

Capacity Credit of Wind, Wave and Solar Photovoltaic

Final Project Presentation



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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.

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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.

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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

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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

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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:
 $CC_{REmix} = 3\% - 27\%$ in an electricity-only system
 $CC_{REmix} = 3\% - 70\%$ in an integrated energy 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.

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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 intradaily 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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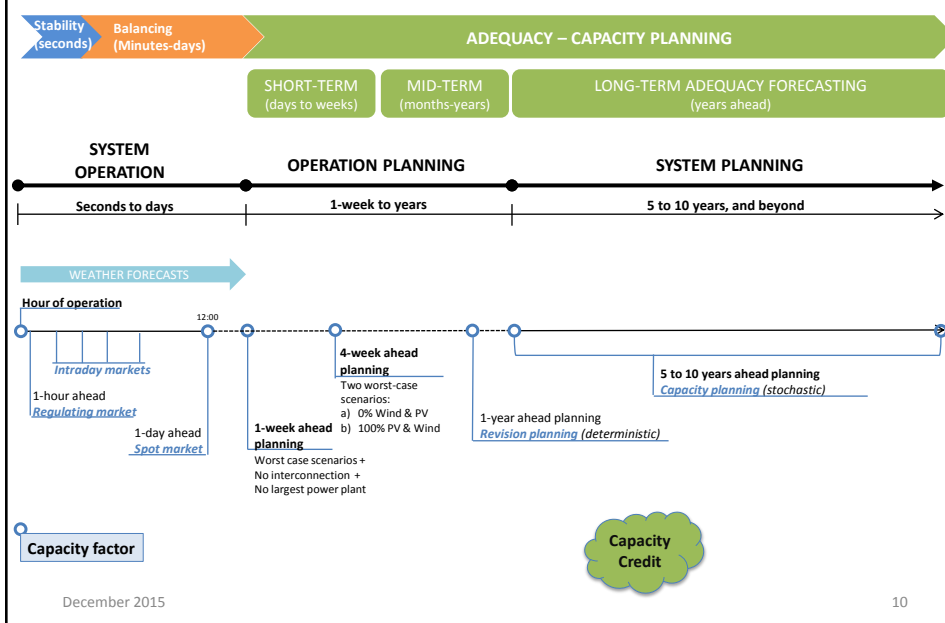
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Project Methodology

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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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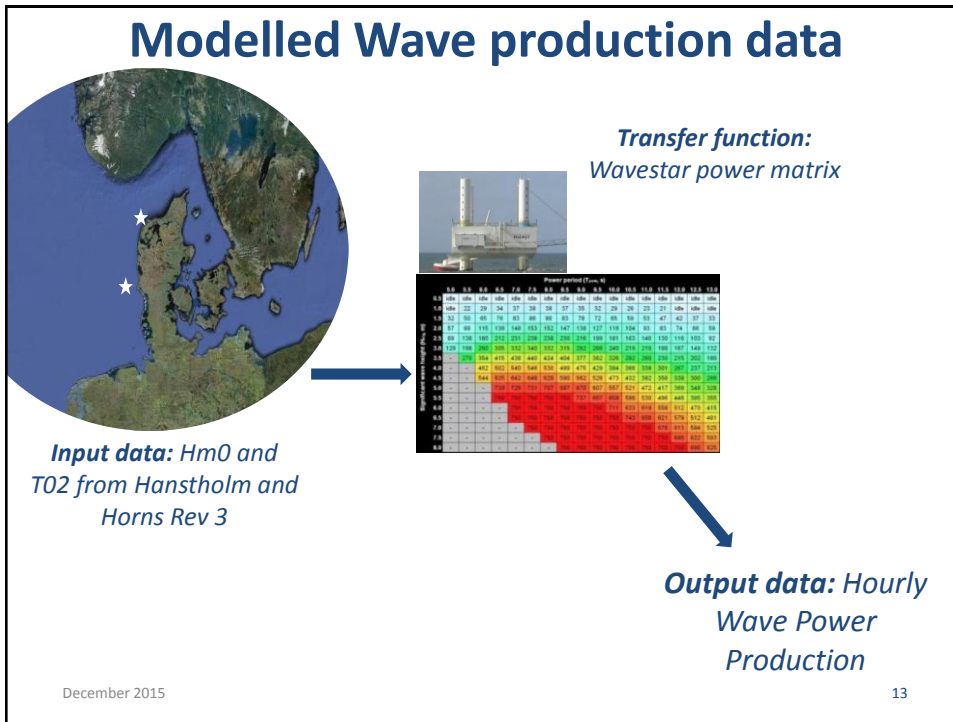
Renewable Energies of the Analysis

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

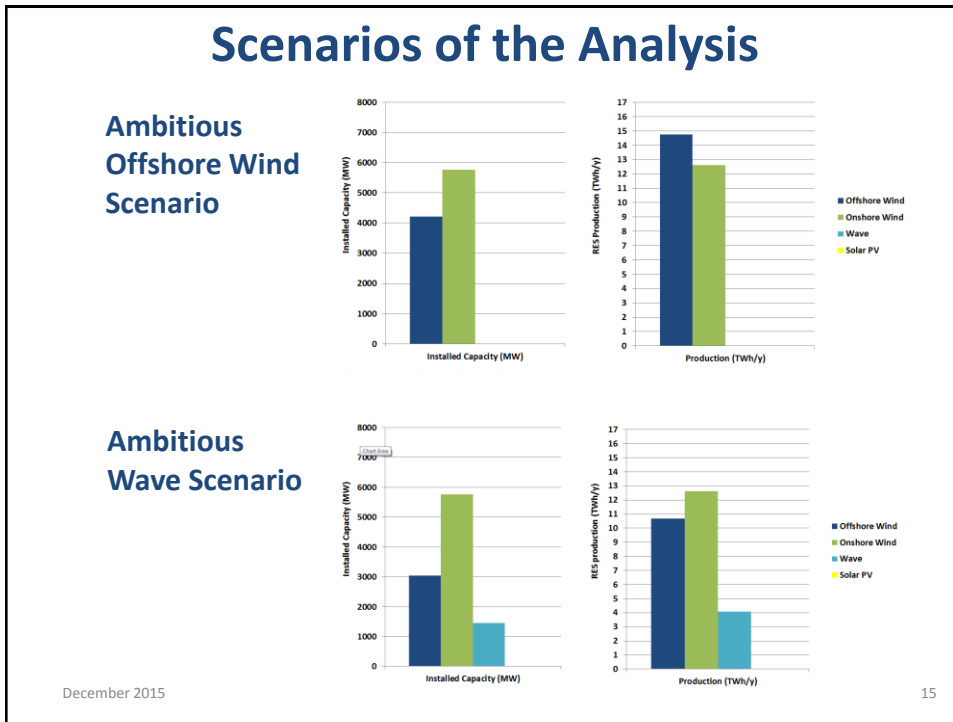


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- ## Scenarios of the Analysis
- i. Year2013
 - ii. Ambitious Offshore Wind Scenario
 - iii. Ambitious Onshore Wind Scenario
 - iv. Ambitious Wave Scenario
 - v. Ambitious Solar PV Scenario
 - vi. Combined RES Scenario
 - vii. Other scenarios: wind-only, 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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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.

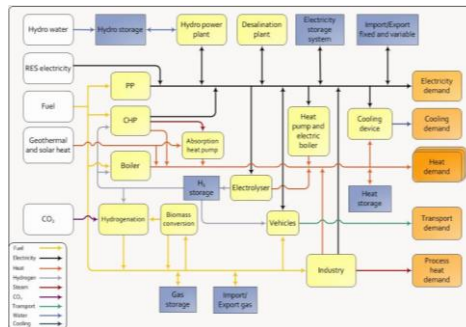
- 1-hour averaged
- 3-hour averaged
- 6-hour averaged
- 12-hour averaged
- 24-hour / 1-day averaged
- 3-hour averaged
- 7-day / 1-week averaged
- 1-month averaged
- 3-month averaged

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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**

Cross-correlation offshore wind and wave production, year2013

Cross-correlation onshore wind and wave production, year2013

	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

year2013

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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

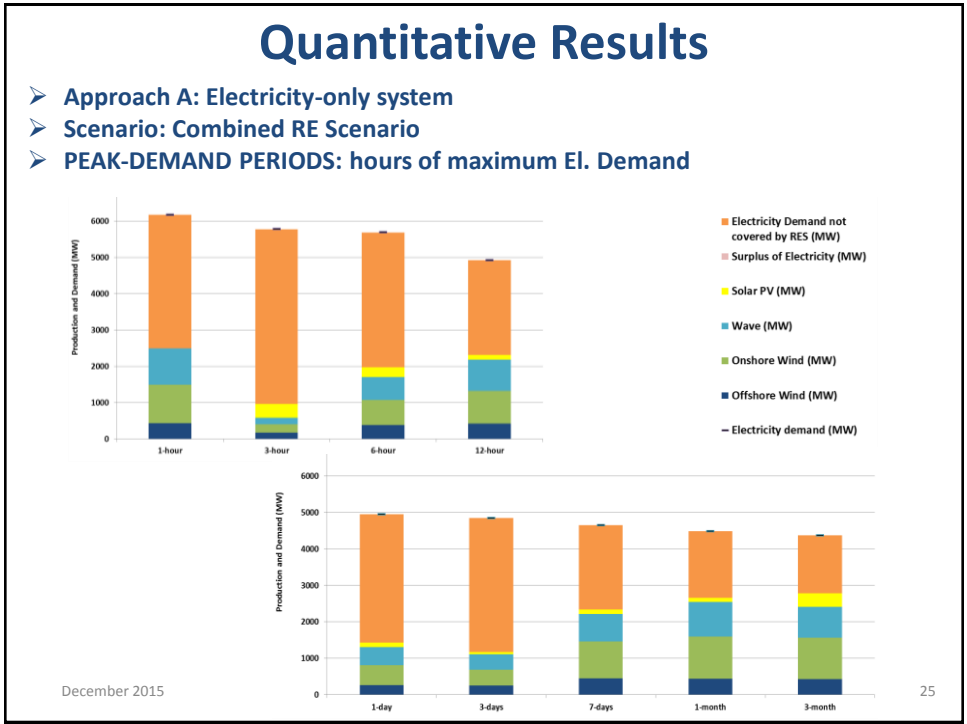
- Approach A: Electricity-only system
- Scenario: Combined RE Scenario
- PEAK-DEMAND PERIODS: hours of maximum El. Demand

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%

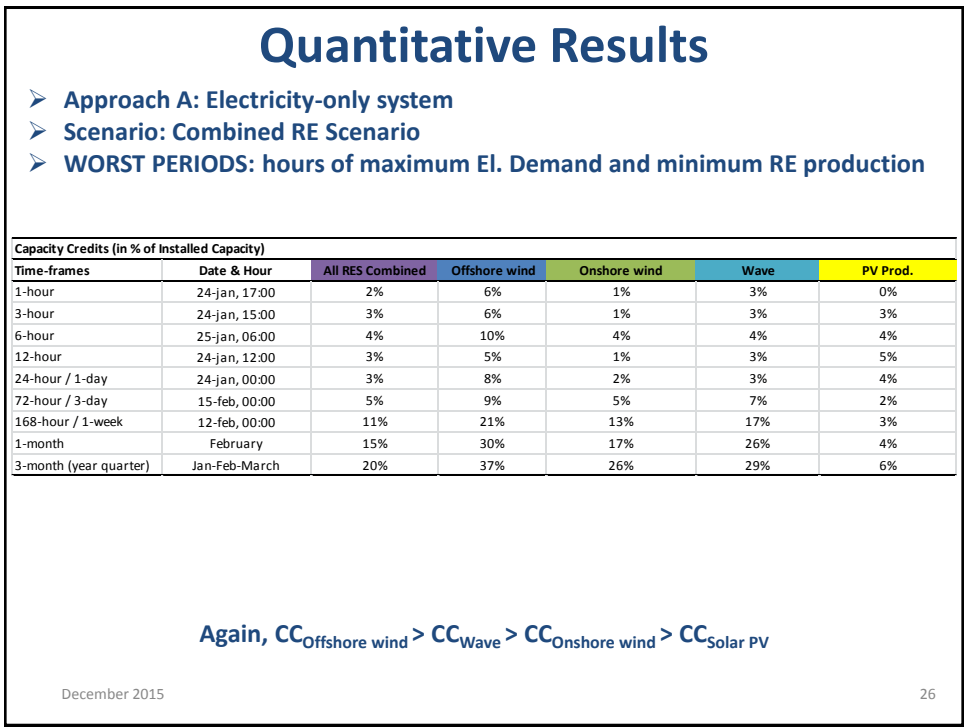
As a general trend $CC_{\text{Offshore wind}} > CC_{\text{Wave}} > CC_{\text{Onshore wind}} > CC_{\text{Solar PV}}$

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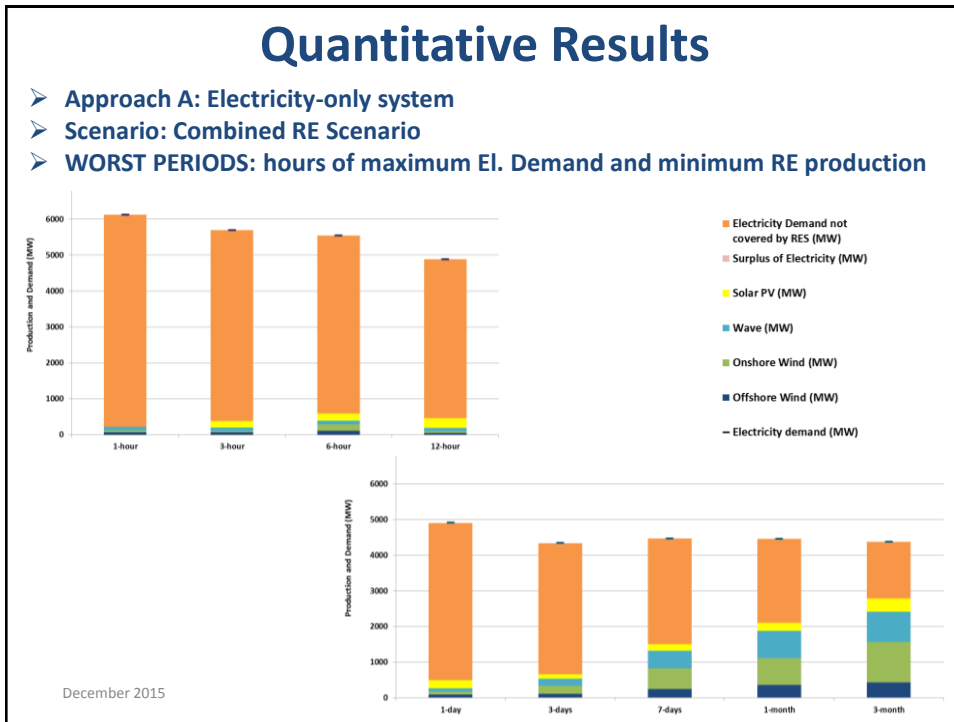
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Quantitative Results


- 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

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