Protecting European Civilisation: Europe's SuperGrid

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Introduction

1. What Europe will look like in 2050.
   I. What will our electrical demand be?
   II. How influential will rooftop solar and storage be?
   III. What effect will electric vehicles have on this demand?
   IV. How will the demand be met by renewables?

2. What Resources are available to meet this demand.
   I. Where will the main sources of generation be located?
   II. How can we access the areas of great potential?

3. How we can distribute this renewable energy.
   I. How do we interconnect countries with great wind and/or solar resources with those with weaker renewable resources?
   II. What are the challenges involved?

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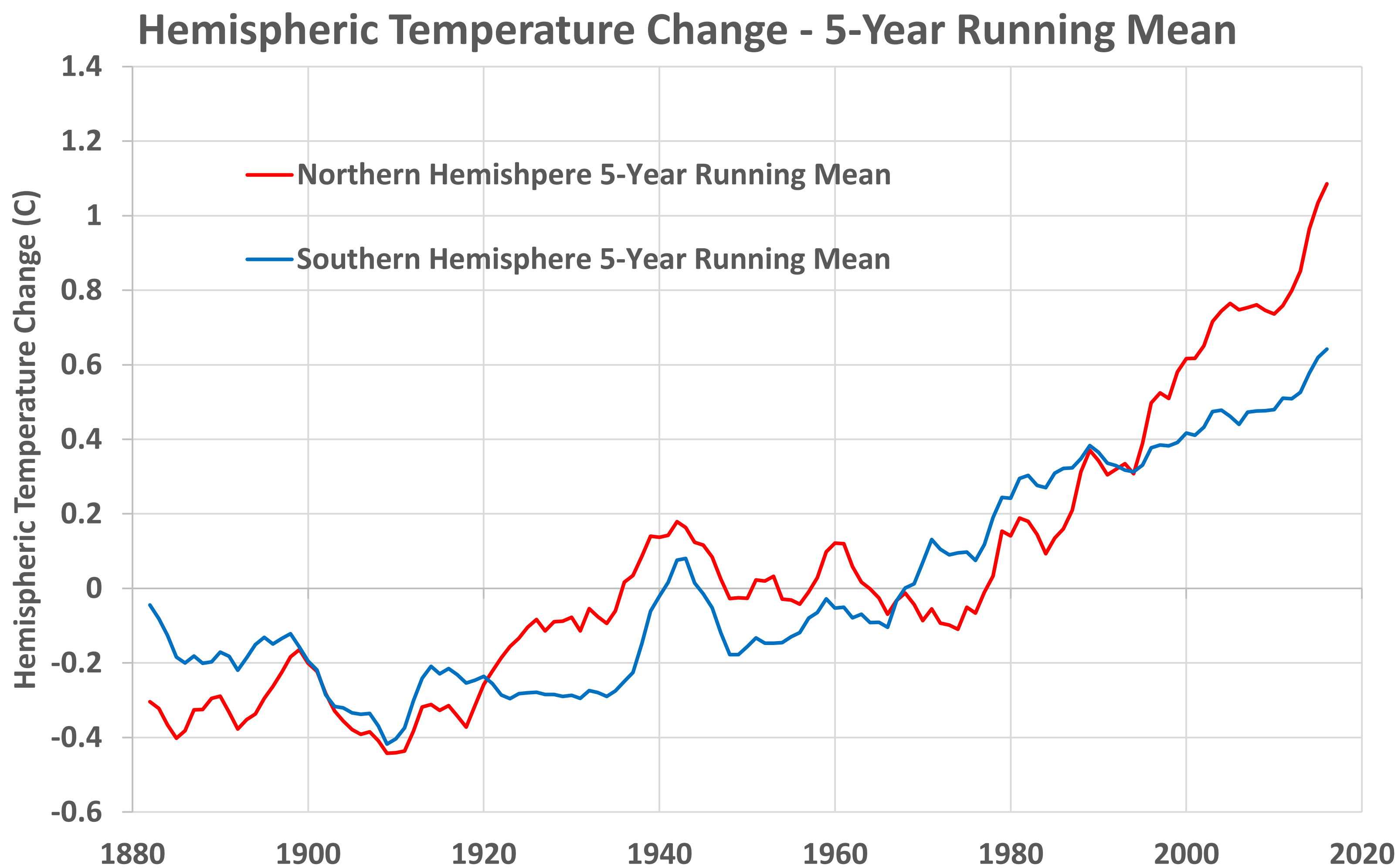
Hemispheric Temperature Change – Annual Mean



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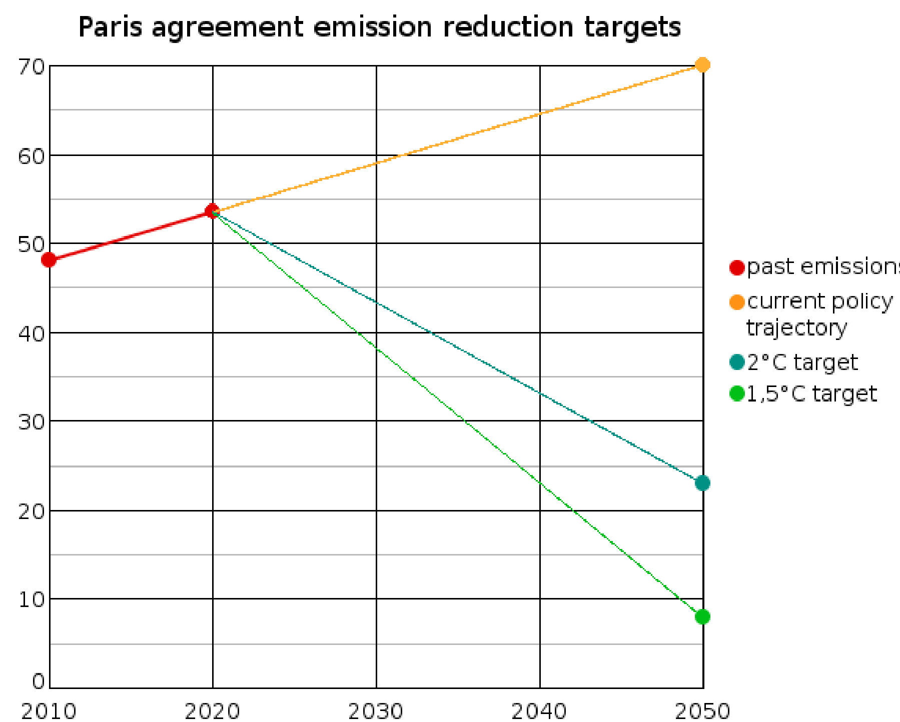
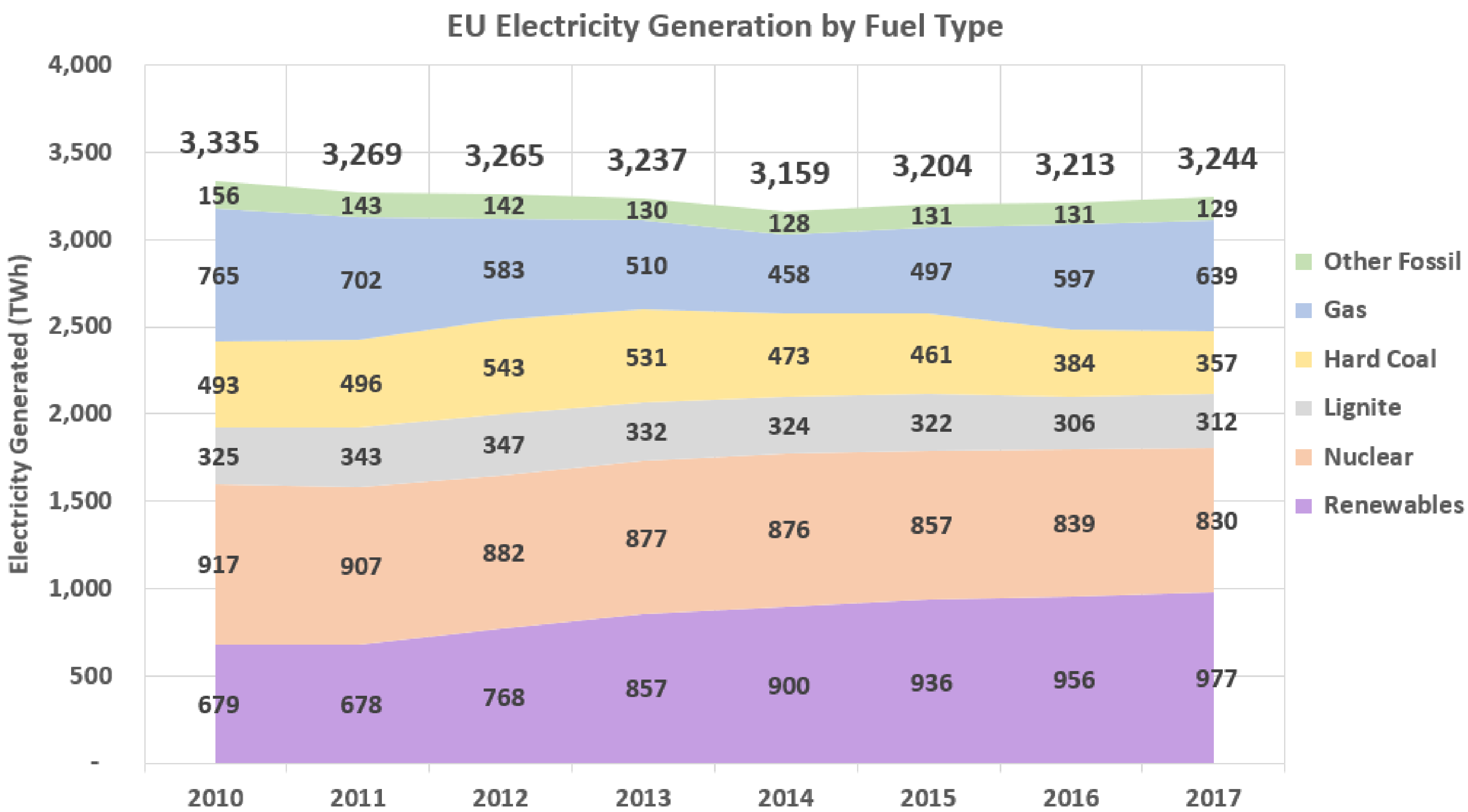
EU 2020 Strategy and the Paris Climate Agreement

- 20% reduction in greenhouse gas emissions (from 1990 levels).
- 20% of EU energy from renewables
  - This target varies between countries depending on their starting points.
- 20% increase in energy efficiency.
- The 2020 strategy feeds into future targets such as reducing EU emissions by 40% by 2040.
- All EU countries are also part of the Paris Climate Agreement.



Source: UNEP

What does European demand look like now?



Source: Eurostat

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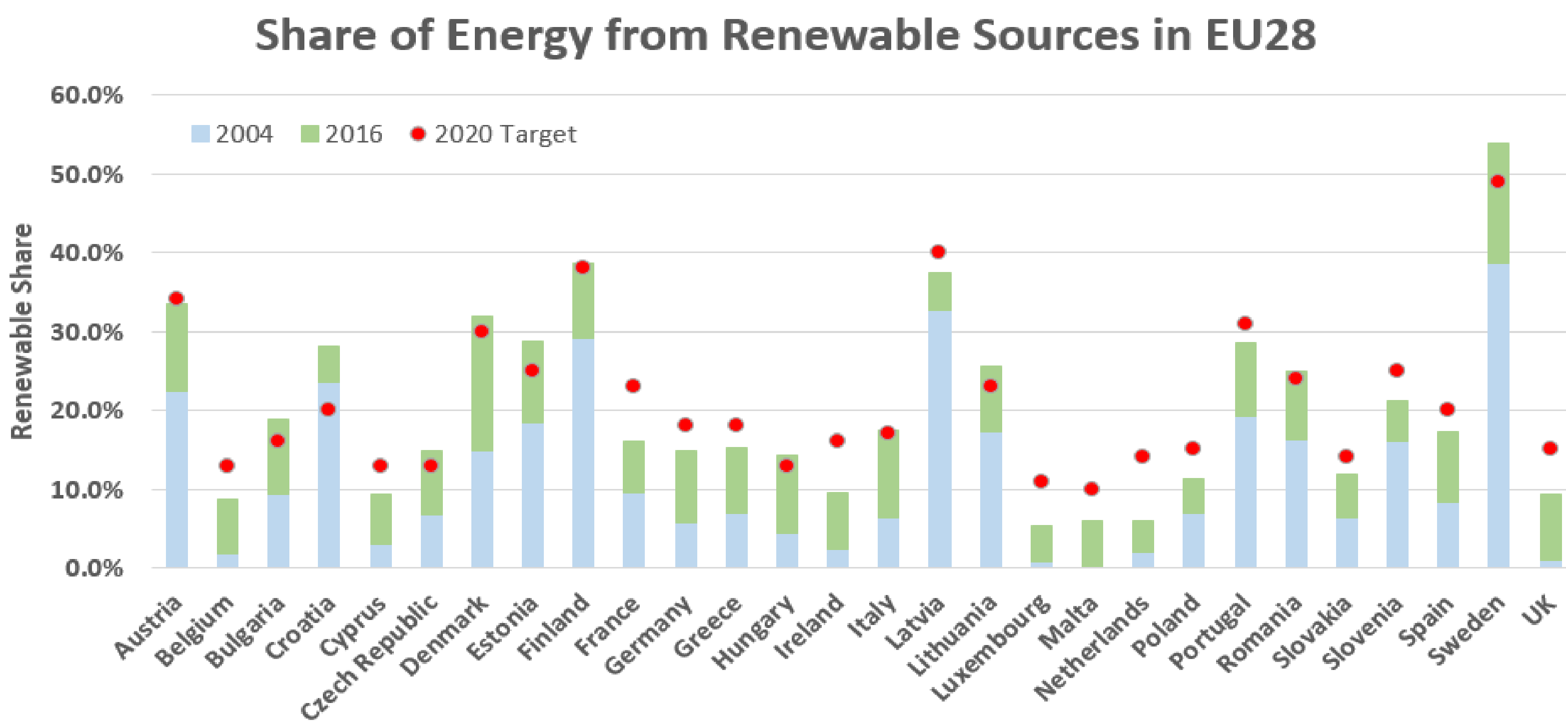
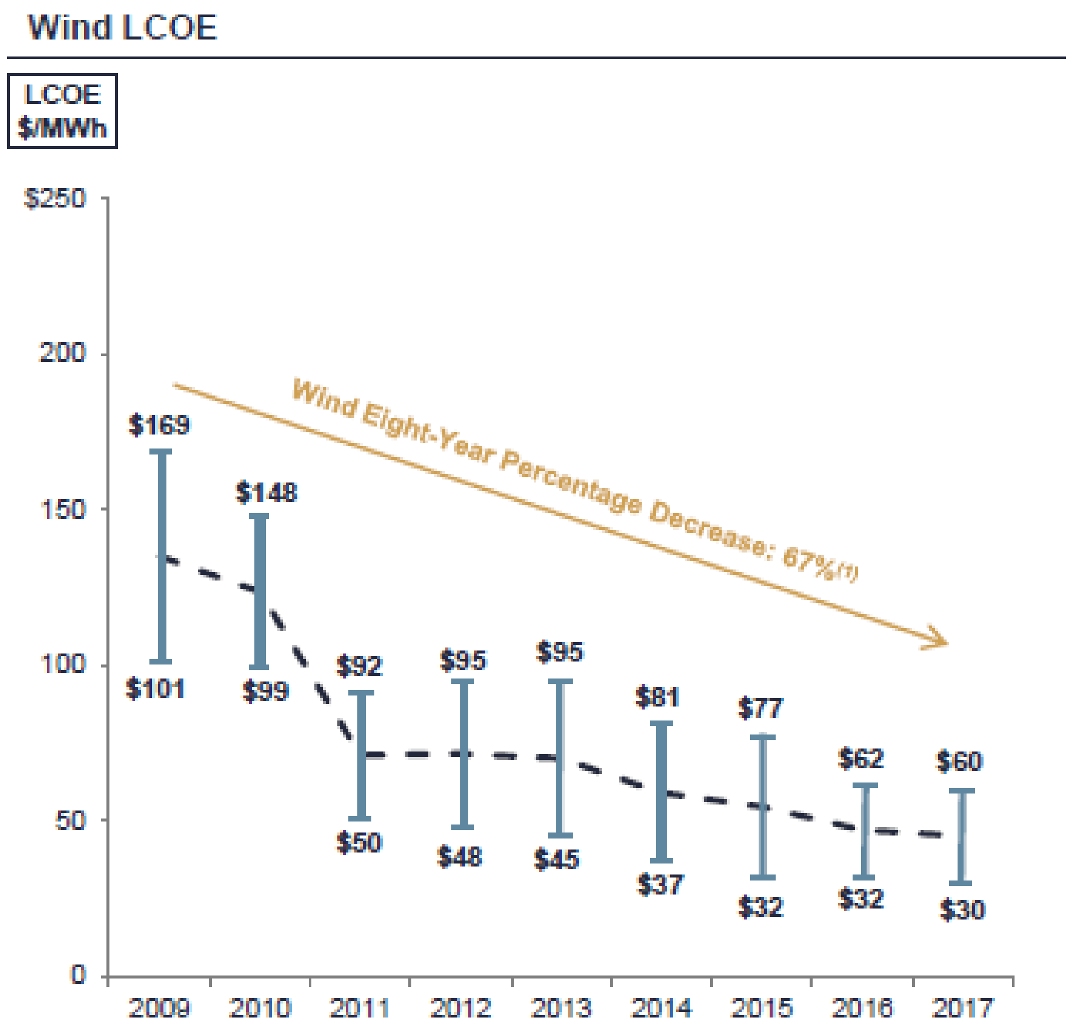
Current State of Renewables in Europe



- 2016 data shows that renewables had a 17% share of energy in the EU28.
- 11 Countries have already met and exceeded their 2020 targets.
- Denmark, Latvia, Austria, and Finland already have a renewable share over 30%.
- Sweden has a renewable share of 53.8%.

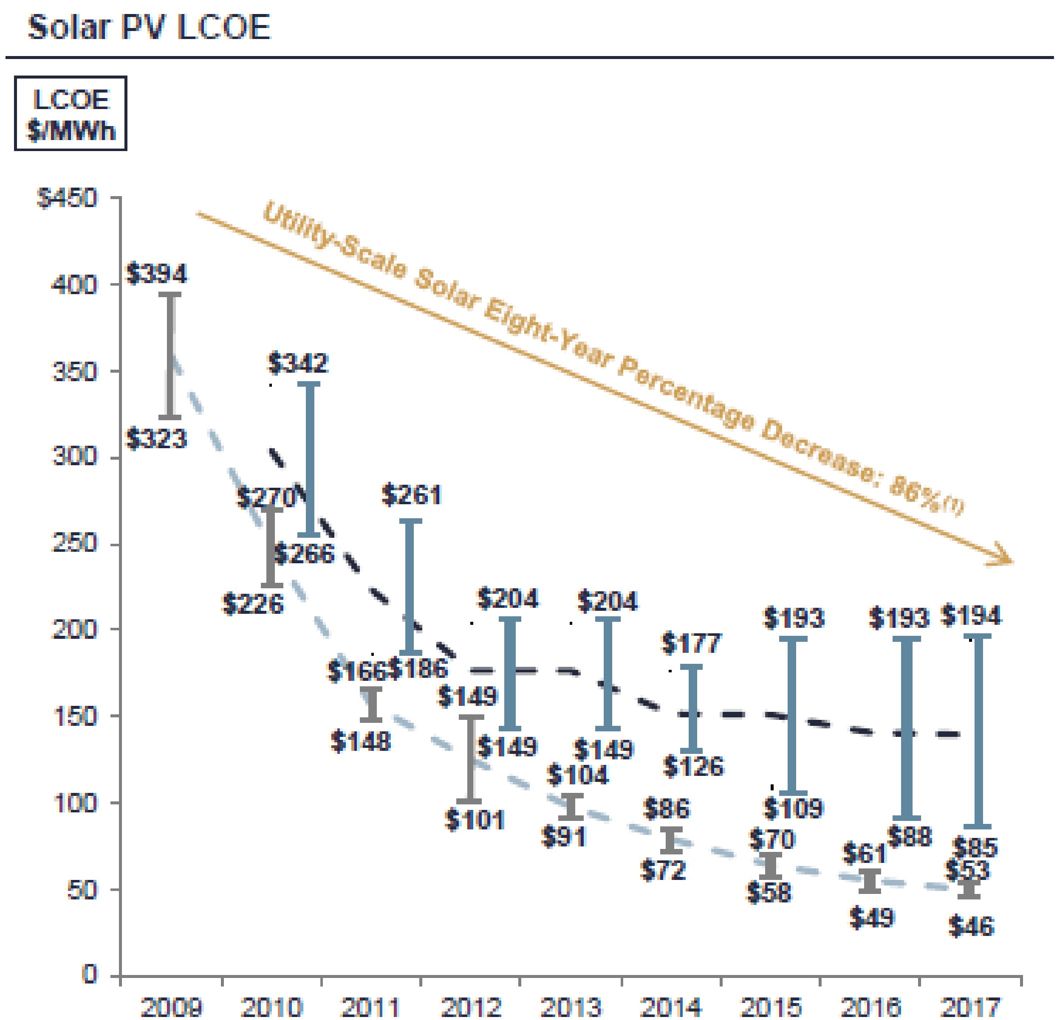
Source: Eurostat

Dropping Cost of Wind



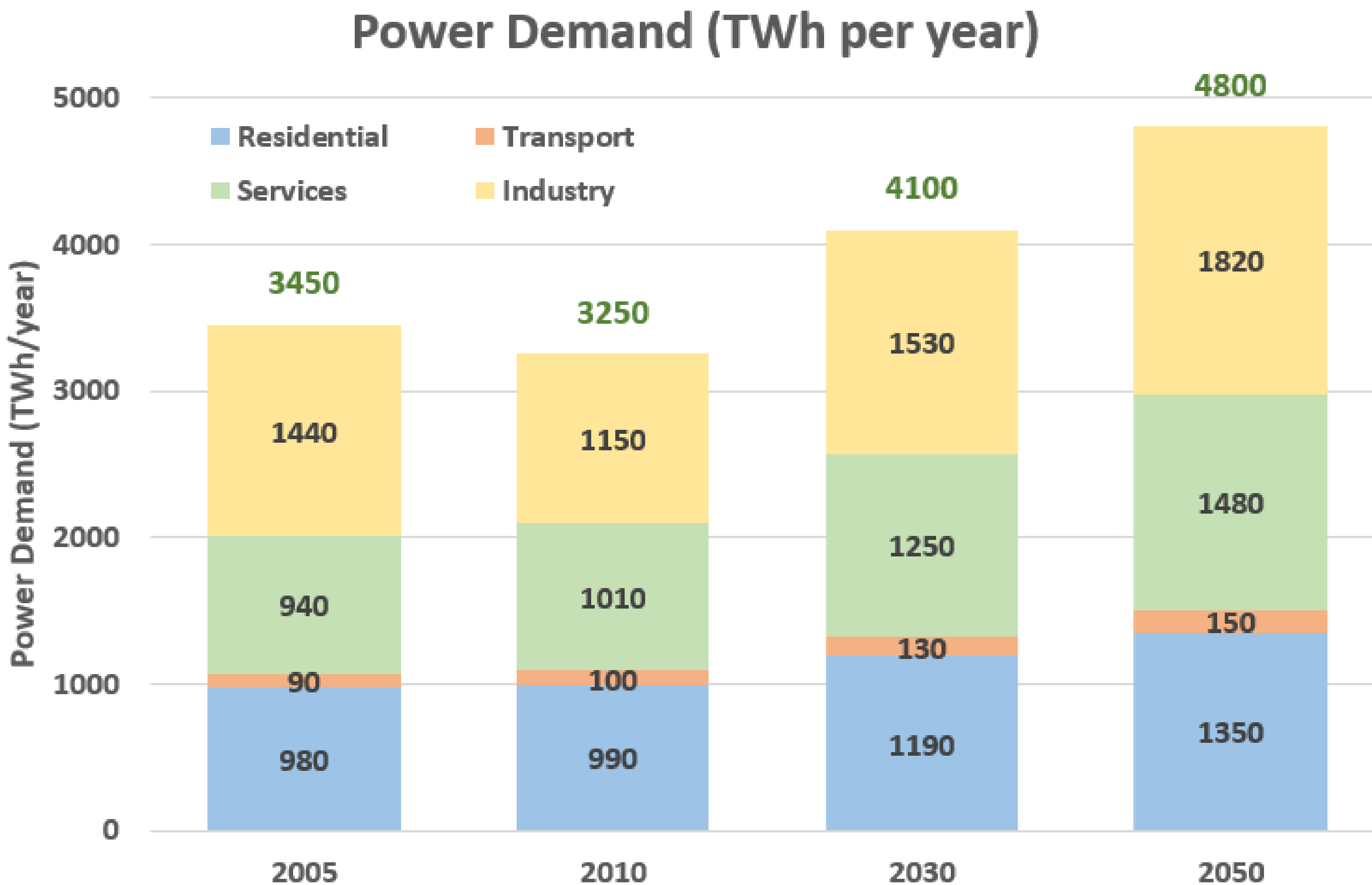
Source: Lazard

Dropping Cost of Solar



Source: Lazard

EU Electricity Demand – Future Trend (Baseline)



Source: SuperNode Research

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Future Power Demand - Assumptions

Reduction in publically supplied electricity through Solar PV and Storage				
Sector	**2005**	**2010**	**2030**	**2050**
Residential	0	0	297.5	675
Transport	0	0	0	0
Services	0	0	125	296
Industry	0	0	153	364
Total	0	0	575.5	1335

- The assumptions made for calculating the effect of Solar PV and storage on future power demand are:
  1. 25% of residential demand will be met through rooftop solar along with battery storage by 2030, with this increasing to a 50% reduction from rooftop solar and storage by 2050.
  2. The service industry will also benefit from a 10% reduction in power demand by 2030, increasing to 20% by 2050.
  3. The manufacturing industry can benefit from reducing its power demand by 10% by 2030 and by 20% by 2050.

Source: SuperNode Research

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Rooftop Solar – How can these reductions be met?

- Meeting the 50% reduction in residential demand would require approximately 128 million homes in Europe to adopt 12m^2 of Solar PV. Assumptions made:
  - 12m^2 of Solar PV on each roof.
  - Panel conversion efficiency of 30%. This assumes that continued development takes the current efficiency from 17% - 18% to 30%.
  - Solar Radiation (kWh/m^2/day) was obtained by taking an average of the solar radiation from Dublin, Berlin, Stockholm, Copenhagen, Seville, Athens, and Naples.

- The 20% reduction in demand from the services sector from solar, under the same assumptions as residential, found that approximately 37.5 million premises will require rooftop solar in order to meet this reduction.
  - 18m^2 of Solar PV on each roof.

- For the industrial sector, it was assumed that, on average, 30m^2 of solar PV could be installed per premises. This means that in order to meet the 20% target, 27.5 million rooftops would be required.
  - 30m^2 of Solar PV on each roof.

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Future Power Demand – Energy Efficiency Assumptions

Reduction in publically supplied electricity through Energy Efficiency Measures				
Sector	**2005**	**2010**	**2030**	**2050**
Residential	0	0	119	270
Transport	0	0	0	0
Services	0	0	62.5	148
Industry	0	0	30.6	72.8
Total	0	0	212.1	490.8

- The assumptions made for calculating the that energy efficiency measures would have on future power demand are:
  - A 10% reduction in demand would be seen by 2030, further increasing to a 20% reduction by 2050 for residential demand.
  - A 5% reduction in demand from the services sector by 2030, increasing to a 10% reduction in demand by 2050.
  - Industry demand reducing by 2% by 2030, and by 4% by 2050.

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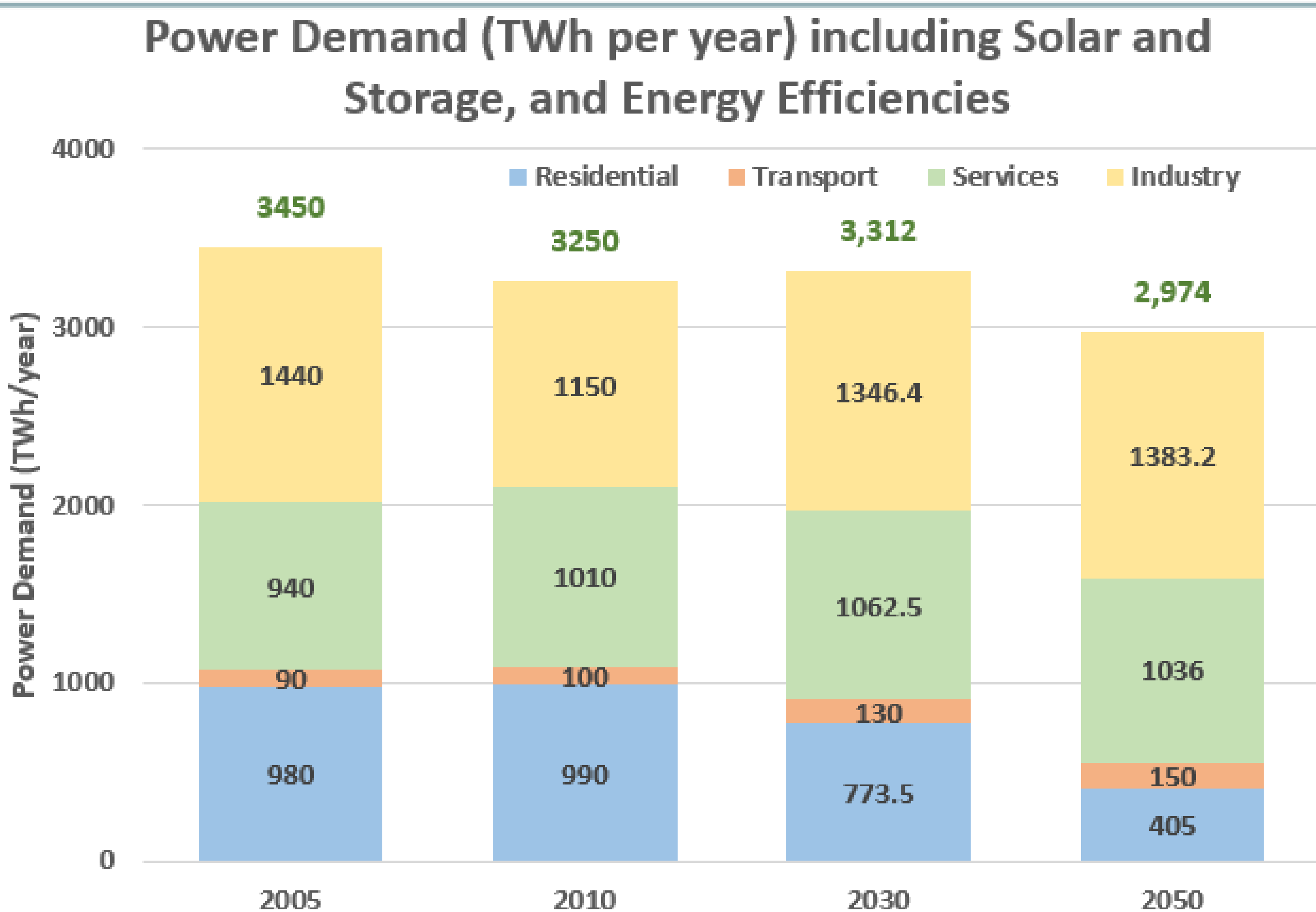
EU Electricity Demand – Future Demand so far



Source: SuperNode Research

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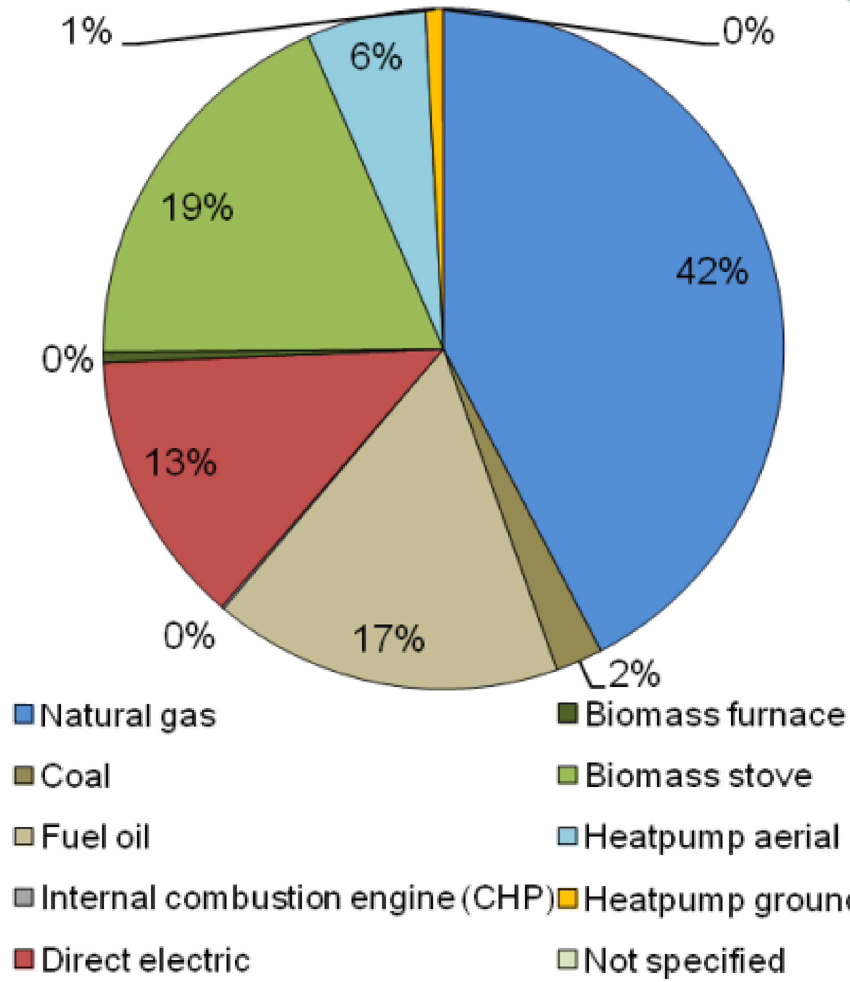
EU Space Heating and Cooling Loads

- Calculated total EU space heating load is 3,158 TWh/annum, 1,904 TWh/annum is Residential, 758 TWh/annum is Service based, 496 TWh/annum is Industry
- Calculated total EU space Cooling load is 540 TWh/annum.
- Improvements in insulation, optimised ventilation with heat recovery, increased urbanisation (heat islands) and global warming will lead to a decrease of the load.
- Growth of population, dwelling size, and comfort levels will lead to an increase in space heating load.



Source: European Commission

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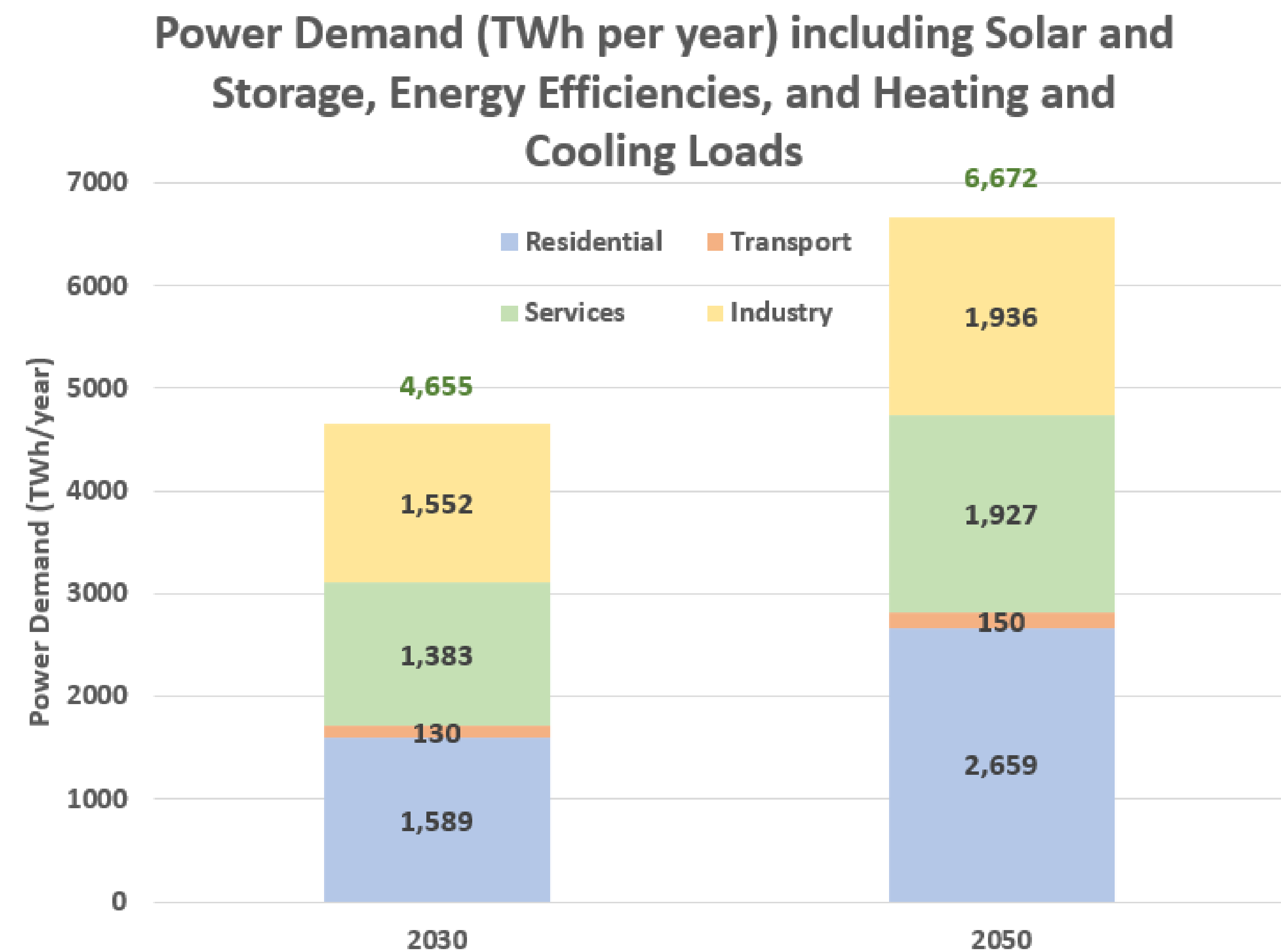
EU Electricity Demand – Future Demand excl. Electrification of Transport



Source: SuperNode Research

Electric Vehicles – What effect will they have?

- The first key assumption was that car ownership will remain the norm.

- The following assumptions were made with regards to performance in 2050:
  - Average Consumption: 12.67 kWh/100km.
  - Average Annual Mileage: 15,000 km.
  - Annual Power Usage per car: 1,900 kWh.
  - Average Charge Time (240V): 8 hours.

- Charging of EV vehicles was mostly performed during the night using smart chargers.

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Commercial Electric Vehicles – What effect will they have?

- The following assumptions were made with regards to performance in 2050:

Parameter	Light Duty Vehicles	Heavy Duty Vehicles	Buses	Untis
Average Consumption	20	80	25	kWh/100km
Average Annual Mileage	21,000	150,000	70,000	km
Annual Power Usage per Vehicle	4,200	120,000	17,500	kWh

- The timing for the charging of commercial vehicles will be very different to private cars.

- Fast charging for buses exist. ABB to install 450kW charger for buses at multiple worldwide locations.

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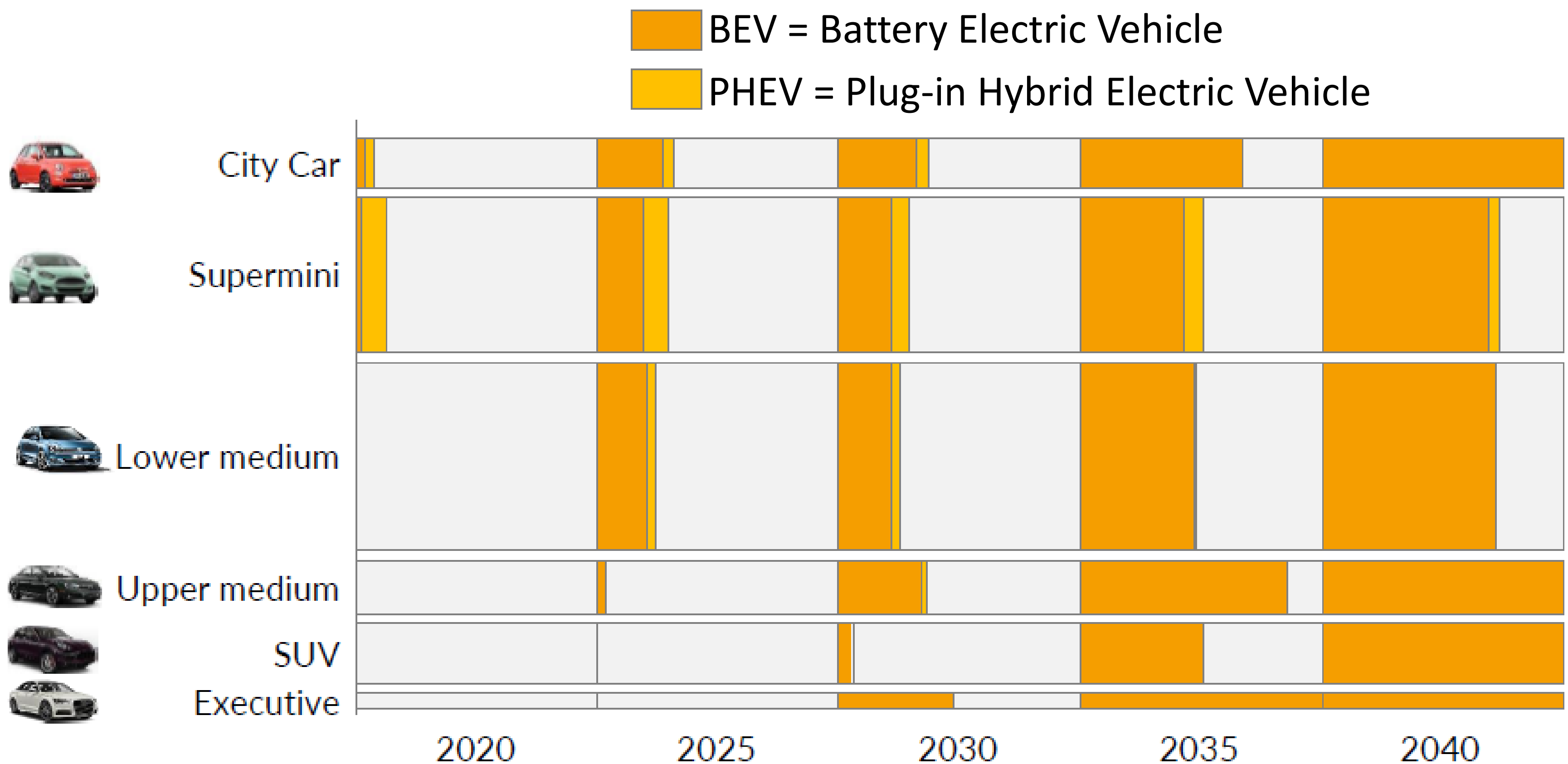
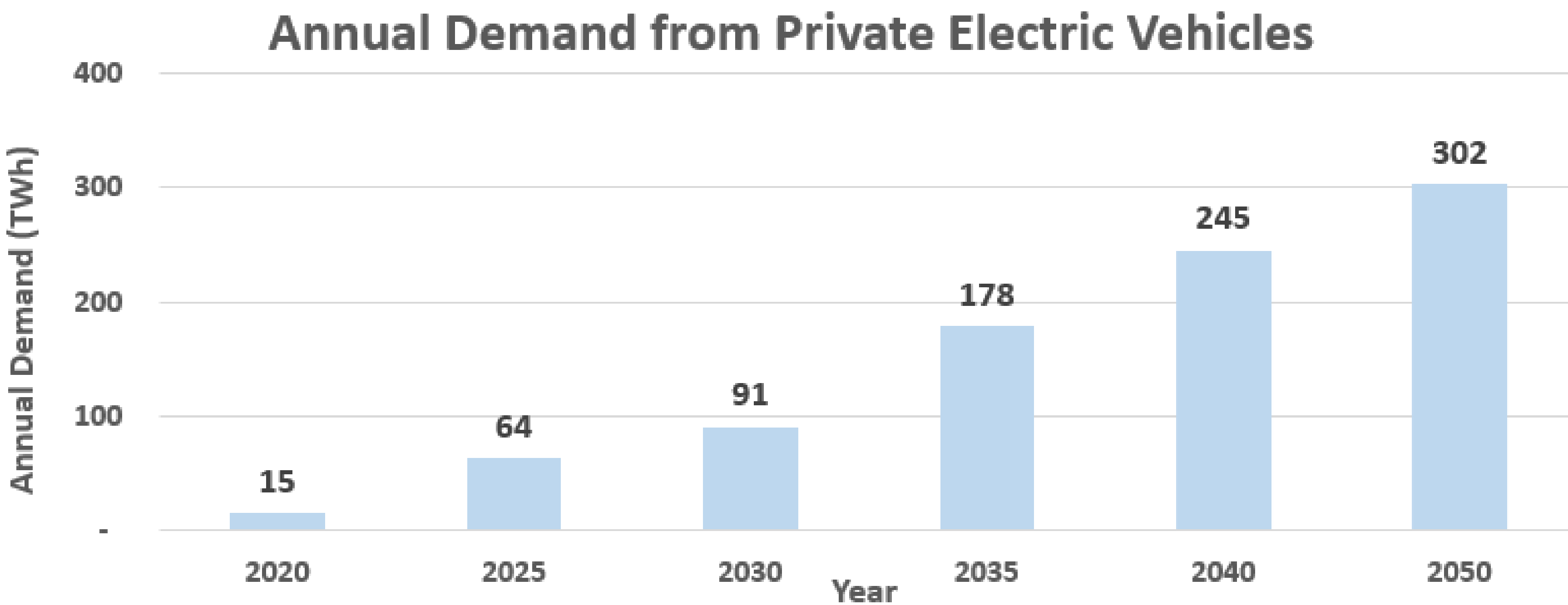
Growth of Electric Vehicles



	2020	2025	2030	2035	2040
Total market share	**5%**	**21%**	**30%**	**59%**	**81%**

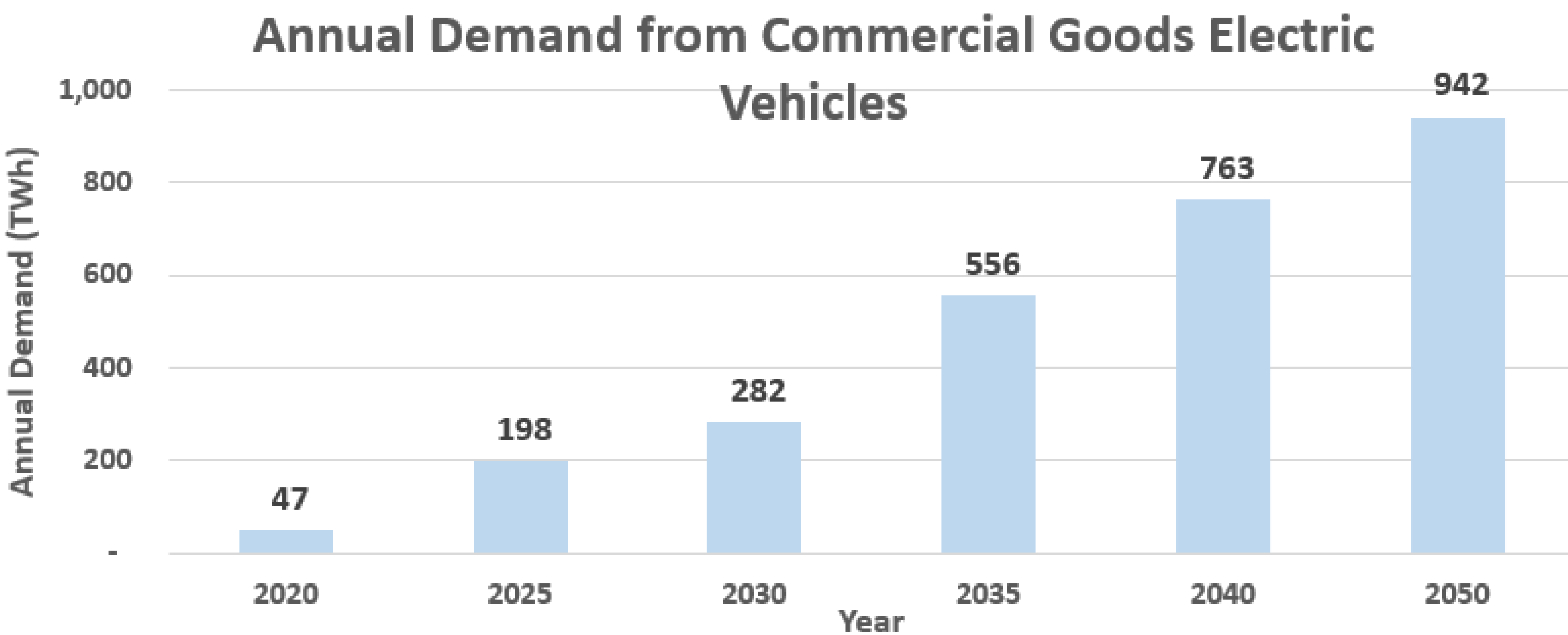
Source: Aurora Energy Research

Annual Demand From Private EV's



Source: SuperNode Research

Annual Demand From Commercial EV's



Source: SuperNode Research

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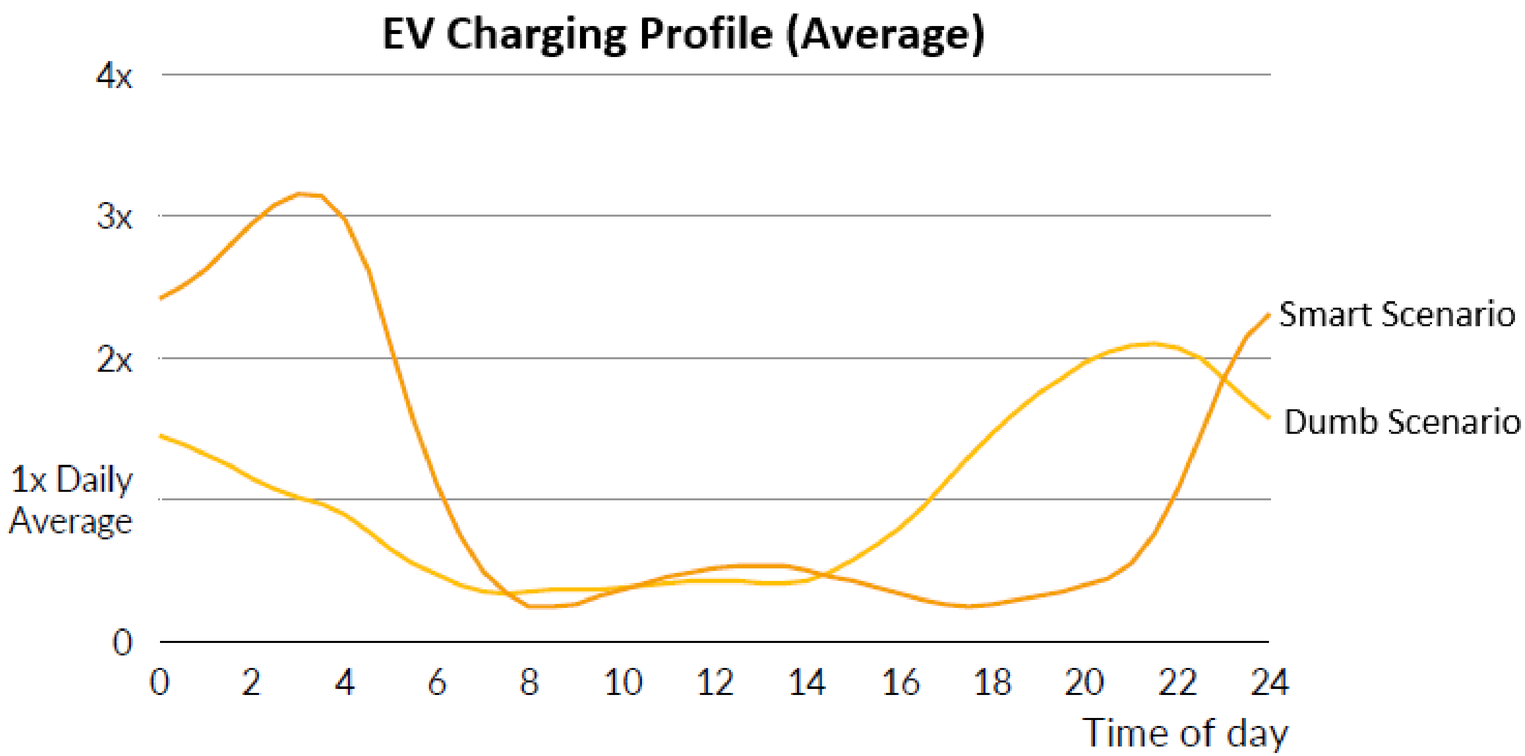
Importance of when Charging Occurs



- Smart Scenario:
  - 10% status quo charging.
  - 90% optimised charging.
- Current Scenario:
  - 90% status quo charging.
  - 10% optimised charging.

Source: Aurora Energy Research

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Importance of when Charging Occurs – Charging Tech

- BMW now offer wireless charging capabilities for its 5 series saloon.
- QualComm have been researching wireless charging while driving.

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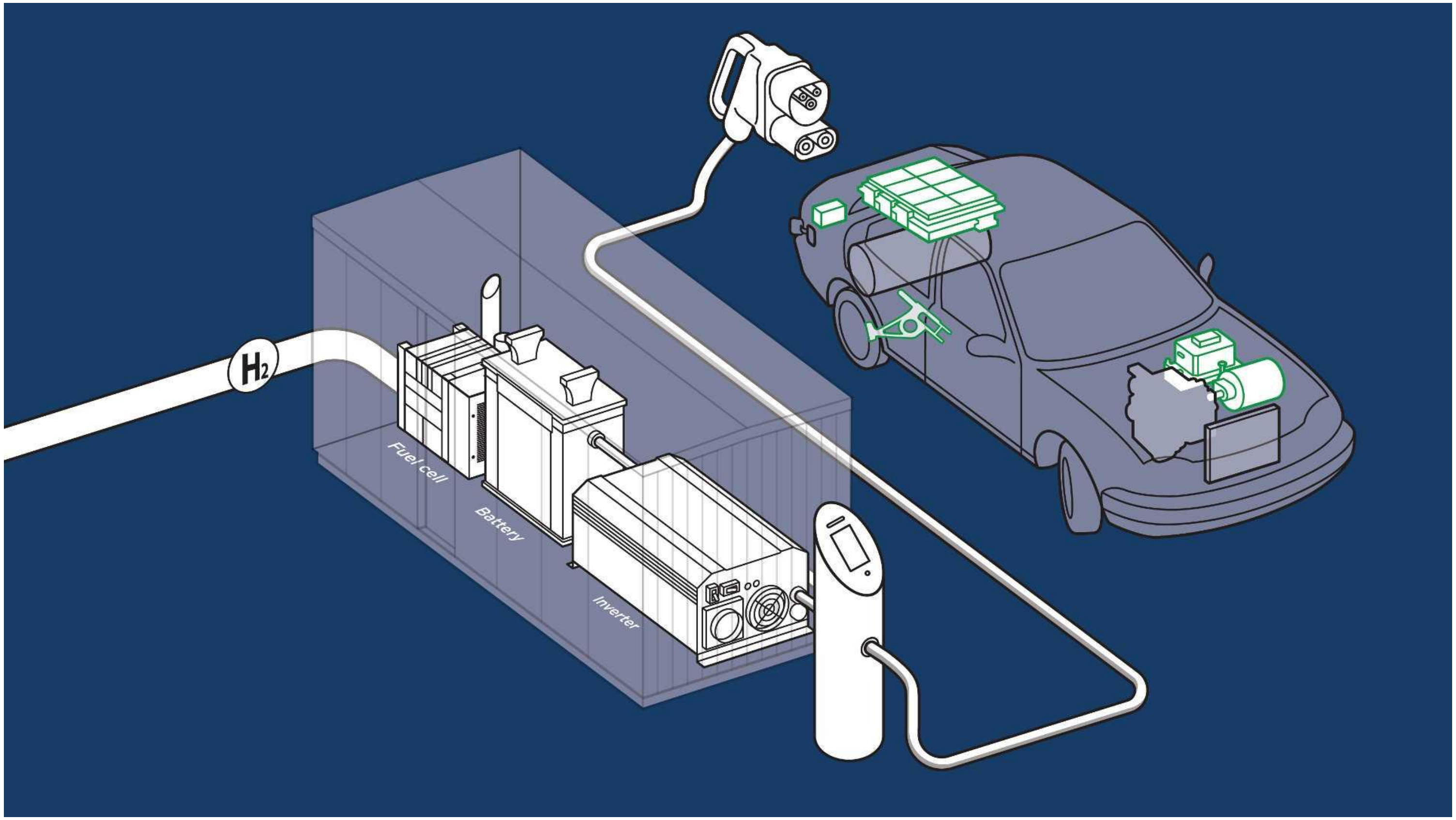
New Charging Technology



- Small-scale hydrogen to power charging stations

Effect of Private EV charging on Current Peak Demand

		Effect on Peak Demand	
EU	**Peak Demand (GW)**	**Smart**	**Current**
Winter	530	+2.89%	+17.58%
Summer	560	+2.73%	+16.64%

Scenario	**Increase in Peak Demand (GW)**
Smart	+15.30
Current	+93.20

- The effect of people charging their EV's at any time leads to a 17.6% increase in peak demand in the Winter, and a 16.6% increase in the summer.

- Smart charging however has a much smaller effect on peak demand, and only leads to a 2.9% increase in peak demand during the winter, and a 2.7% increase during the summer.

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Effect of Commercial EV charging on Peak Demand

		Effect on Peak Demand	
EU	**Peak Demand (GW)**	**Smart**	**Current**
Winter	530	+8.49%	+50.94%
Summer	560	+8.04%	+48.21%

Scenario	Increase in Peak Demand (GW)
Smart	+45.00
Current	+270.00

- The effect of people charging commercial and private EV's at any time leads to a 50.9% increase in peak demand in the Winter, and a 48.2% increase in the summer.

- Smart charging however has a much smaller effect on peak demand, and only leads to a 8.5% increase in peak demand during the winter, and a 8.0% increase during the summer.

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Effect of EV charging on Peak Demand - Commercial Electric Vehicles

- The introduction of Autonomous HGV's will usher in an era of 24hr goods transport.

- Without regulation, commercial vehicles will massively increase the peak demand.
  - As with cars, the timing of charging is crucial.

- Charging stations could have battery storage which may be charged by PV during the day and from the grid during periods of low demand.

- The use of solar PV on commercial vehicles will also alleviate increases in peak demand.

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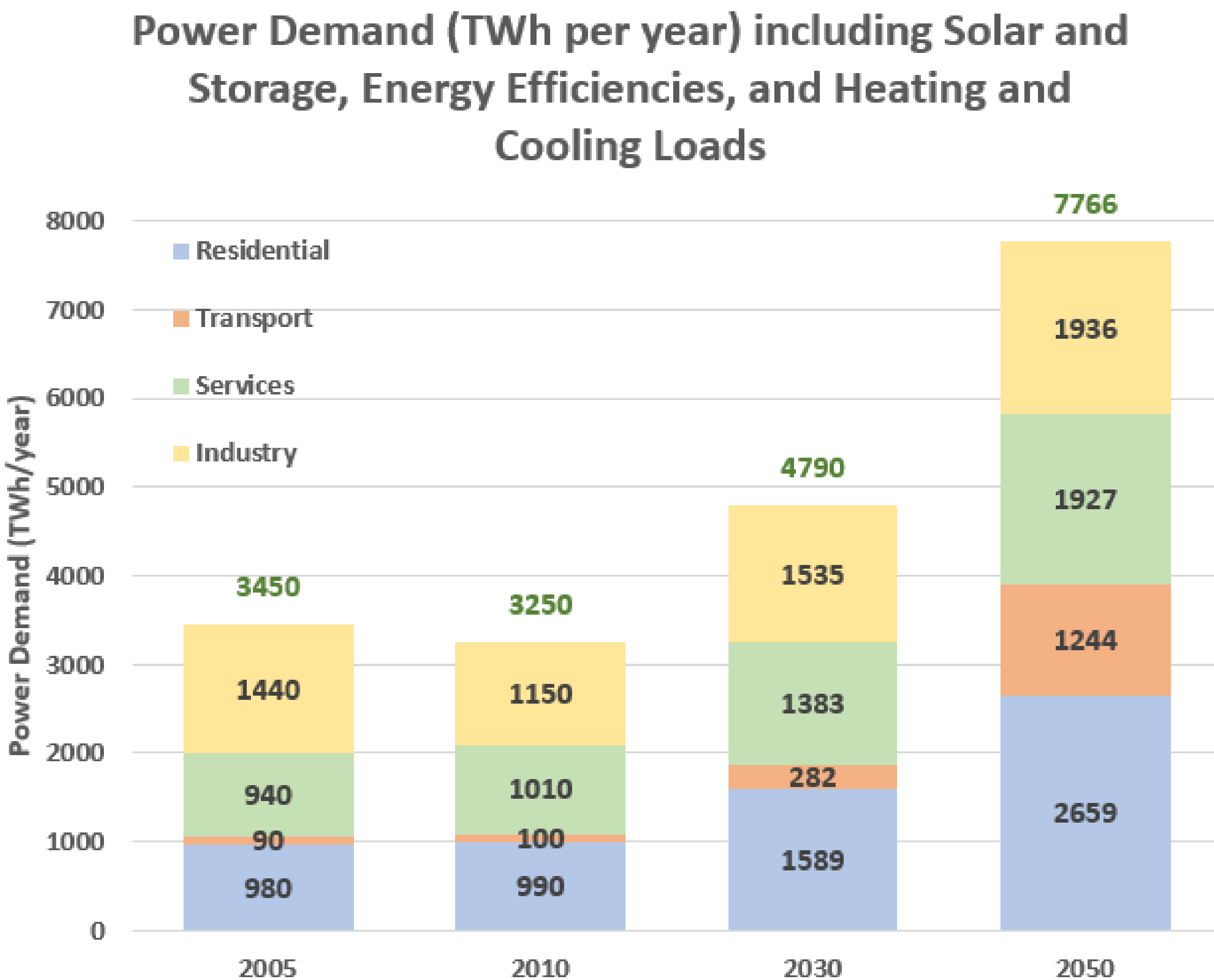
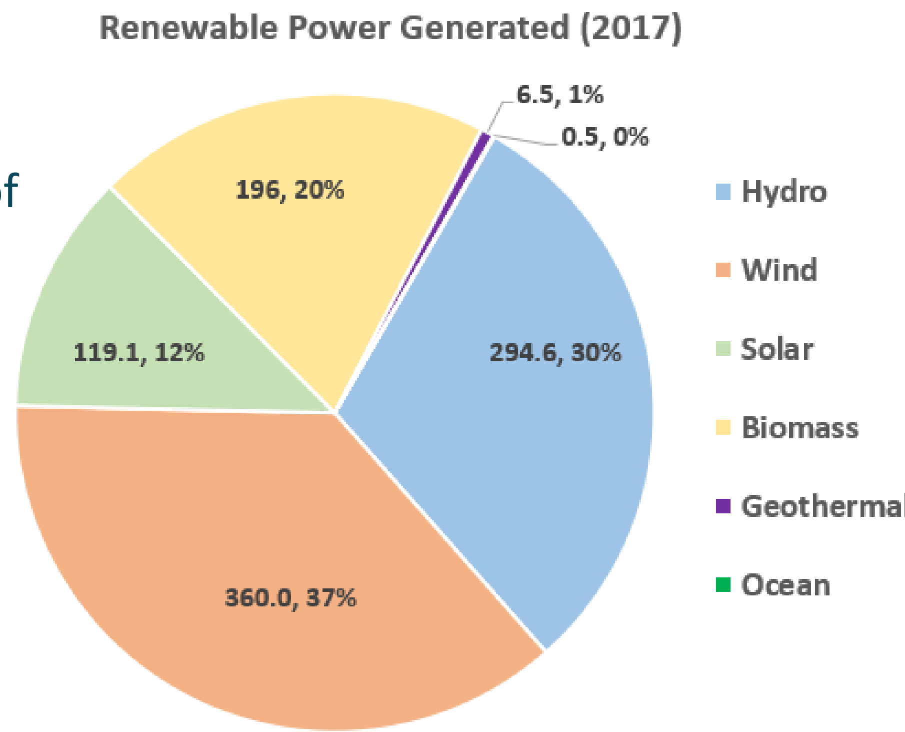
Effect of EV charging, Heating, and Cooling on Power Demand – Final Demand



Source: SuperNode Research

How Renewables can meet this Demand: Current Trend

- In 2015, Renewable Energies accounted for 77% of new EU generating capacity.
- Renewables generated 976.7 TWh of electricity in 2017 (30% of total demand).
- In 2016, 86% of new capacity was from renewable energies.
- As of 2017, there was 428 GW of Renewable capacity installed, including:
  - 169 GW of Wind.
  - 137 GW of Hydro (excluding pumped storage).
  - 107 GW of Solar PV.



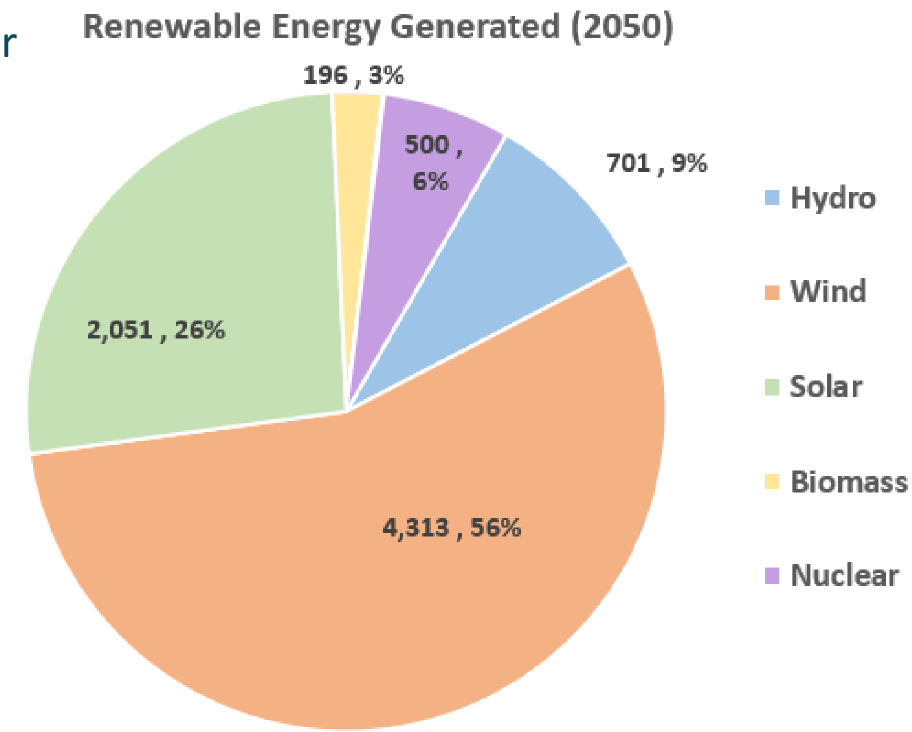
2015 Renewables Total: 977 TWh

Source: EWEA

How Renewables can meet this Demand: Future Need

- The assumptions made for 2050:
  - Wind turbines have a capacity factor of 60%.
  - By 2050, 59% of total demand will come from Wind.
  - Solar PV has a capacity factor of 30%.
  - By 2050, 35% of total demand will come from Solar.
  - All other renewable source remain at 2017 capacities in 2050.

- The required Total Renewable capacities are:
  - Hydro: 160 GW (23 GW New)
  - Wind: 820 GW (651 GW New)
  - Solar: 780 GW (671 GW New)



2050 Renewables Total: 7,768 TWh

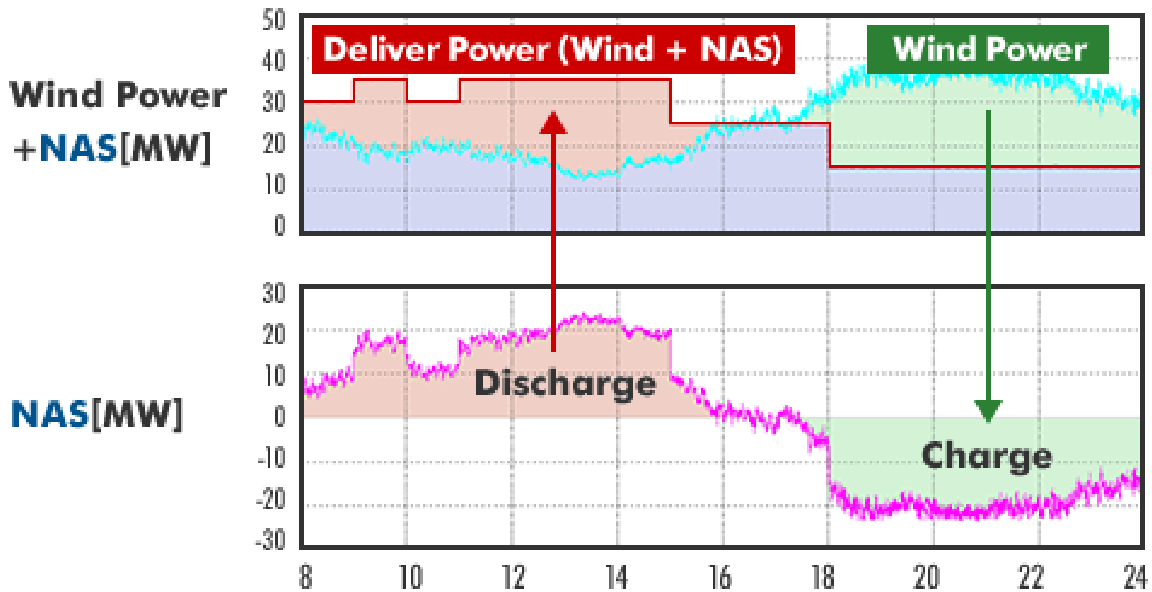
Source: SuperNode Research

Current State of Storage

- Both wind and solar remain variable sources of energy.
- This can lead to periods where low output from renewable sources cannot meet demand.
- This inverse is also true where there may be periods of large production and low demand.
- Reliability of power availability is crucial to grid operators, and the addition of storage to renewables reduces the intermittent nature of renewables.

What are the Challenges?

- Predicting future wind and solar resources with accuracy is difficult.
- They require conventional generating stations during periods of low production in order to meet demand.
- Storage of excess production is a solution which can output stored energy during periods of low generation. Rokkasho Village Wind Farm is a prime example of this.



Source: NGK Insulators

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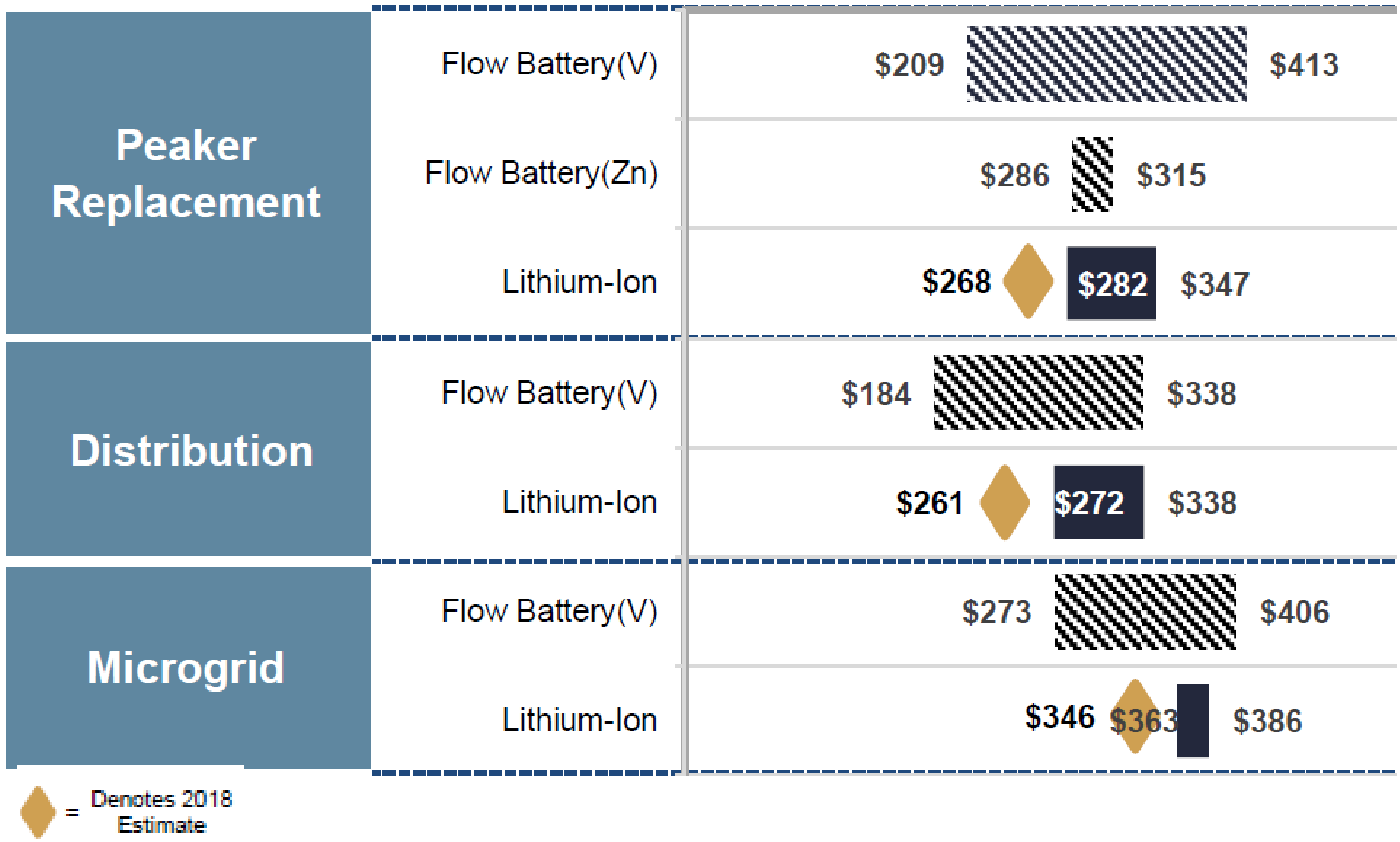
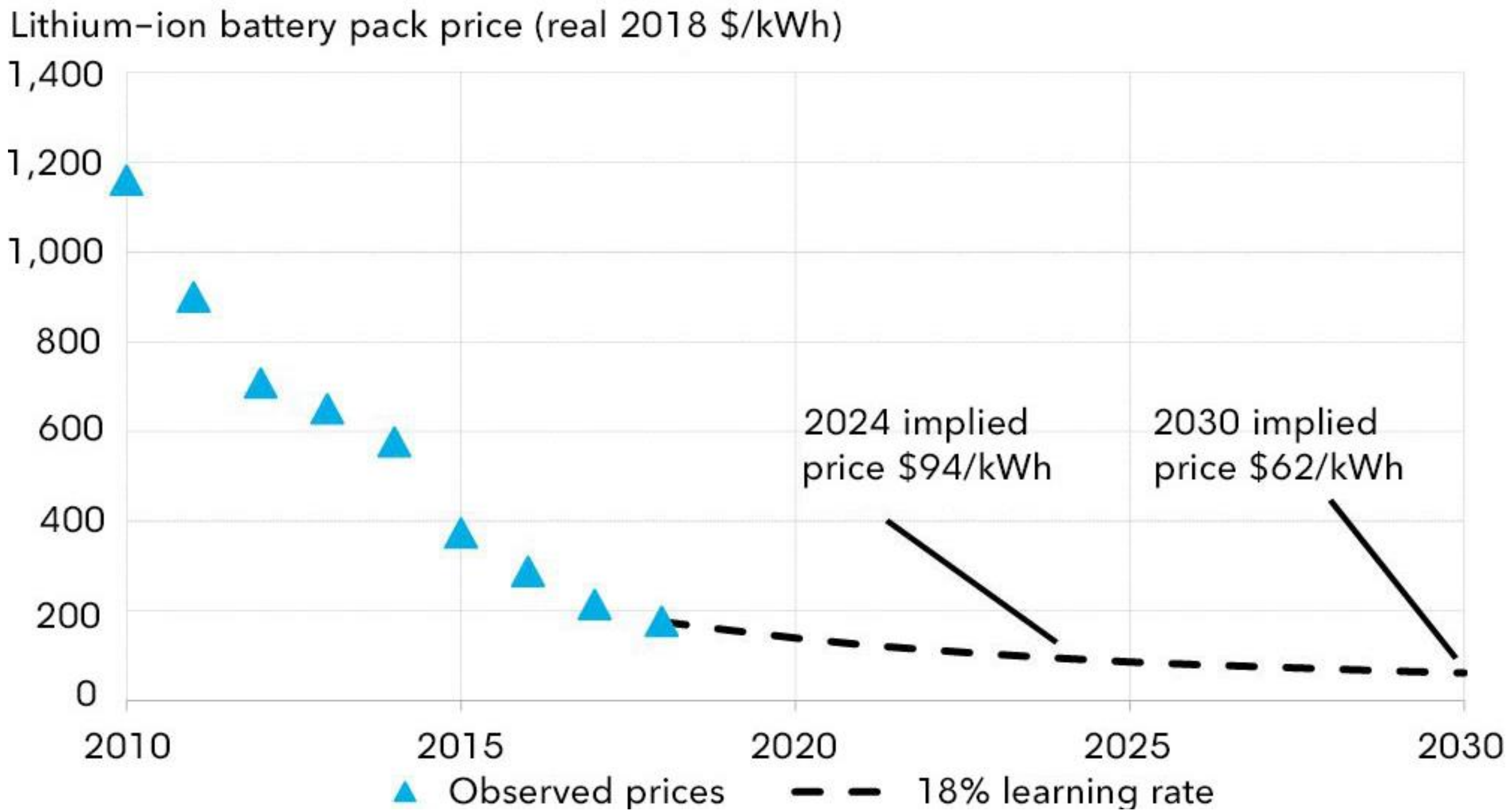
Levelised Cost of Storage (LCOS)



Source: Lazard

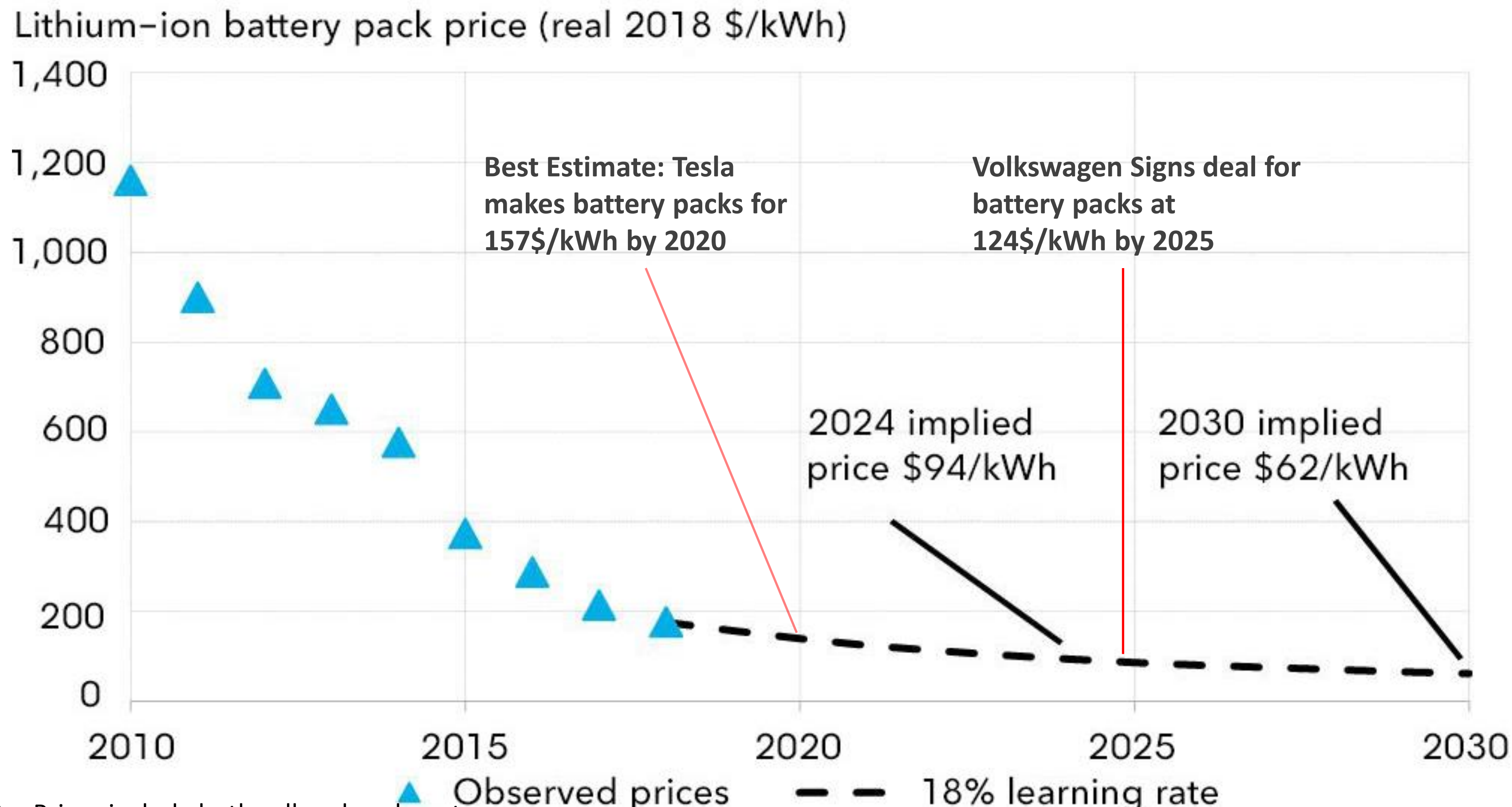
Lithium-ion Battery Prices – Historical and Forecast



Note: Prices include both cell and pack costs.
Average of BEV and PHEV batteries

Source: Bloomberg New Energy Finance

Lithium-ion Battery Prices – Forecast and Developments

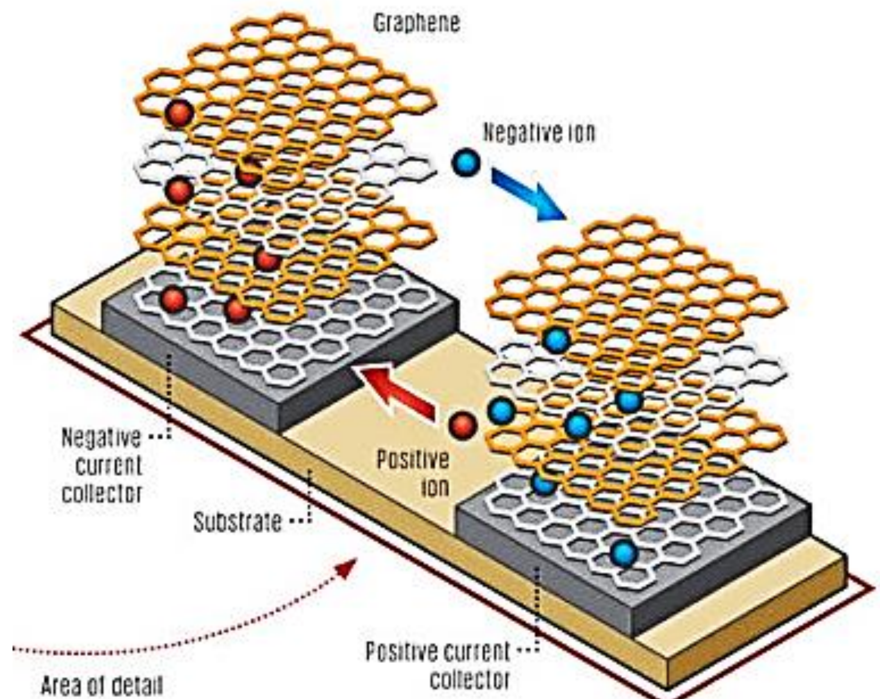


Note: Prices include both cell and pack costs.
Average of BEV and PHEV batteries

Source: Bloomberg New Energy Finance

Storage: Future Trend

- Large Scale battery storage is becoming more prominent, both in Sodium Sulphur and Lithium-ion forms.
- Projects currently operating with storage offer a glimpse into how their outputs can be better managed.
- Future technologies such as Graphene Supercapacitors will offer:
  - Greater energy density,
  - Faster charging times,
  - Faster discharging times,
  - Lighter than Lithium Cells
  - Paired with dry electrolytes, can cycle almost infinitely.



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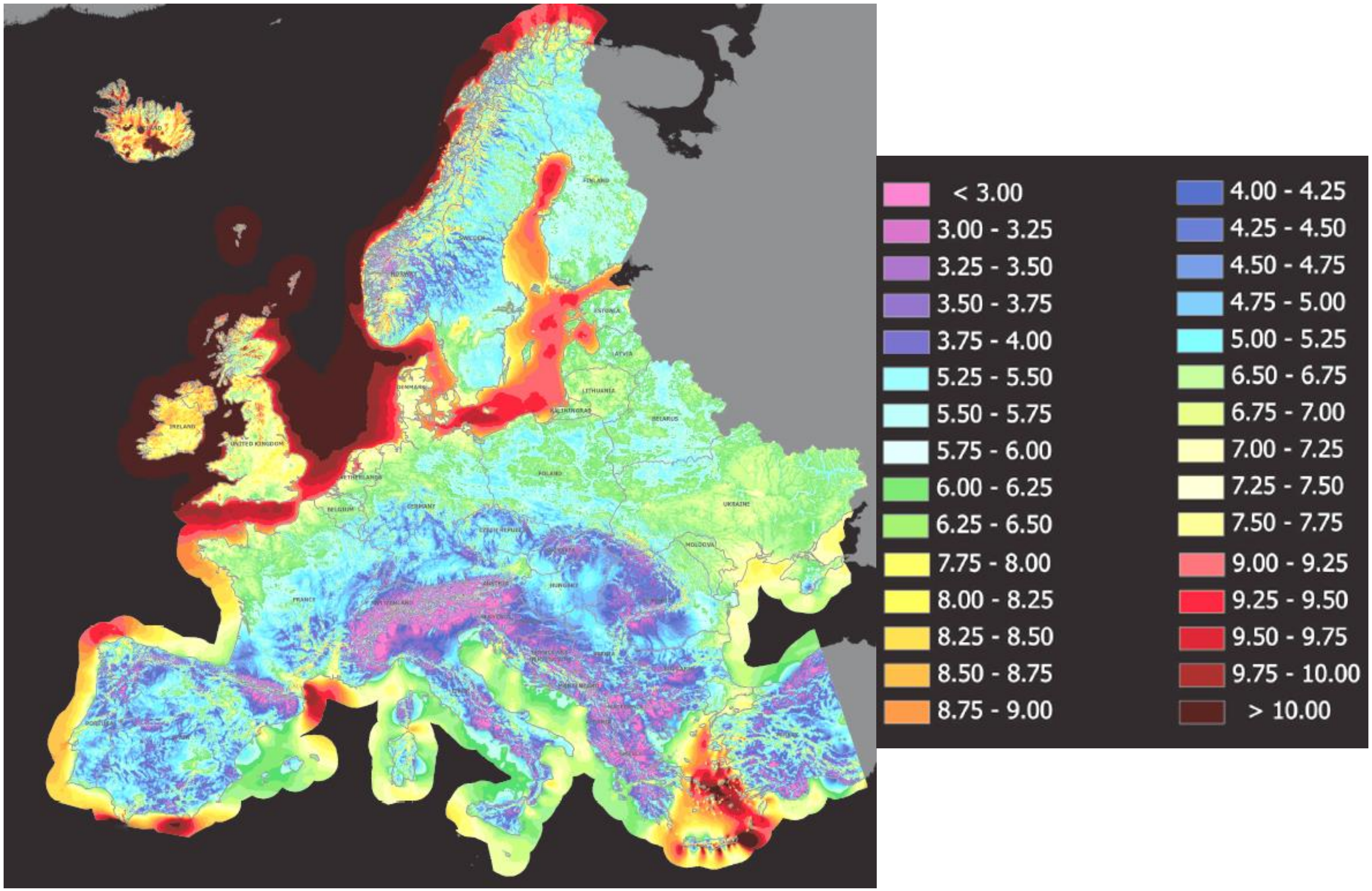
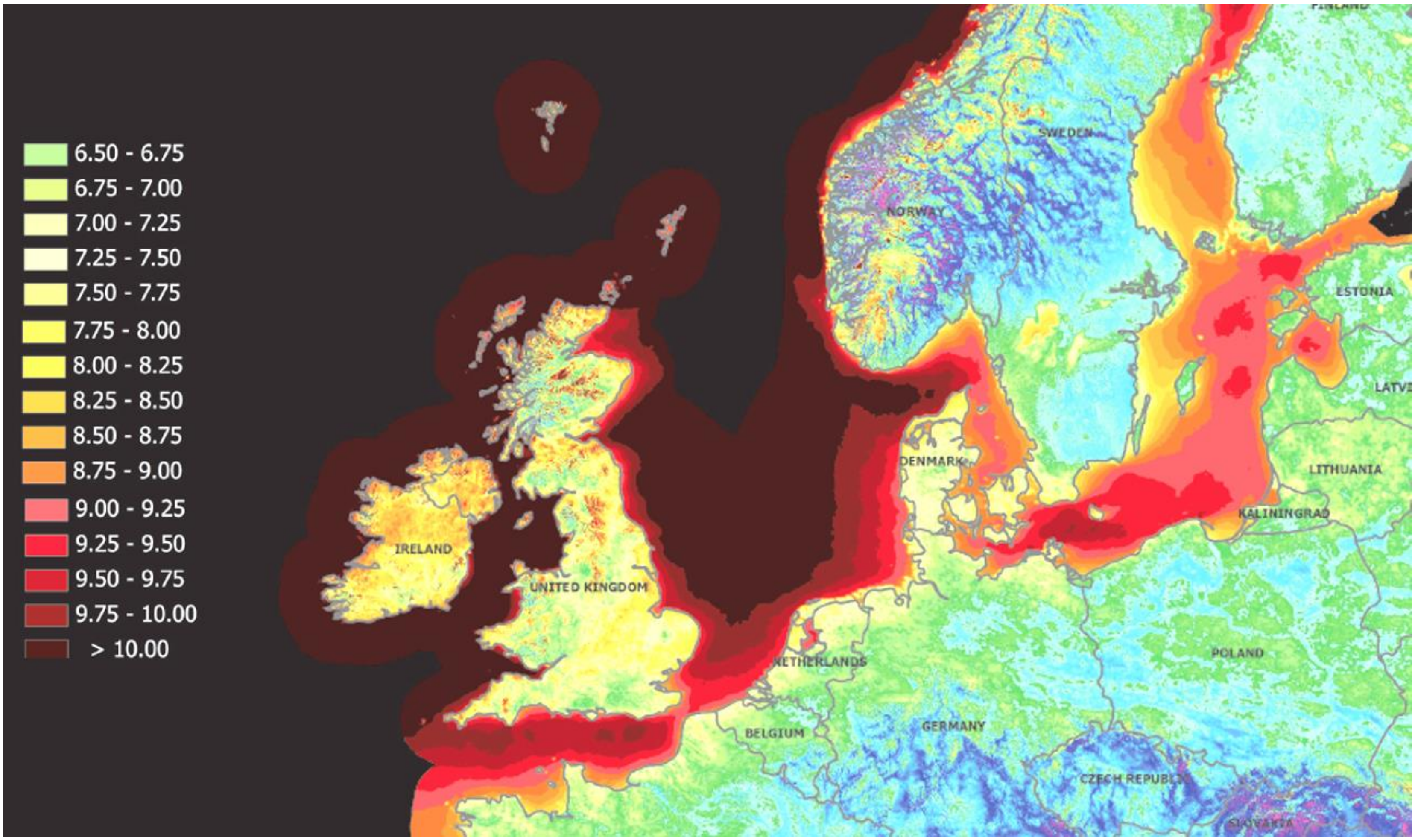
Offshore Wind Resource – Europe



Source: AWS Truepower

Offshore Wind Resource – Northern Europe



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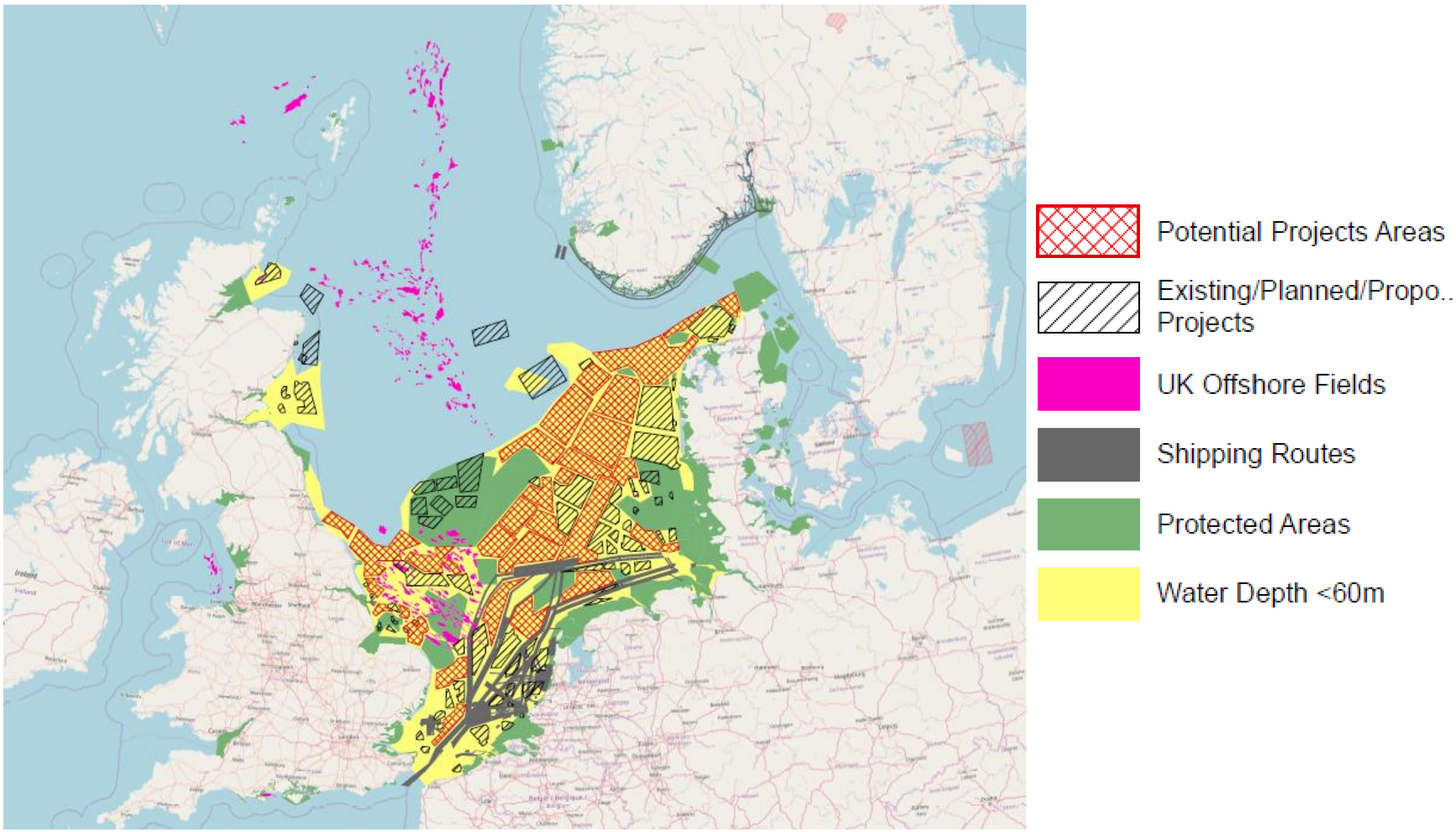
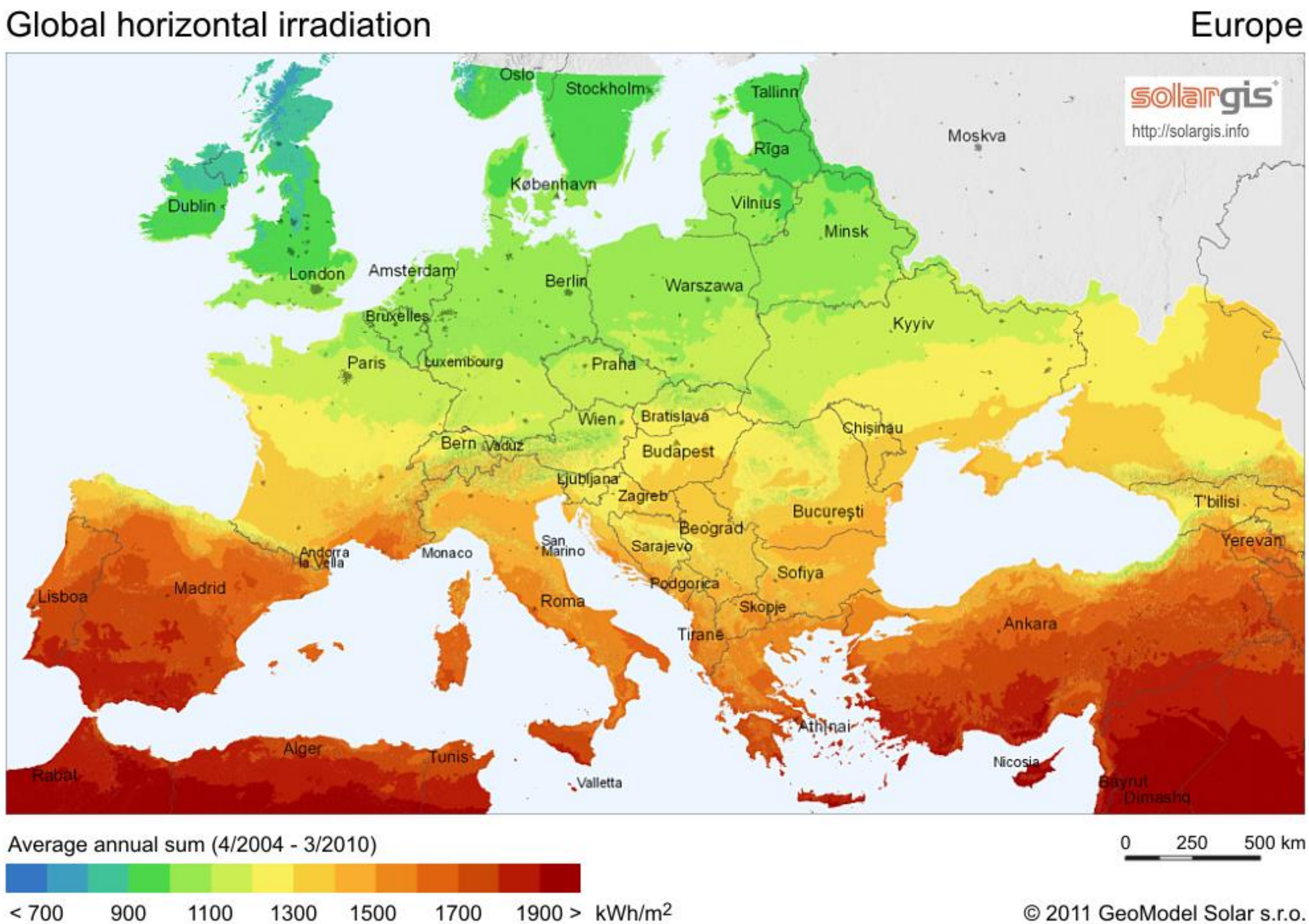
Source: AWS Truepower

North Sea Wind – The Poster Child

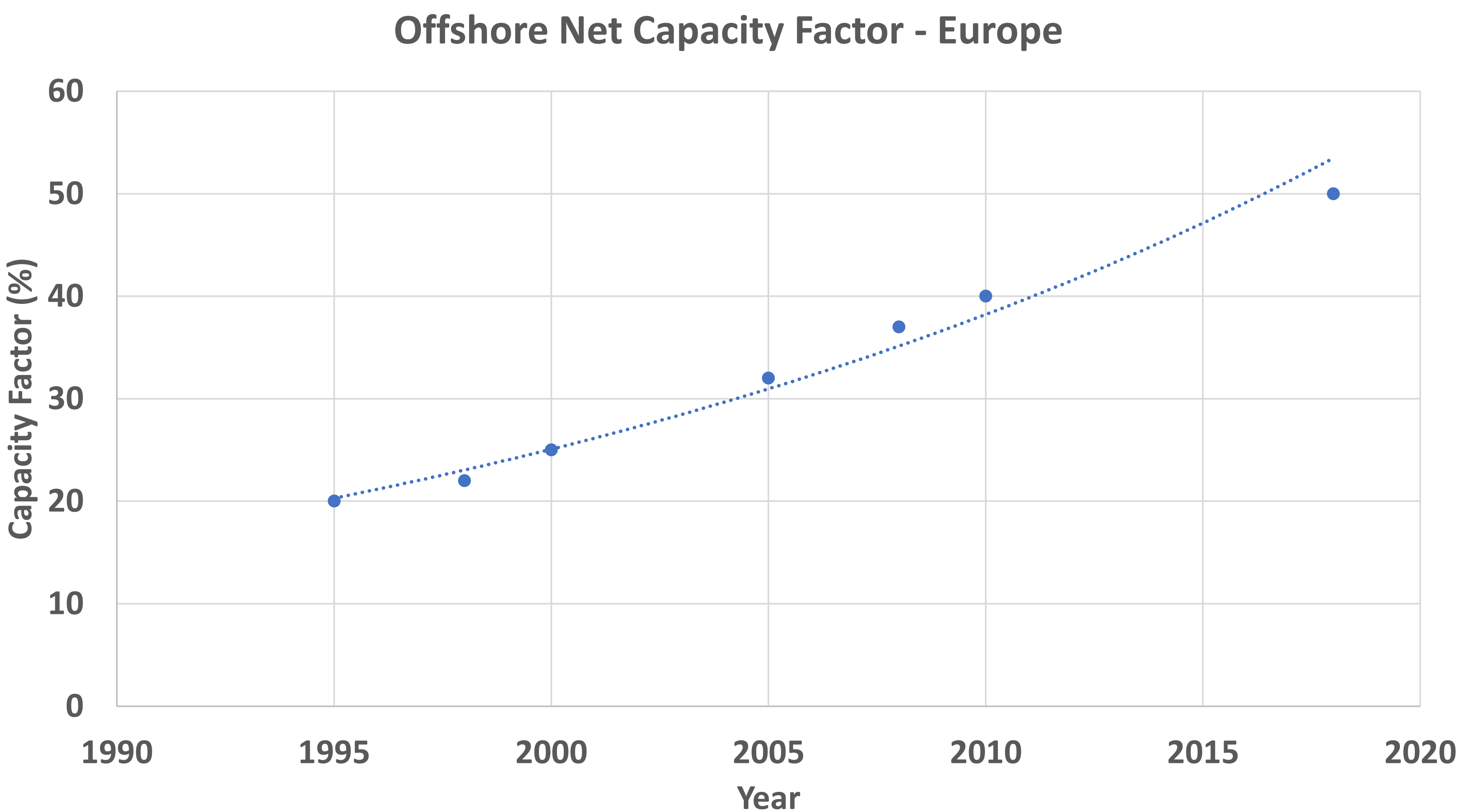


Solar Resource - Europe



Source: Solar GIS

Turbine Technology – Capacity Factor Increases



Source: US Dept. of Energy

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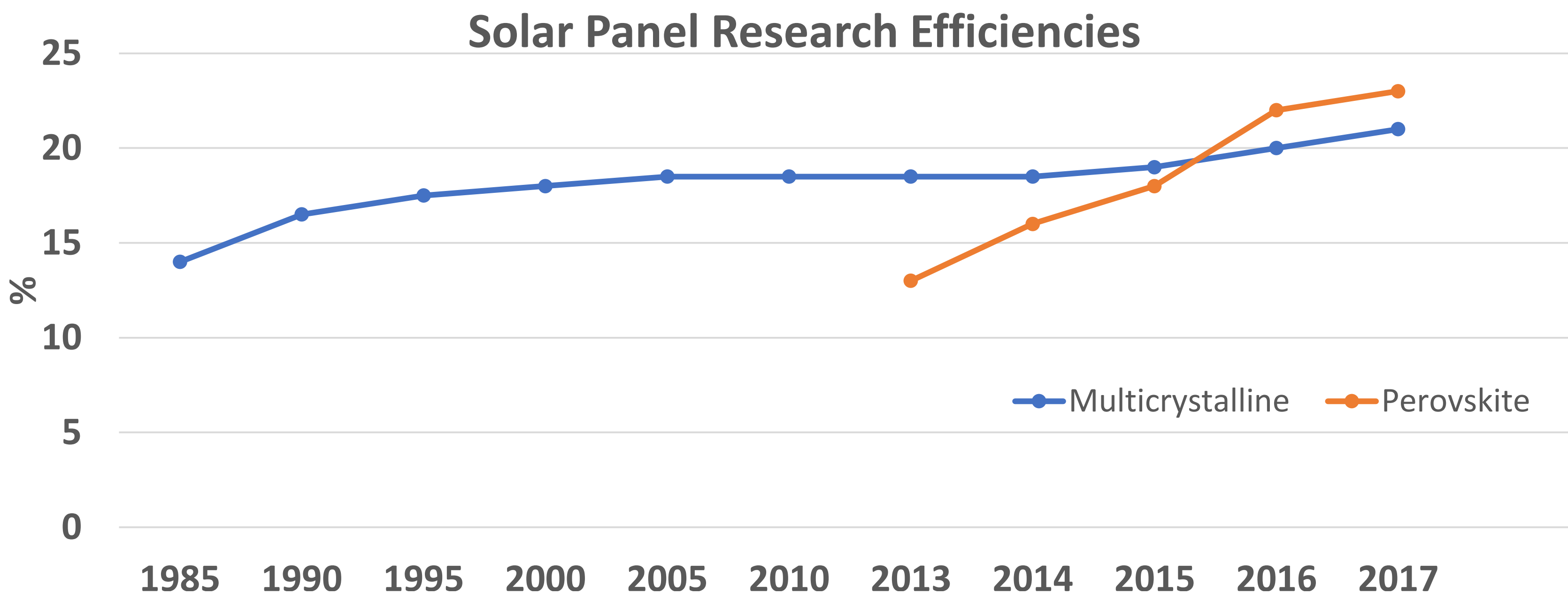
Solar Panel Efficiencies



- Current operational efficiencies of the order of 20%
- Research continuing into technology improvements
- A substantial increase in efficiency by 2050 is an entirely reasonable assumption

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Introducing the SuperGrid

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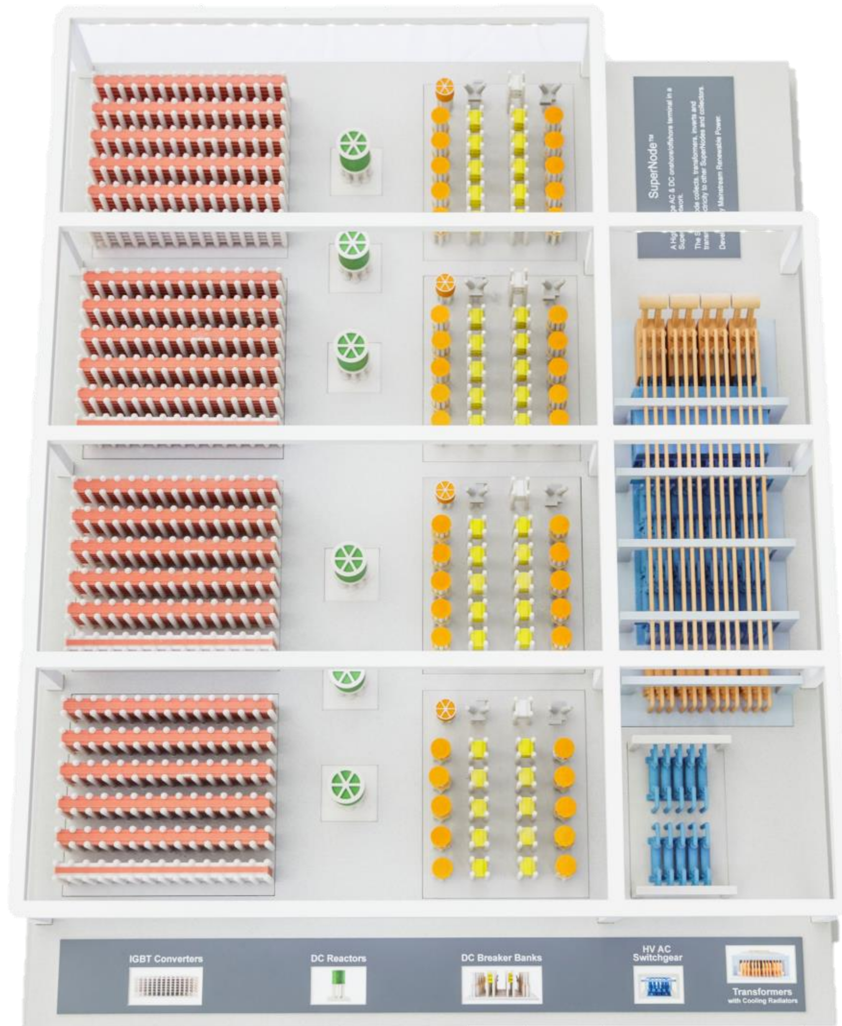
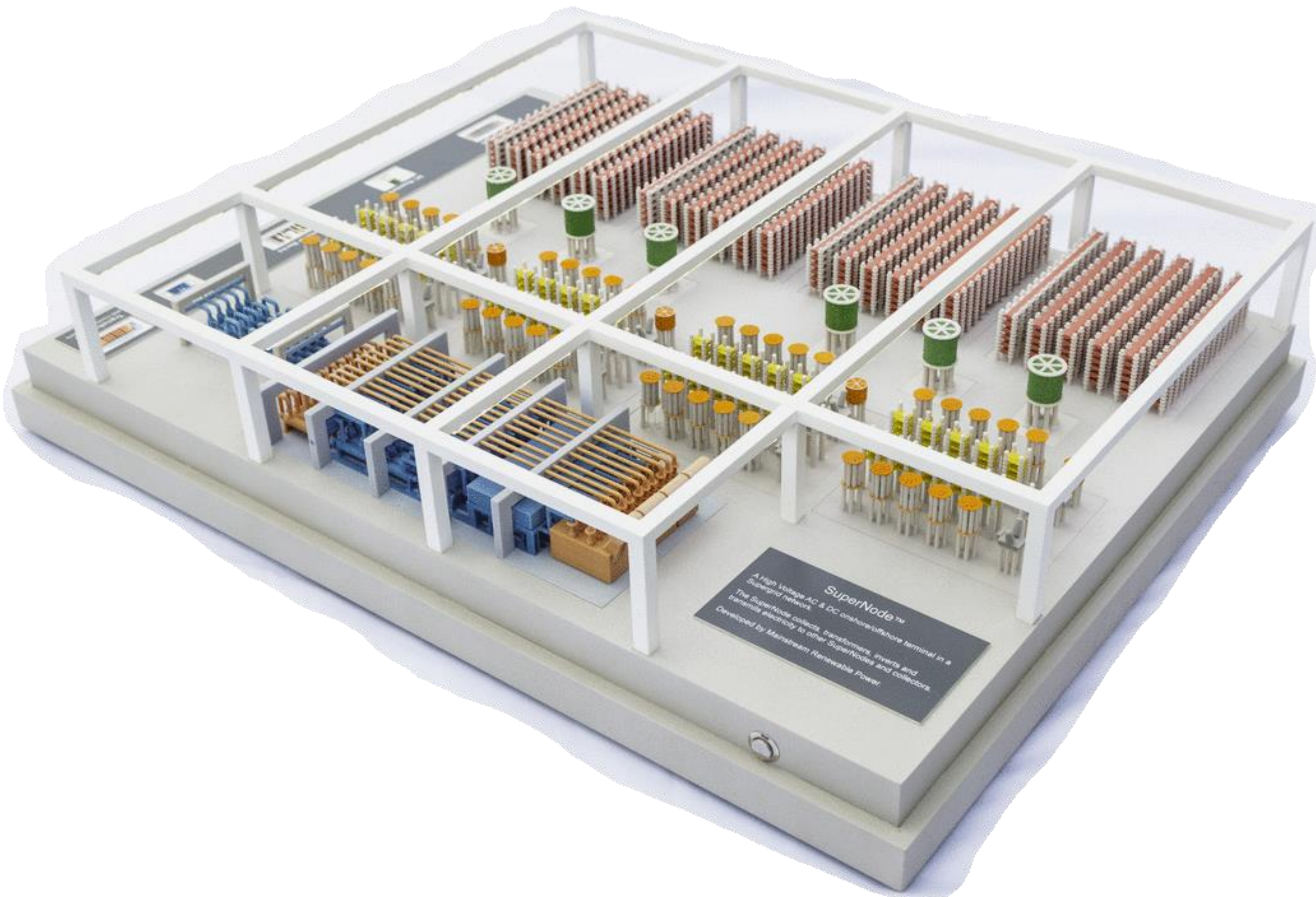
SuperNode Overview



SuperNode Overview



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Costs of Fossil Fired Generation

Country	Coal		Natural gas		Nuclear
	Including CO_2 cost ($/MWh)	Without CO_2 cost ($/MWh)	CCGT ($/MWh)	OCGT ($/MWh)	
USA	142.5	128.9	53.8	148.3	None Planned(N.P.)
Germany	95.5	75.3	89.6	N.P.	N.P.
UK	180.6	N.P.	89	218.3	124.7
France	N.P.	N.P.	72	N.P.	179
Australia	144	75.2	72.8	177.6	N.P.
Average	140	93	75	181	

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Costs of Renewable Generation

Country	Year	Wind		Solar
		Onshore ($/MWh)	Offshore ($/MWh)	Solar PV ($/MWh)
Peru	2016	35	None planned	48
Chile	2020	41	N.P.	29.1
Morocco	2017	40	N.P.	19
Egypt	2017	39	N.P.	
Texas	2017	20*	N.P.	
Germany	2017	33.6		86.7
Germany	2024		52.54	
UK	2017	50		
UK	2024		64	
Netherlands	2016		86.8	
Mexico	2017	19.5	N.P.	17.7
Average 2017		31	68	40.1

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In Summary

Generation Type	Coal no CO_2	Coal with CO_2	CCGT	Open Cycle Gas Turbine	Nuclear
Average cost $/MWhr	140	93	75	181	152

Generation Type	Wind onshore	Wind offshore	Solar PV
Average cost $/MWhr	31	68	40.1

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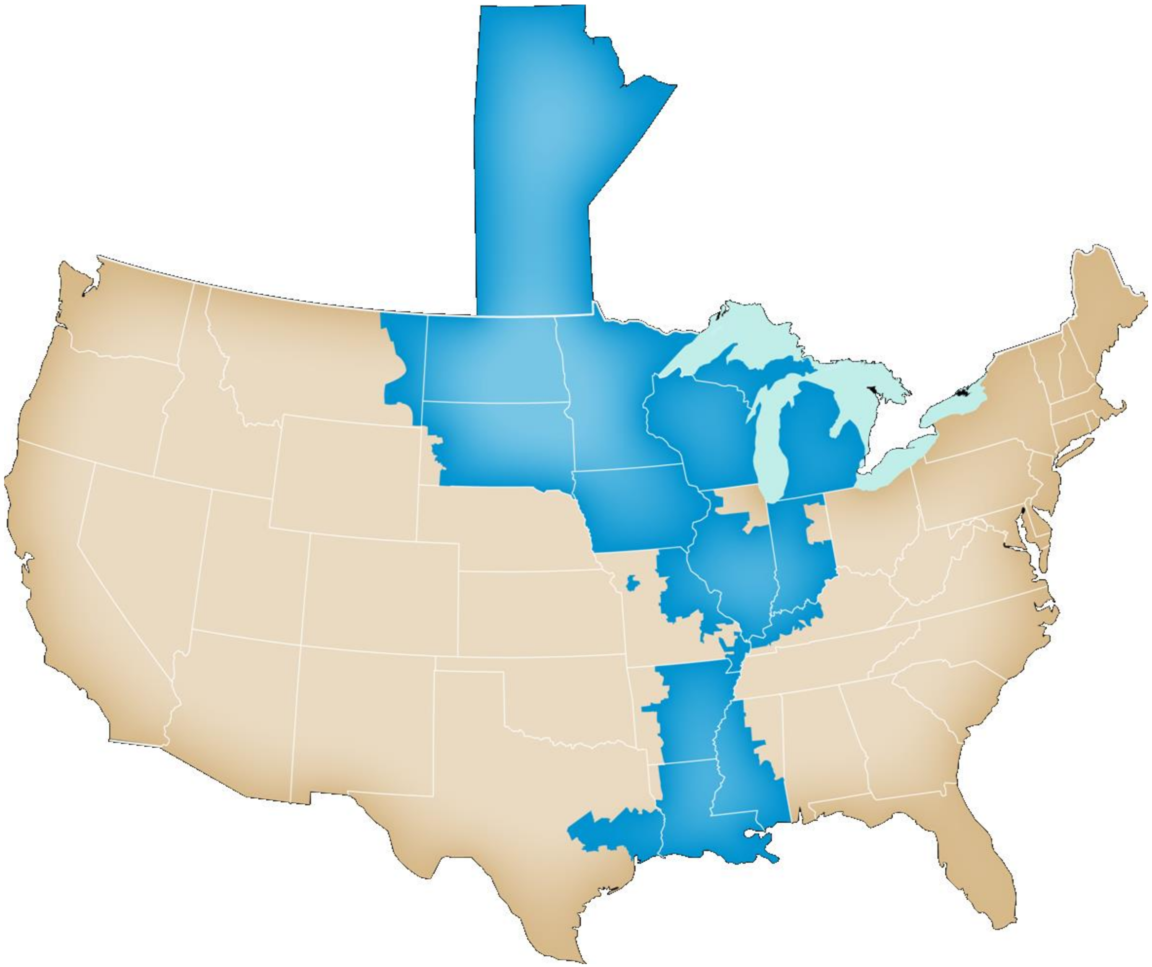
Mid Continental Independent System Operator (MISO)



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