capacity of the generators. A value of 100% denotes one-for-one substitution with no loss of system reliability and 0% indicates that the RE source can displace no conventional capacity.

## Goal of the project

1. Enhance the understanding of capacity credit when renewable energy sources are a big part in the electricity generation mix
2. Investigate and Propose a new methodology for evaluating the capacity credit of renewable energy sources



## Conclusions (I)

- 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

# Conclusions (II)

- ENTSO-E assumes Capacity Credit of RES = 0

But, based on year 2013 hourly data,

- We have proved RES have a positive capacity credit:
  - Daily average in worst periods:
    $\mathbf{CC_{REmix}}$ **= 3% - 27%** in an electricity-only system
    $\mathbf{CC_{REmix}}$ **= 3% - 70%** in an integrated energy system
  - Monthly average in worst periods: $\mathbf{CC_{REmix}}$ **= 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.

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# 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.

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# Project Methodology

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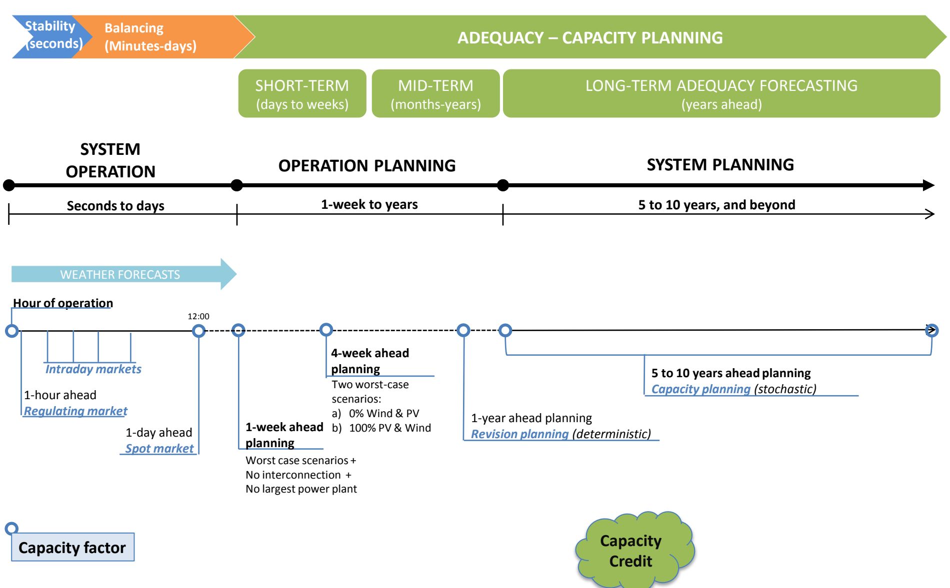
# System Planning vs System Operation

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## Factors that positively affect the capacity credit

- ✓ Correlation among RES
- ✓ Correlation of RE production and demand
- ✓ Diversification of the RE mix (Average number of hours per year of null RE production)
- ✓ Penetration level of the RE mix in the system
- ✓ Average capacity factors of the RE technologies in the system

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## Renewable Energies of the Analysis

Hour by hour distributions of the different RES have been based on actual measurements for year 2013 whenever possible.

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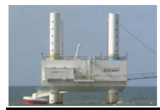
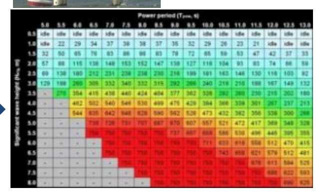
# Modelled Wave production data

***Input data:*** *Hm0 and T02 from Hanstholm and Horns Rev 3*

***Transfer function:***
*Wavestar power matrix*





***Output data:*** *Hourly Wave Power Production*

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# Scenarios of the Analysis

i. Year2013
ii. Ambitious Offshore Wind Scenario
iii. Ambitious Onshore Wind Scenario
iv. Ambitious Wave Scenario
v. Ambitious Solar PV Scenario
vi. Combined RES Scenario
vii. Other scenarios: wind-only, wave-only, solar PV-only
viii. Århus Wind-Solar PV Scenario

- Annual total RE production is kept constant at 27.3 TWh/y
- Production from offshore and onshore wind is kept equal or higher than 10.7 and 12.6 TWh/y, respectively
- Capacity factors of each technology type are defined by 2013 values.

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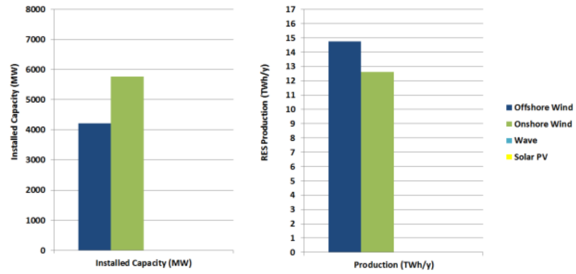
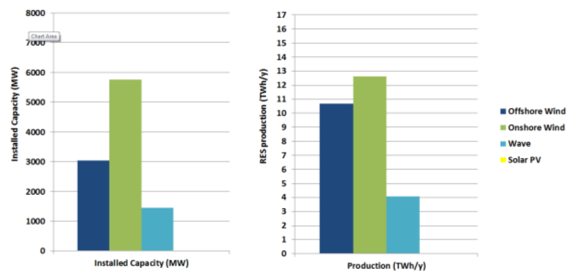
# Scenarios of the Analysis

**Ambitious Offshore Wind Scenario**




**Ambitious Wave Scenario**

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# Selected study periods

"How well the aggregated production of variable RES aligns with periods during which the system faces a high risk of an outage, i.e. periods of peak demand?"

i. **Worst periods**: Electricity demand is maximum and RE production is minimum

ii. **Peak demand periods**: Electricity demand is maximum

iii. **Hi-RES periods**: RE production is maximum

iv. **Best periods**: RE production is maximum and demand is minimum

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# Selected time spans

Nine different time spans are considered in the analysis of each study period. Intended to represent the contribution of RES on an hourly basis, intra-day basis, intra-week basis, weekly basis, monthly basis and season basis.

- 1-hour averaged
- 3-hour averaged
- 6-hour averaged
- 12-hour averaged
- 24-hour / 1-day averaged
- 3-hour averaged
- 7-day / 1-week averaged
- 1-month averaged
- 3-month averaged

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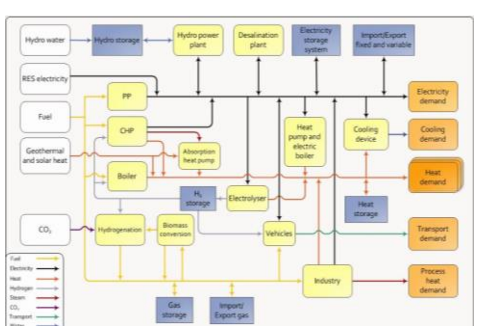
# Two System Approaches

1. **Electricity-only system**: looks into the electricity sector as an isolated energy system
   - In-house model developed for the project

2. **Integrated energy system**: approach is founded on a holistic system perspective that integrates the consumption in all energy sectors: transport, heat, industry and electricity.
   - **EnergyPLAN Model**, an advanced energy system's model

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# Project Results

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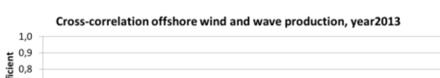
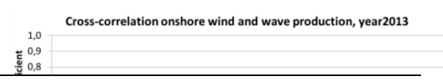
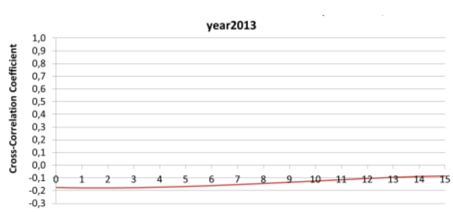
# Qualitative Results

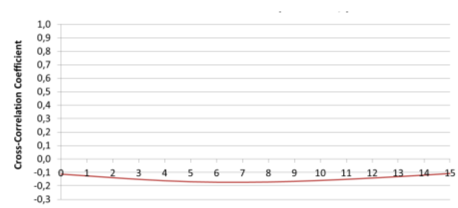
✓ **Cross-Correlation between renewable energy sources**




| | Offshore wind | Onshore wind | Wave | Solar PV |
|---|---|---|---|---|
| Offshore wind | 1 | 0.85 (t=0 h) | 0.68 (t=1-2 h) | -0.18 (t=1-2 h) |
| Onshore wind | - | 1 | 0.61 (t=2-4 h) | -0.19 (t=8-9 h) |
| Wave | - | - | 1 | -0.18 (t=0-1 h) |
| Solar PV | - | - | - | 1 |

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# Qualitative Results

✓ **Cross-Correlation among RE production and demand**

| Scenarios | Cross-Correlation |
|---|---|
| Year 2013 [1271 : 3531 : 0 : 478.3 TWh/y] | 0.13 |
| Ambitious Offshore Wind Scenario [14.8 - 12.5 - 0 - 0 TWh/y] | 0.11 |
| Ambitious Onshore Wind Scenario [10.7 - 16.6 - 0 - 0 TWh/y] | 0.12 |
| Ambitious Wave Scenario [10.7 - 12.5 - 4 - 0 TWh/y] | 0.12 |
| Ambitious Solar PV Scenario [10.7 - 12.5 - 0 - 4.2 TWh/y] | 0.16 |
| Combined RES Scenario [4.1 - 9.5 - 8.1 - 5.6 TWh/y] | 0.17 |
| Offshore Wind – Only | 0.07 |
| Onshore Wind – Only | 0.14 |
| Wave – Only | 0.07 |
| Solar PV – Only | 0.13 |
| Heide et.al. (Århus) Scenario [0 - 21.7 - 0 - 5.6 TWh/y ] | 0.19 |

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# Qualitative Results

✓ **Diversification of the RE mix,** as average number of h/year

i) with no production from RES

ii) with a production below 1% of maximum production,

iii) with a production below 5% of maximum production,

| Hours per year when, | Offshore wind | Onshore wind | Wave Prod. | PV Prod. |
|---|---|---|---|---|
| Production = 0 | 4 h/y | 0 h/y | 45 h/y | 4232 h/y |
| Production <1% max. prod. | 163 h/y | 309 h/y | 132 h/y | 4613 h/y |
| Production <5% max. prod. | 877 h/y | 1505 h/y | 1094 h/y | 5509 h/y |

| Hours per year when, | Off- and on-shore wind | Off- and on-shore wind, and wave | Off- and on-shore wind, and PV | Off- and on-shore wind, wave and PV |
|---|---|---|---|---|
| Production = 0 | 0 h/y | 0 h/y | 0 h/y | 0 h/y |
| Production <1% max. prod. | 519 h/y | 251 h/y | 376 h/y | 190 h/y |
| Production <5% max. prod. | 2786 h/y | 2510 h/y | 2424 h/y | 2070 h/y |

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# Qualitative Results

✓ **Capacity factors for RE technologies in Denmark are represented by 2013 values:**

i) Offshore Wind: 40%

ii) Onshore Wind: 25%

iii) Wave: 32%

iv) Solar PV: 11%

Energinet.dk (Energinet.dk, 2011) and the Danish Energy Authority (Energistyrelsen, 2014) project an improvement of wind and wave harnessing technologies; and as such, their capacity factors are indeed expected to increase significantly, in 5% to 10%.

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# Quantitative Results

- **Approach A: Electricity-only system**
- **Scenario: Combined RE Scenario**
- **PEAK-DEMAND PERIODS: hours of maximum El. Demand**

| Capacity Credits (in % of Installed Capacity) | | | | | | |
|---|---|---|---|---|---|---|
| Time-frames | Date & Hour | All RES Combined | Offshore wind | Onshore wind | Wave | PV Prod. |
| 1-hour | 25-jan, 17:00 | 18% | 37% | 24% | 34% | 0% |
| 3-hour | 25-jan, 09:00 | 7% | 15% | 5% | 6% | 7% |
| 6-hour | 25-jan, 12:00 | 14% | 33% | 16% | 22% | 5% |
| 12-hour | 25-jan, 12:00 | 16% | 36% | 21% | 29% | 2% |
| 24-hour / 1-day | 25-jan, 00:00 | 10% | 23% | 12% | 17% | 2% |
| 72-hour / 3-day | 16-jan, 00:00 | 8% | 22% | 10% | 14% | 1% |
| 168-hour / 1-week | 22-jan, 00:00 | 17% | 38% | 23% | 26% | 2% |
| 1-month | January | 19% | 37% | 26% | 32% | 2% |
| 3-month (year quarter) | Jan-Feb-March | 20% | 37% | 26% | 29% | 6% |

**As a general trend $CC_{Offshore\ wind} > CC_{Wave} > CC_{Onshore\ wind} > CC_{Solar\ PV}$**

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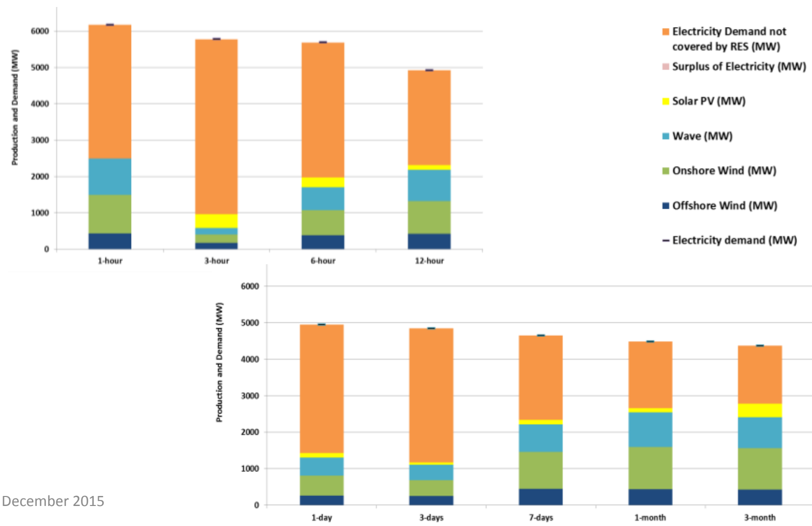
# Quantitative Results

- Approach A: Electricity-only system
- Scenario: Combined RE Scenario
- PEAK-DEMAND PERIODS: hours of maximum El. Demand

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# Quantitative Results

- Approach A: Electricity-only system
- Scenario: Combined RE Scenario
- WORST PERIODS: hours of maximum El. Demand and minimum RE production

| Capacity Credits (in % of Installed Capacity) | | | | | | |
|---|---|---|---|---|---|---|
| Time-frames | Date & Hour | All RES Combined | Offshore wind | Onshore wind | Wave | PV Prod. |
| 1-hour | 24-jan, 17:00 | 2% | 6% | 1% | 3% | 0% |
| 3-hour | 24-jan, 15:00 | 3% | 6% | 1% | 3% | 3% |
| 6-hour | 25-jan, 06:00 | 4% | 10% | 4% | 4% | 4% |
| 12-hour | 24-jan, 12:00 | 3% | 5% | 1% | 3% | 5% |
| 24-hour / 1-day | 24-jan, 00:00 | 3% | 8% | 2% | 3% | 4% |
| 72-hour / 3-day | 15-feb, 00:00 | 5% | 9% | 5% | 7% | 2% |
| 168-hour / 1-week | 12-feb, 00:00 | 11% | 21% | 13% | 17% | 3% |
| 1-month | February | 15% | 30% | 17% | 26% | 4% |
| 3-month (year quarter) | Jan-Feb-March | 20% | 37% | 26% | 29% | 6% |

**Again, $CC_{Offshore\ wind} > CC_{Wave} > CC_{Onshore\ wind} > CC_{Solar\ PV}$**

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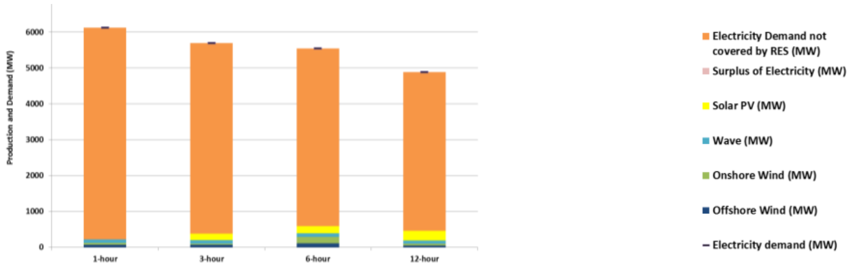
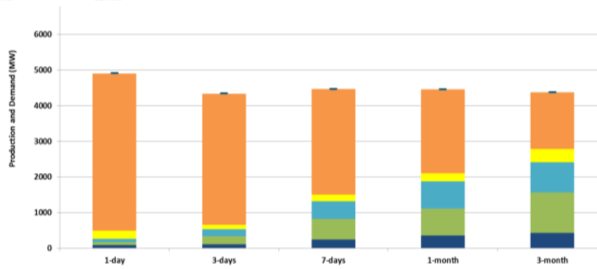
# Quantitative Results

- Approach A: Electricity-only system
- Scenario: Combined RE Scenario
- WORST PERIODS: hours of maximum El. Demand and minimum RE production

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# Quantitative Results

- Approach A: Electricity-only system

| | Ambitious Wave Scenario [10.7 - 12.5 - 4 - 0 TWh/y] | | | |
|---|---|---|---|---|
| | Worst periods | Peak demand periods | Hi-RES periods | Best periods |
| 1-hour to 6-hour | 3% ≤ CC ≤ 3% | 8% ≤ CC ≤ 30% | 92% ≤ CC ≤ 93% | 83% ≤ CC ≤ 90% |
| 12-hour to 24-hour | 2% ≤ CC ≤ 4% | 16% ≤ CC ≤ 27% | 81% ≤ CC ≤ 87% | 78% ≤ CC ≤ 82% |
| 3-day to 1-week | 7% ≤ CC ≤ 16% | 14% ≤ CC ≤ 28% | 58% ≤ CC ≤ 81% | 58% ≤ CC ≤ 81% |
| 1-month to 3-month | 22% ≤ CC ≤ 30% | 30% ≤ CC ≤ 31% | 43% ≤ CC ≤ 53% | 43% ≤ CC ≤ 53% |

- Approach B: Integrated Energy System

| | EnergyPLAN - Ambitious Wave Scenario - Case study I [10.6 - 12.6 - 4 - 0 TWh/y] | | | |
|---|---|---|---|---|
| | Worst-case Scenario | Peak demand Scenario | Hi-RES Scenario | Best-case Scenario |
| 1-hour to 6-hour | 3% ≤ CC ≤ 5% | 75% ≤ CC ≤ 79% | 92% ≤ CC ≤ 93% | 83% ≤ CC ≤ 90% |
| 12-hour to 24-hour | 2% ≤ CC ≤ 5% | 42% ≤ CC ≤ 70% | 81% ≤ CC ≤ 88% | 78% ≤ CC ≤ 88% |
| 3-day to 1-week | 7% ≤ CC ≤ 19% | 19% ≤ CC ≤ 24% | 58% ≤ CC ≤ 81% | 58% ≤ CC ≤ 81% |
| 1-month to 3-month | 22% ≤ CC ≤ 30% | 30% ≤ CC ≤ 30% | 43% ≤ CC ≤ 53% | 43% ≤ CC ≤ 53% |

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**Questions or comments?**
**Thank you for your attention**

**Julia Fernández Chozas**
<info@juliafchozas.com>

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