Challenges of renewable energy integration into power systems

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Aim and intended learning outcome

Main Aim:

- Explore the main concepts and challenges behind smart grids and low-carbon networks, two prominent changes in power systems

Main Intended Learning Outcomes:

- Describe what is meant by smart grids and low-carbon technologies
- Explain the key planning and operational issues of low carbon electricity systems

Outline

- Introduction to smart grids and low-carbon technologies

- Challenges of the integration of renewable energy resources into the power grid
  - ✓ Long-term security
  - ✓ Short-term security
  - ✓ Market

- Possible solutions

Questions to start with

What is a *smart grid* and why we need it?

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A smart grid is…

…an electricity grid that develops to support an efficient, timely transition to a ***low carbon economy*** to meet ***carbon reduction*** targets, ensure energy ***security*** and wider energy goals while ***minimising costs*** to consumers. It will ***empower and incentivise consumers*** to manage their demand, adopt new technologies and minimise costs to their benefit and that of the electricity system as a whole.

…an electricity network system that uses ***digital technology*** to monitor and manage the transport of electricity and coordinate the needs and capabilities of all generators, grid operators, end users and electricity market stakeholders in such a way that they can ***optimise asset utilisation*** and operation and, in the process, ***minimise both costs and environmental impacts*** while maintaining ***system reliability, resilience and stability***.

Another definition of a smart grid

The use of <u>*information processing, communication and control*</u> in the power grid to:

- enable informed participation by consumers
- accommodate all generation and storage options
- optimise asset utilisation and operating efficiency
- minimise costs and emissions
- provide robustness and resiliency to disturbances



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Why do we need to change?

Can't we just keep on doing business as usual?

The International Energy Agency has estimated that

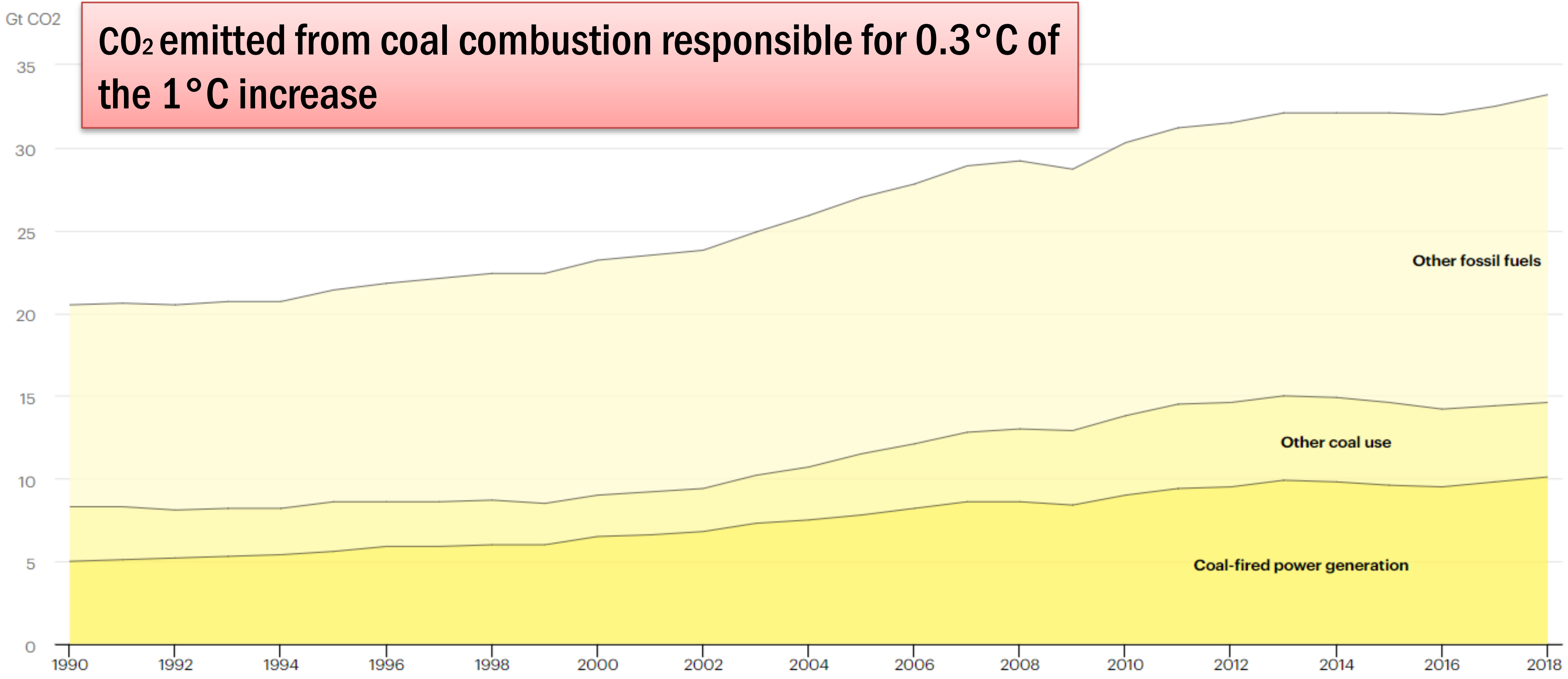
- Energy consumption worldwide grew by 2.3% in 2018,nearly twice the average rate of growth since 2010. The biggest gains came from natural gas (nearly 45% of the increase)
- Fossil fuels met nearly 70% of the growth
- Renewables grew by over 4%, not fast enough to meet the demand increase
- CO_2 emissions rose 1.7% in 2018 and hit a new record

Based on current policies in 2037 cumulative energy-related emissions will exceed the carbon budget required to hold temperature increases below 2°C. Emission reductions of a further 470 Gt will be needed by 2050 to reduce warming to 2°C.

Source: International Energy Agency, Report 2019 (https://www.iea.org), IRENA (International Renewable Energy Agency), Report 2018

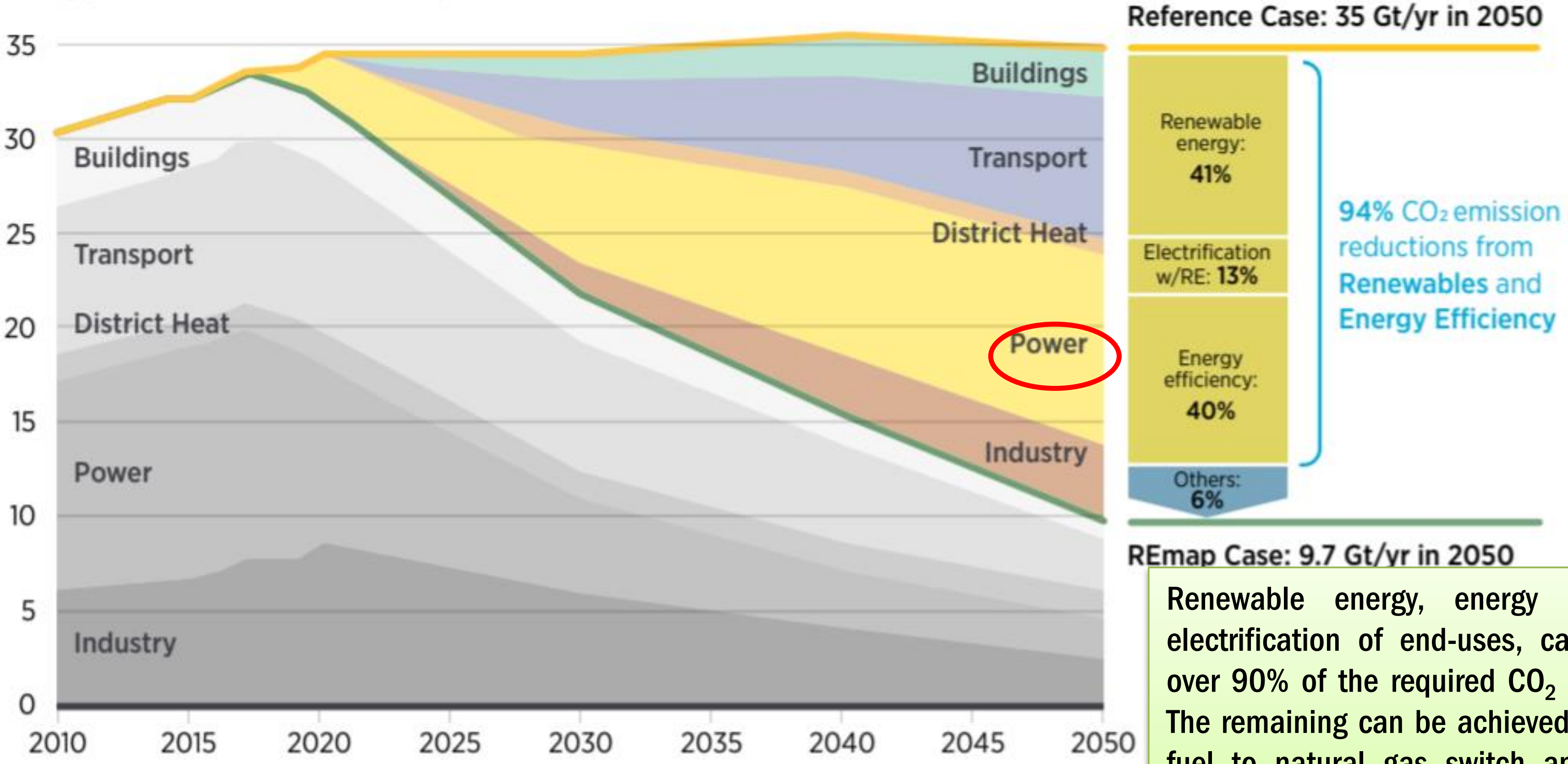
Global energy-related CO_2 emissions by source

CO_2 emitted from coal combustion responsible for 0.3°C of the 1°C increase



Source: International Energy Agency, Report 2019 (https://www.iea.org)

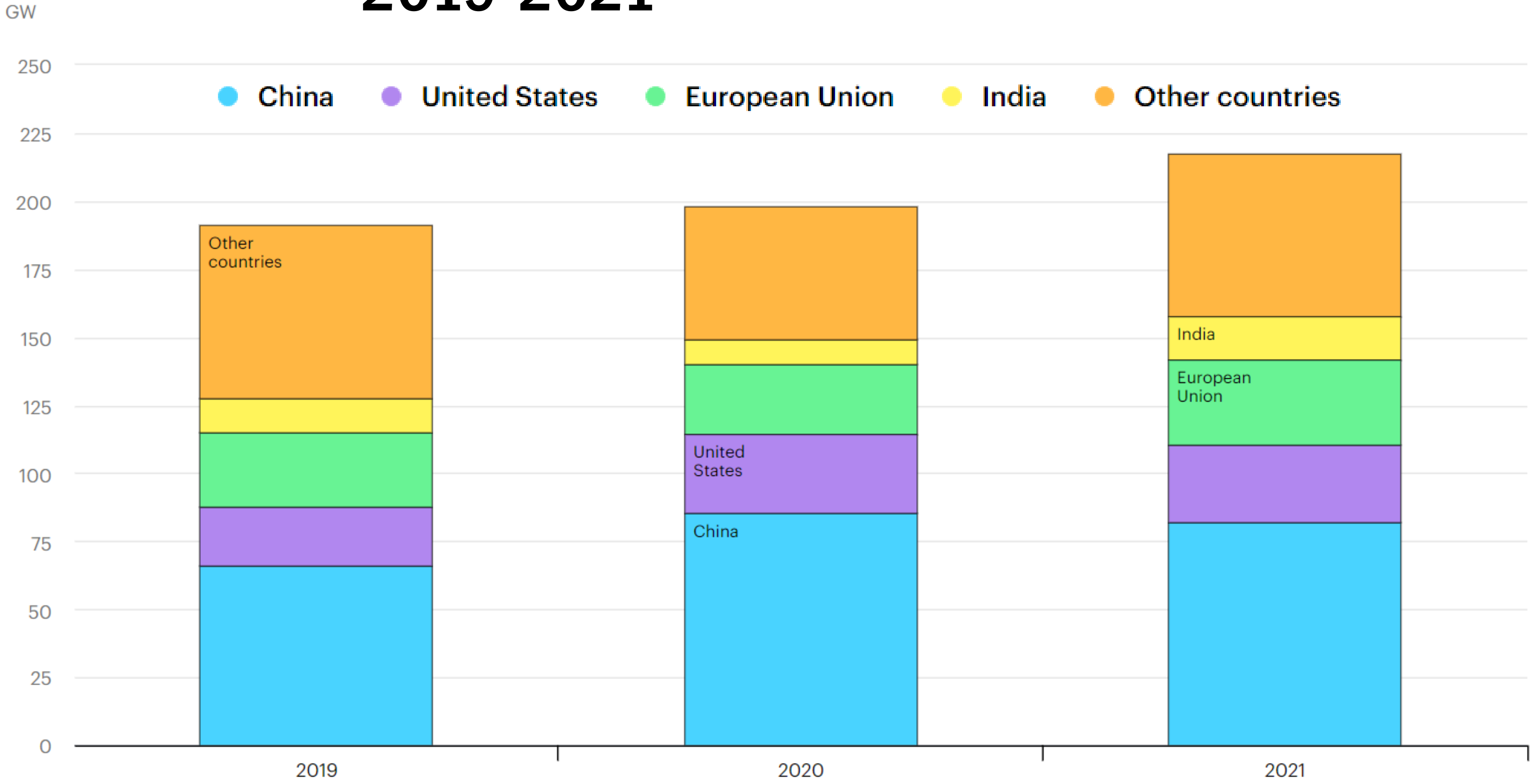
Annual energy-related CO2 emissions



Renewable energy, energy efficiency, electrification of end-uses, can provide over 90% of the required CO_2 reduction. The remaining can be achieved by fossil-fuel to natural gas switch and carbon capture in industry

Source: IRENA (International Renewable Energy Agency), Report 2018

Renewable capacity additions by country/region 2019-2021



Source: International Energy Agency, Report 2020 (https://www.iea.org)

Low-carbon technologies

Produce power with lower amounts of carbon dioxide emissions than conventional power plants

- *Renewable technologies*
- *Carbon capture and storage*
- *Combined Cycle Gas Turbine*
- *Nuclear, ...*

Renewable technologies

- **First-generation technologies**
  - Emerged from the industrial revolution at the end of the 19th century (Manchester), to replace in part more expensive coal-fired steam-based systems
  - Include **hydropower, biomass combustion, and geothermal power**

Renewable technologies

- **Second-generation technologies**
  - Include **solar heating and cooling, wind power, modern forms of bioenergy, and solar photovoltaics**
  - Entering markets as a result of research, development and demonstration (RD&D) investments since the 1980s



Renewable technologies

- **Third-generation technologies**
  - Under development
  - Include **advanced biomass gasification, concentrating solar thermal power, and ocean and tidal energy**

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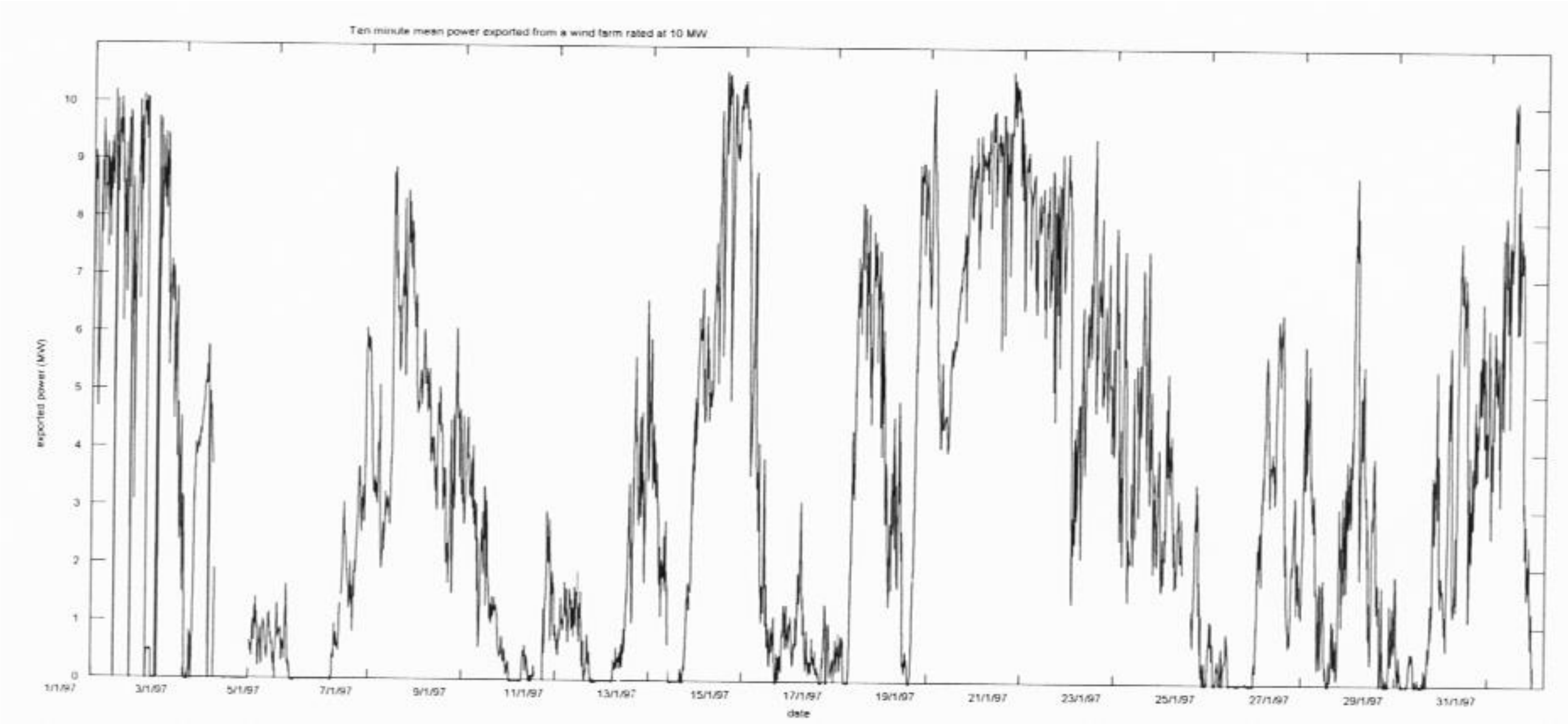
Wind (and solar): are they the solution?

Can we trust this?



Ten minute-mean real power exported from a 10MW wind farm over a month

Impact on…

- **Long term security**
  - Generation adequacy
  - Capacity credit of wind
- Short term security
  - Balancing
  - Spinning and standing reserve
- Energy market

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What is meant by variable generation

Variable renewable energy is a renewable energy source that is non-dispatchable due to its fluctuating nature, like wind power and solar power, as opposed to a controllable renewable energy source such as hydroelectricity, or biomass

How intermittent is conventional thermal generation?

Long-term security

- *Generation adequacy*: capability to meet demand with a certain level of reliability of supply
- **LOLP (Loss of Load Probability)** widely used:
  - Probability of peak demand exceeding available generation
- How do I assess the adequacy of conventional generation?
  - Generators are subject to failures (*intermittent*)
  - Capacity Outage Probability Table (COPT)
  - Excess installed capacity above expected peak demand (*capacity margin*)

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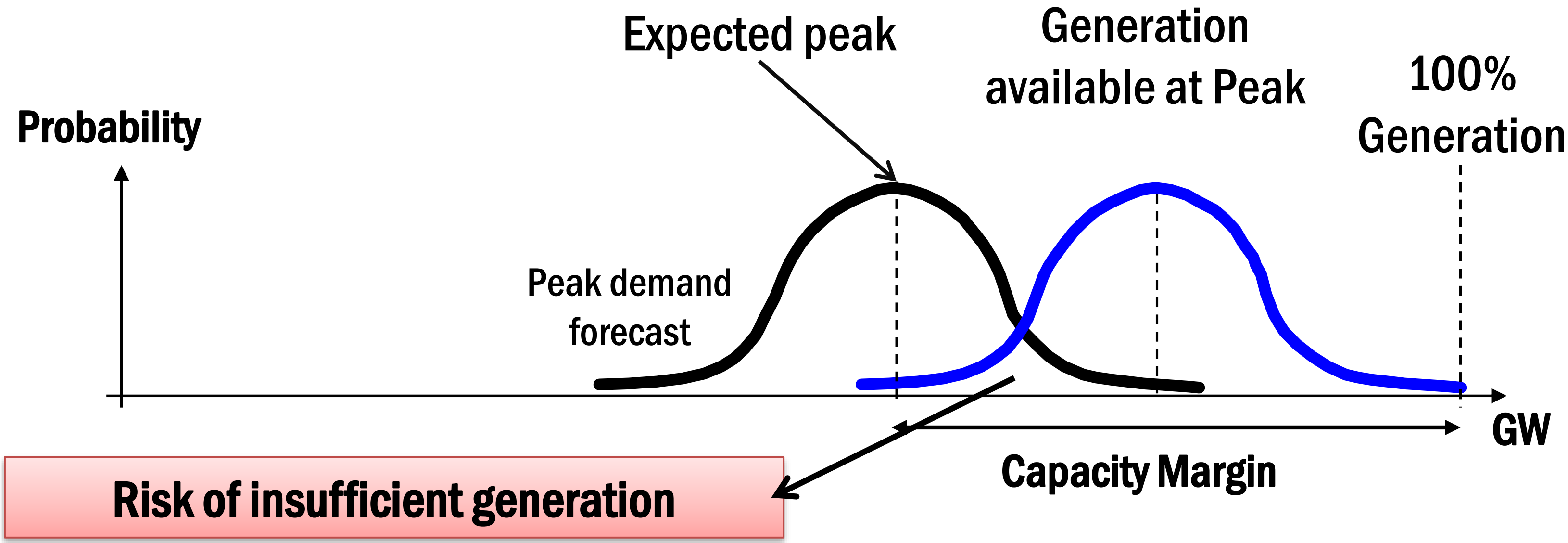
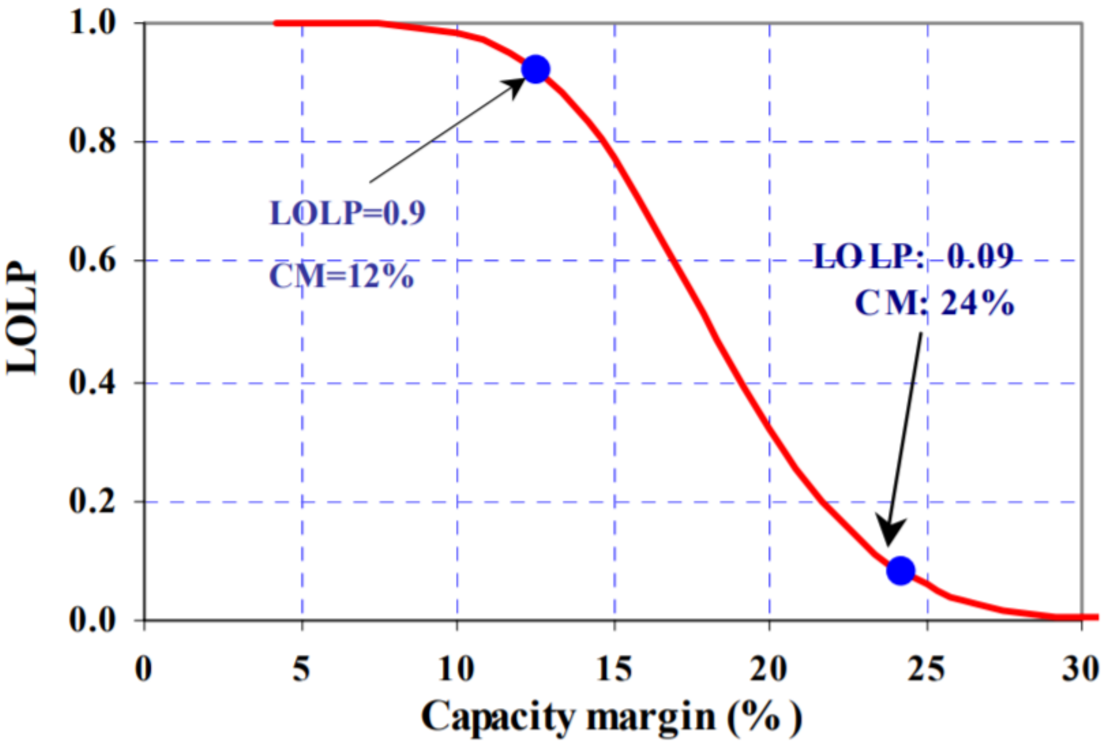
Determining the capacity margin



- The higher the margin, the lower the LOLP
- Generation capacity **adequate** if LOLP meets threshold level (e.g., 9% in the UK)

R. Billinton and R.N. Allan, Reliability evaluation of power systems, Springer, 1996

LOLP versus capacity margin



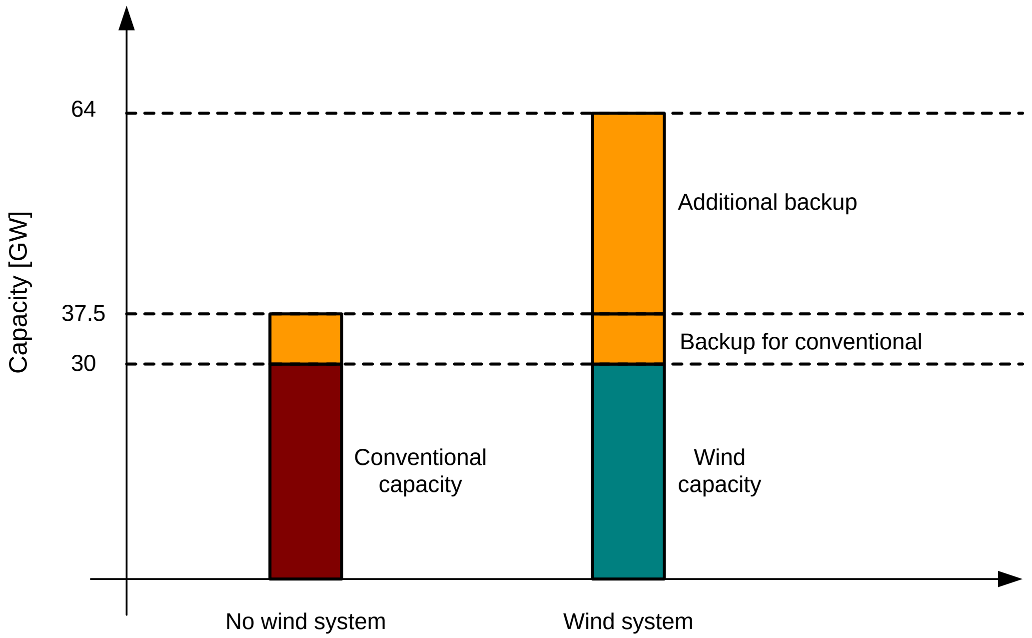
Source: Nedic, D., Shakoor, A., Strbac, G., Black, M., Watson, J. and Mitchell, C.(2005). *Security Assessment of Future UK Electricity Scenarios*. Available at: http://dcms2.lwec.ulcc.ac.uk/content/security-assessment-future-electricity-scenarios

Capacity credit

<u>Capacity credit</u> (or capacity value): measure of the amount of load that can be served on an electricity system by variable plants with no increase in the LOLP or other similar index.

Implications of capacity credit

Necessary to retain a significant proportion of conventional plant to ensure that the security of supply



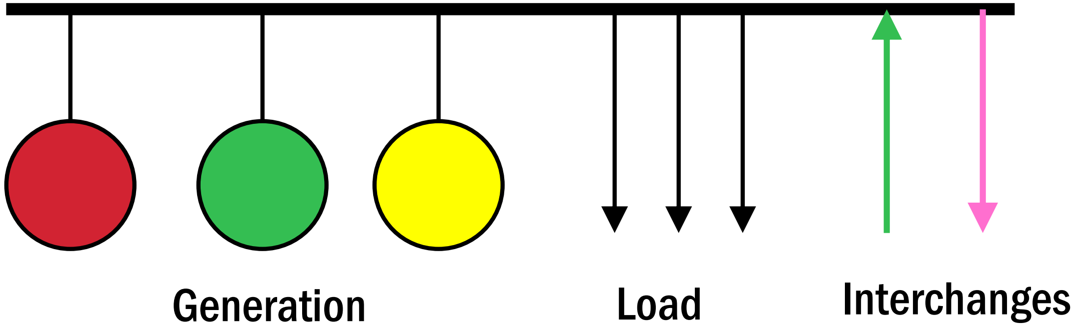
- 30GW wind requires 34GW backup
- 30GW wind displaces 3.5GW conventional plant

Implication of capacity credit

- Wind or solar may displace a significant amount of energy produced by large conventional plant, but relatively small capacity
- It will therefore be necessary to retain a significant proportion of conventional plant to ensure that the security of supply is maintained
- Thus, wind or solar rich systems will feature an increasingly large generation capacity margin which exceeds demand by a significant amount

Short-term security

- Balancing production and consumption in and close to real time
- System variables are total generation, total load and net interchange with other systems

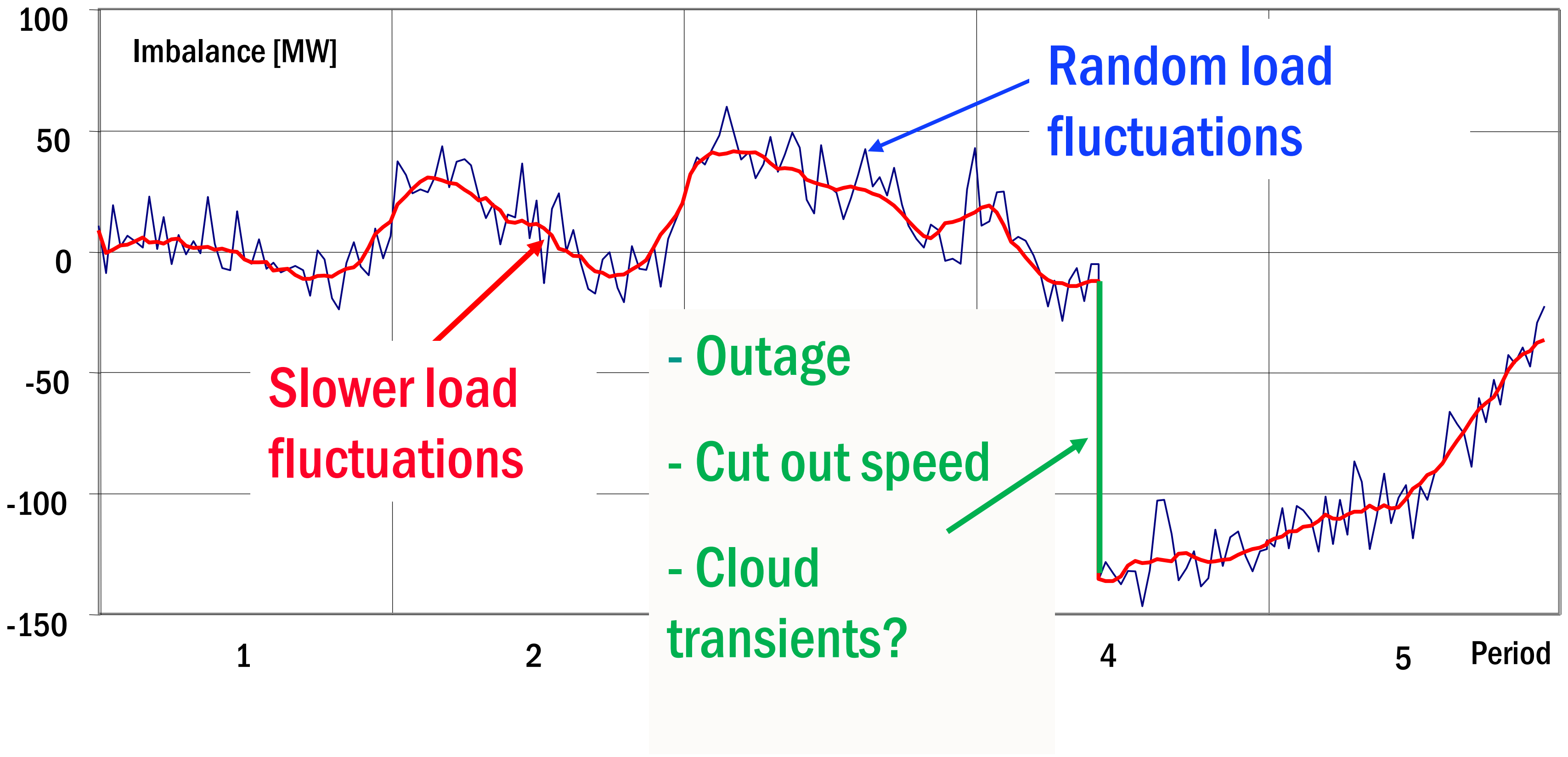


Balancing production-consumption

- If production = consumption, frequency remains constant
- Excess load causes a drop in frequency
- Excess generation causes an increase in frequency
- System operator must maintain the frequency within limits
- Frequency deviations must be corrected quickly so the system can withstand further problems



Example of imbalances



Balancing services

- Regulation service
  - Provided by generating units with a governor
- Load following service
  - Provided by generating units that can respond at a sufficient rate
- Reserve services
  - Spinning reserve
  - Standing reserve

Classification of balancing services

- **Regulation** and **load following** services
  - Almost continuous action
  - Quite predictable
  - *Preventive* security actions
- **Reserve** services
  - Use is unpredictable
  - *Corrective* security actions

Balancing challenges

- Variable generation (e.g., wind, solar) is non-dispatchable
- Variable generation increases reserve and balancing costs
- Main drivers are:
  - Forecast lead time and balancing time scales
  - Magnitude of fluctuations to be managed
  - Availability of reserve options
  - Start-ups and plant dynamics
- Balancing and reserve options will also impact on
  - Renewable energy curtailment
  - Emissions

Relevant generator characteristics

Parameter	Nuclear	Coal	CCGT	OCGT	Pumped hydro storage
Minimum Stable Generation (P_{min}) [p.u.]	0.5-0.6	0.2-0.4	0.15-0.5	0.2-0.5	0
Efficiency [%]	32-33%	up to 48%	up to 60%	up to 40%	70-85
Minimum up time (T_{up}) [h]	36	20	6	4	0
Cold start (T_{down}) [h]	24	10	4	<0.1	0
Technically feasible cold start [h]	up to 48	5	3	<0.1	0
Technically feasible ramp [%/min]	10	4	4	12	40-100
New power plant ramp [%/min]	10	6	8	20	40-100

Illustrative example

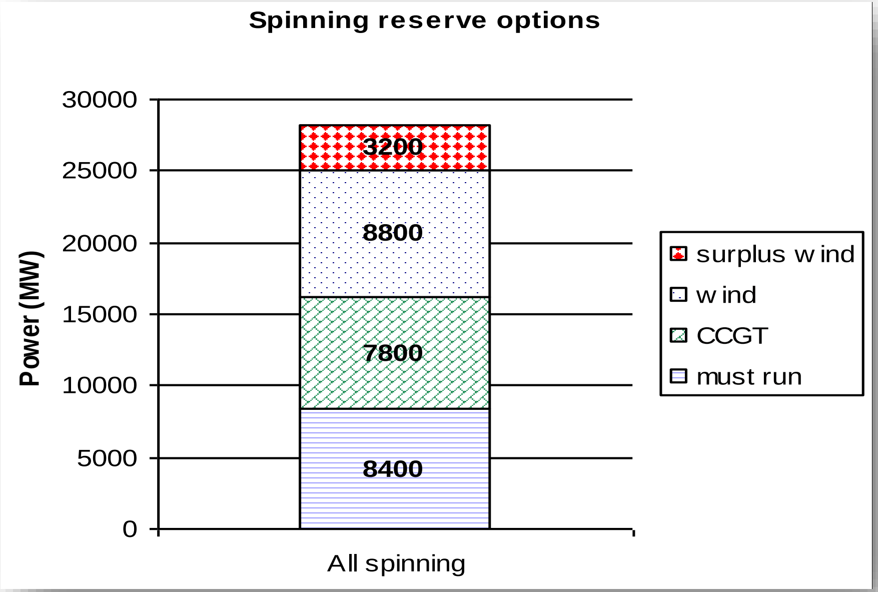
• Wind installed	26,000 MW
• Expected wind output	12,000 MW
– Reserve scheduled by TSO	6,500 MW
• Demand	25,000 MW
• Inflexible generation (nuclear and coal)	
– Must run	8,400 MW

Illustrative example

- Reserve options:
  - 26 CCGT units (spinning)
    - Rated output 550 MW
    - Min stable generation (MSG) 300 MW
      - » (each generator provides 250MW of reserve while generating 300MW)
  - OCGT capacity (standing) 2,000 MW

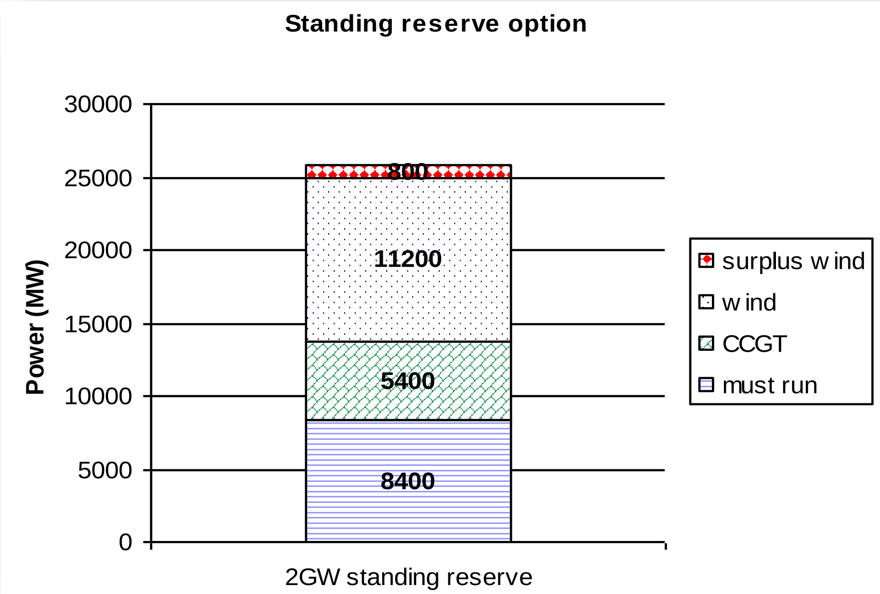
Synchronised reserve only

- 26 CCGT units need to run
  - Synchronised Reserve = 6,500 MW
  - Power delivered = 7,800 MW
- Power output:
  - Must run 8,400 MW
  - CCGT 7,800 MW
  - Wind 12,000 MW
  - TOTAL **28,200 MW**
- Surplus wind of **3,200 MW**

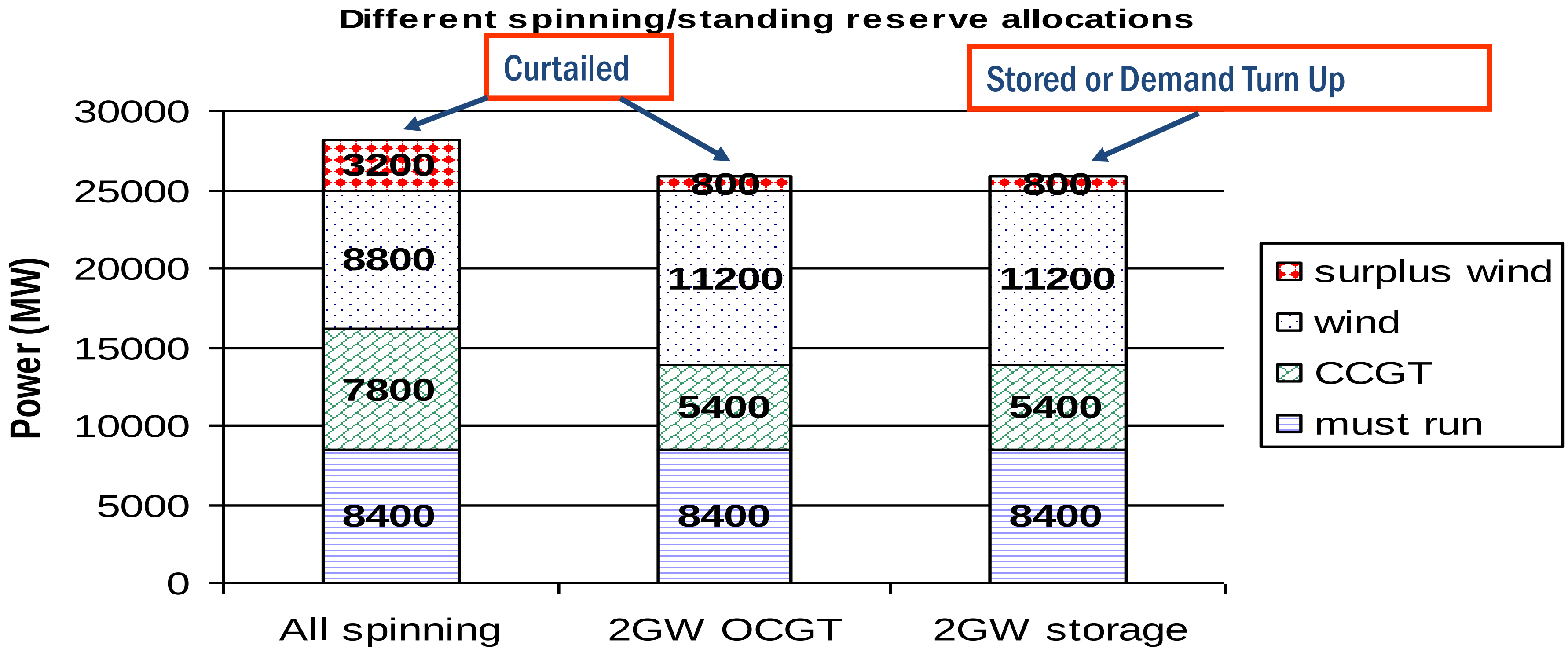


Synchronised + standing reserve

- Standing Reserve (OCGT or storage) 2000MW
- 18 CCGT units need to run
  - Synchronised Reserve = 4500MW
  - Power delivered = 5400MW
- Power output:
  - Must run 8,400MW
  - CCGT 5,400MW
  - Wind 12,000MW
  - TOTAL 25,800 MW
- Surplus wind of 800 MW



Comparison of reserve options



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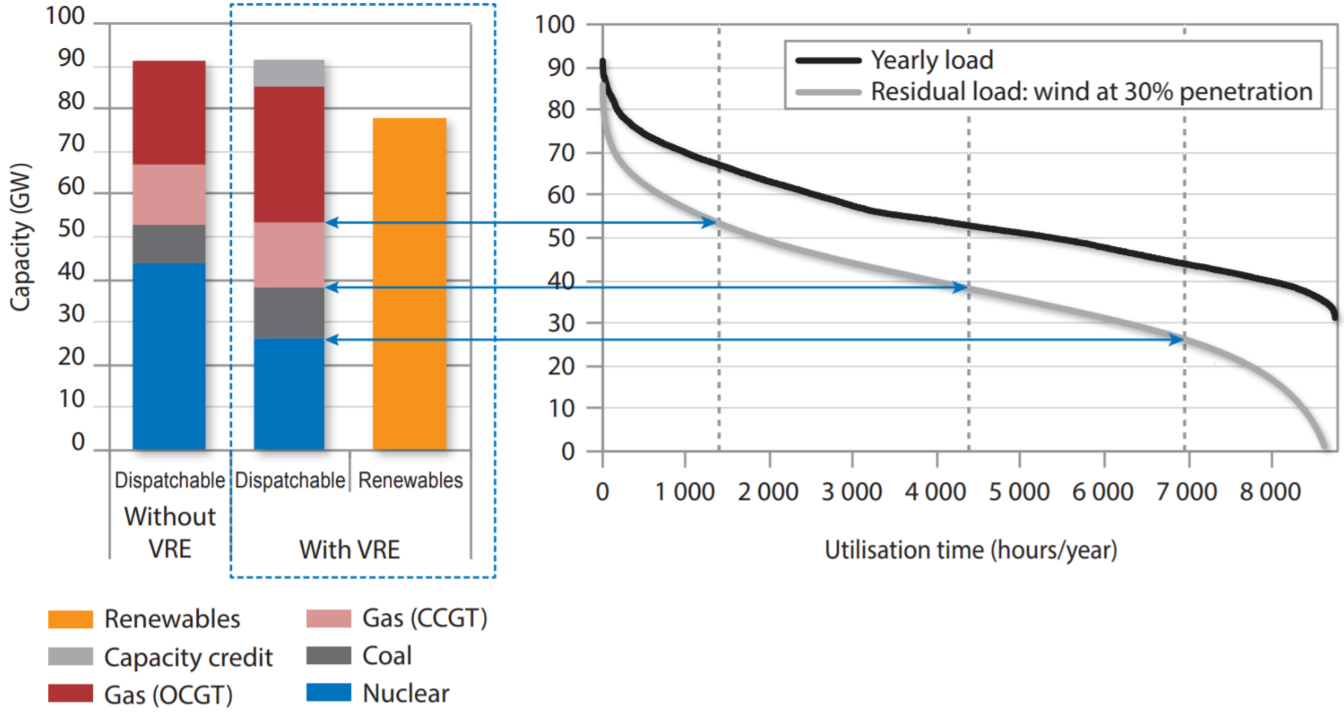
Capacity factor

Capacity factor : energy produced by a generator as a percentage of that which would be achieved if the generator were to operate at maximum output 100% of the time

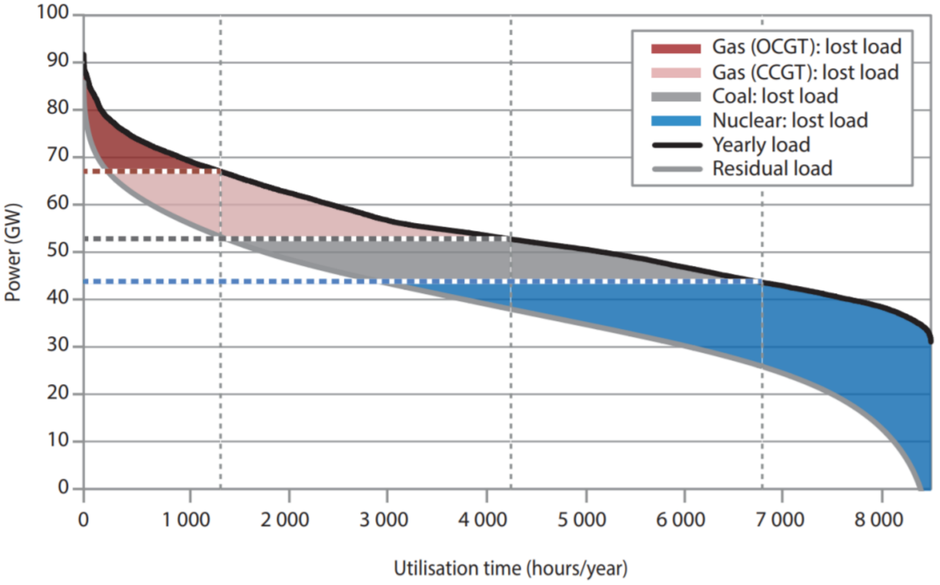
- Capacity factors of base load thermal generators ~ 85%
- Capacity factors of wind turbines ~ 20% - 40%

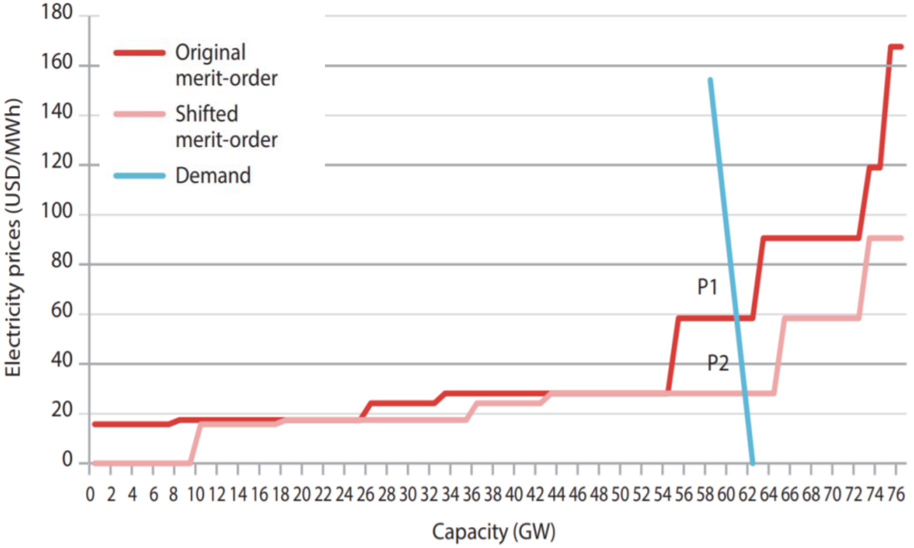
Generation mix with wind power plants



Source: © OECD/IEA 2015 *Projected Costs of Generating Electricity*, IEA Publishing. Licence: www.iea.org/t&c. Available at: https://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf

Prices and capacity factors reduction





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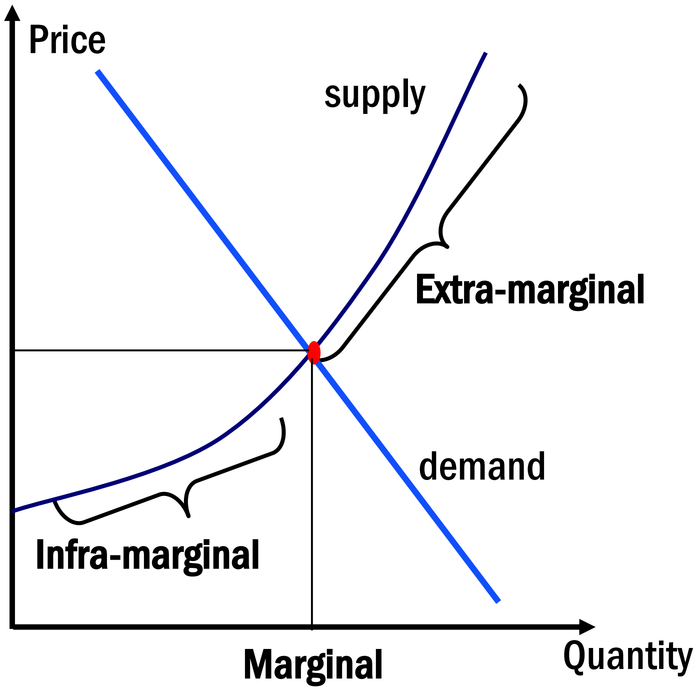
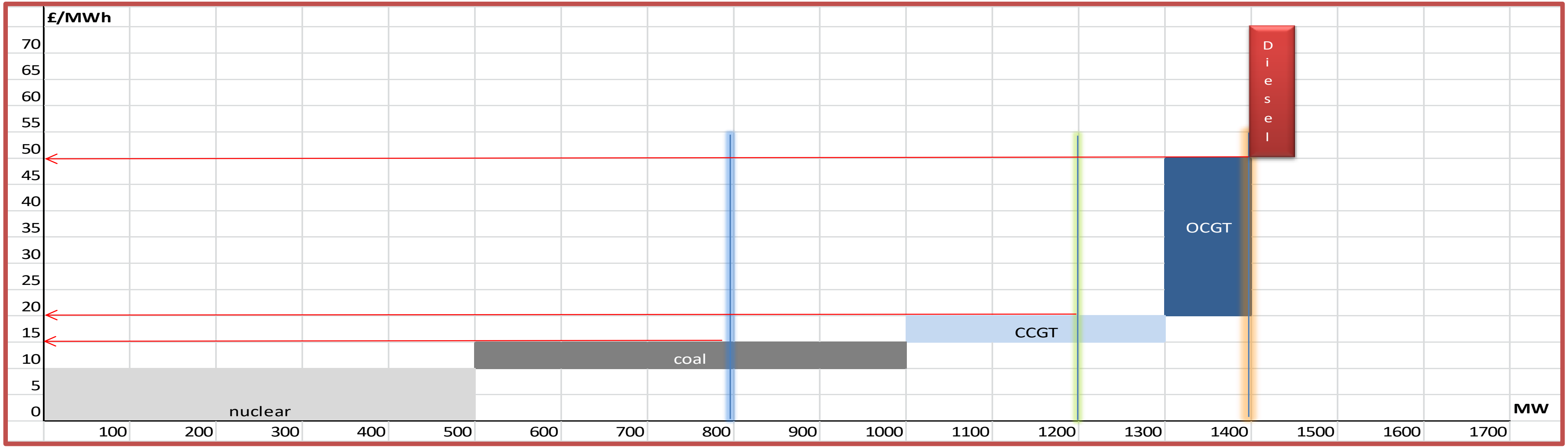
Energy market

- ***Marginal producer*:**
  - Sells this last unit
  - Gets exactly its bid
- **Infra-marginal producers:**
  - Get paid more than their bid
  - Collect economic profit
- **Extra-marginal producers:**
  - Sell nothing

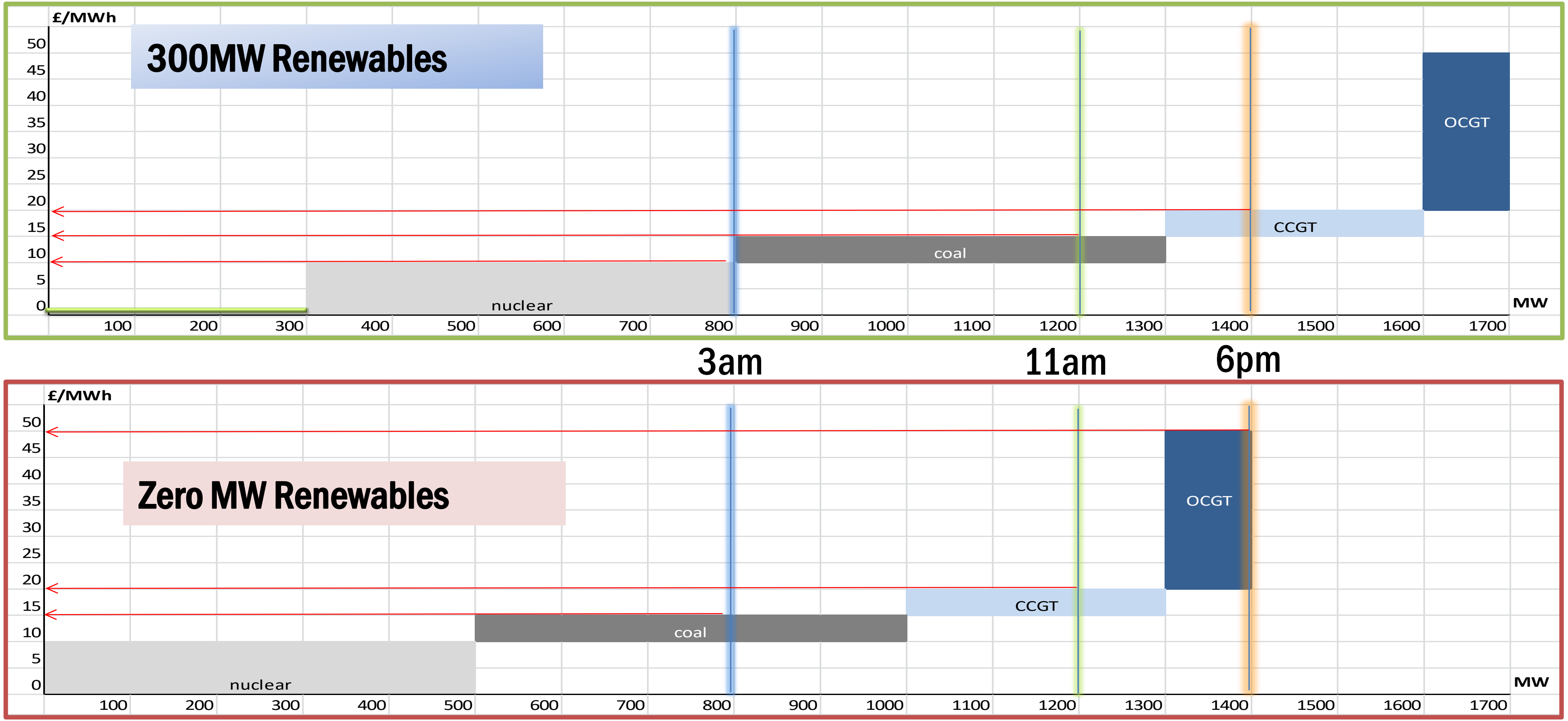


A market sketch without renewables

- Nuclear, coal, CCGT, OCGT and Diesel with respectively
- Marginal costs of 10£/MWh, 15£/MWh, 20£/MWh, 50£/MWh and 70£/MWh
- Maximum capacity of 500MW, 500MW, 300MW, 100MW, and 50MW
- MSG=0 for all generators
- Inelastic demand at 3am (800MW), 11am (1200MW), and 6pm (1400MW)



A market sketch with renewables



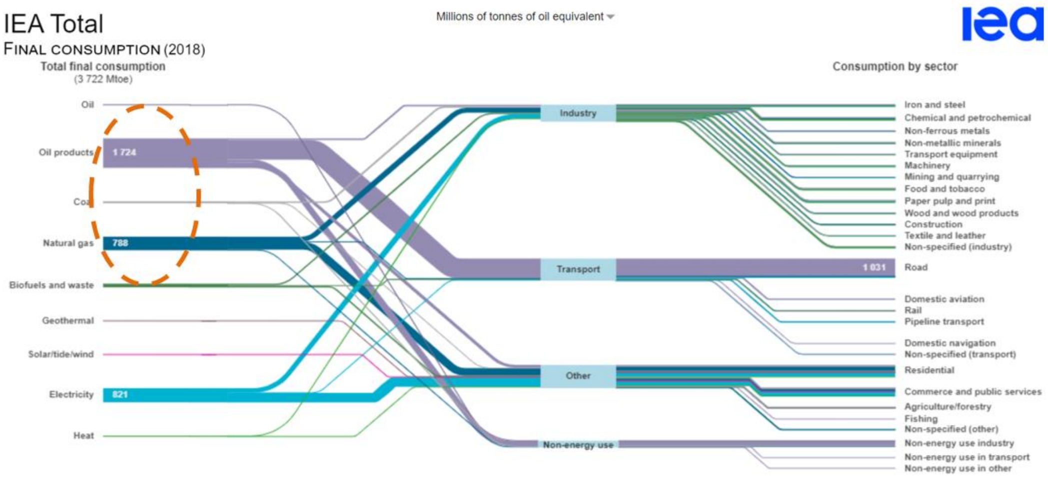
Effect of variable sources

- Generation from renewable sources is variable
- Market prices become **more variable and volatile**
- Power from variable generation might need to be **curtailed**
- Base load producers might be **unable to cover their costs**

Possible solutions

- New market structures
- New flexibility options (e.g., dispatchable power plants, demand response, energy efficiency, energy storage facilities)
- New balancing services
- New management and operational tools
- New multi-energy approach (interaction with other energy sectors)

It's not only about electricity - Worldwide



Source: International Energy Agency (IEA), https://www.iea.org/sankey/#?c=IEA%20Total&s=Final%20consumption

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THANK YOU!

ANY QUESTIONS?