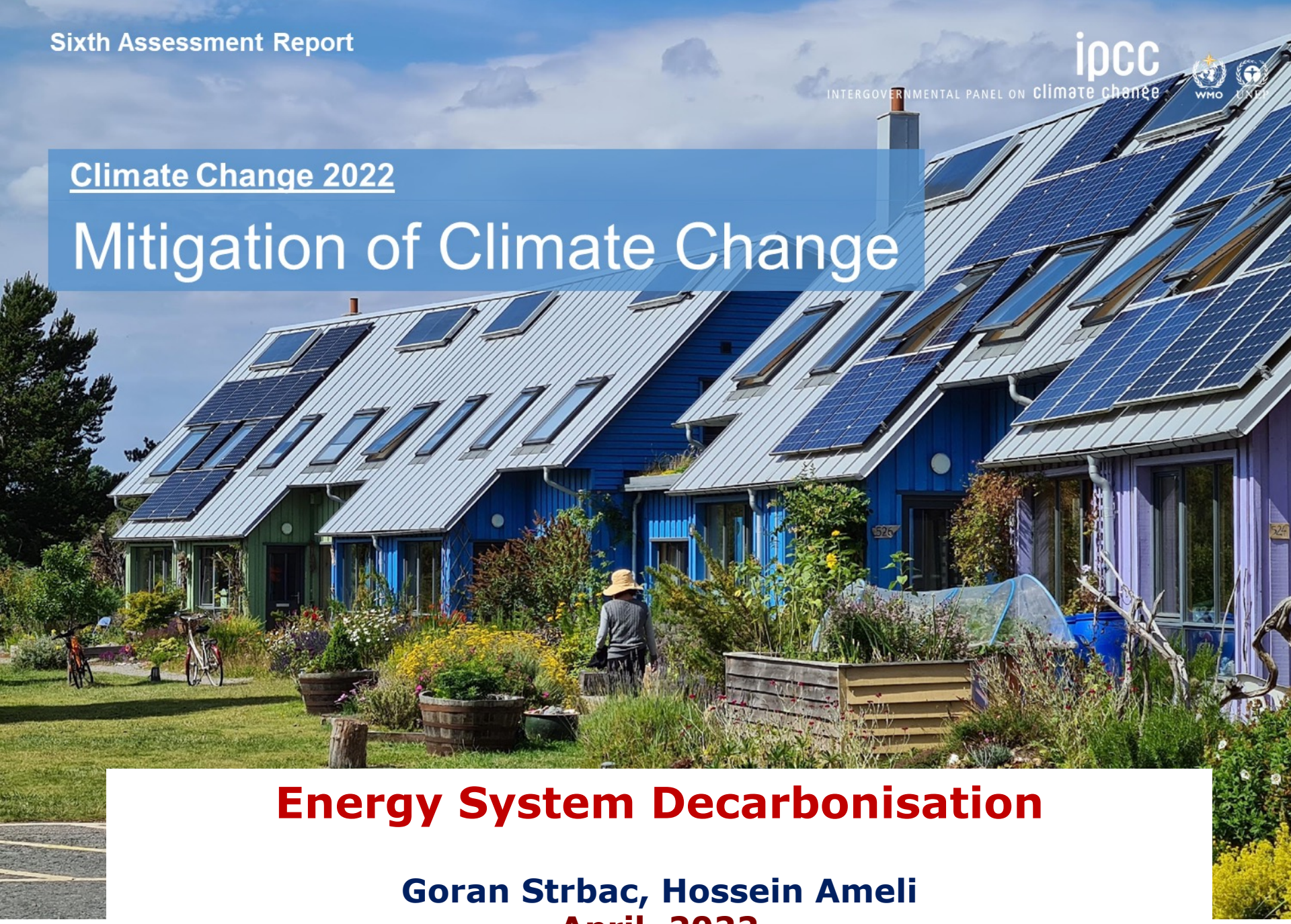

Energy System Decarbonisation

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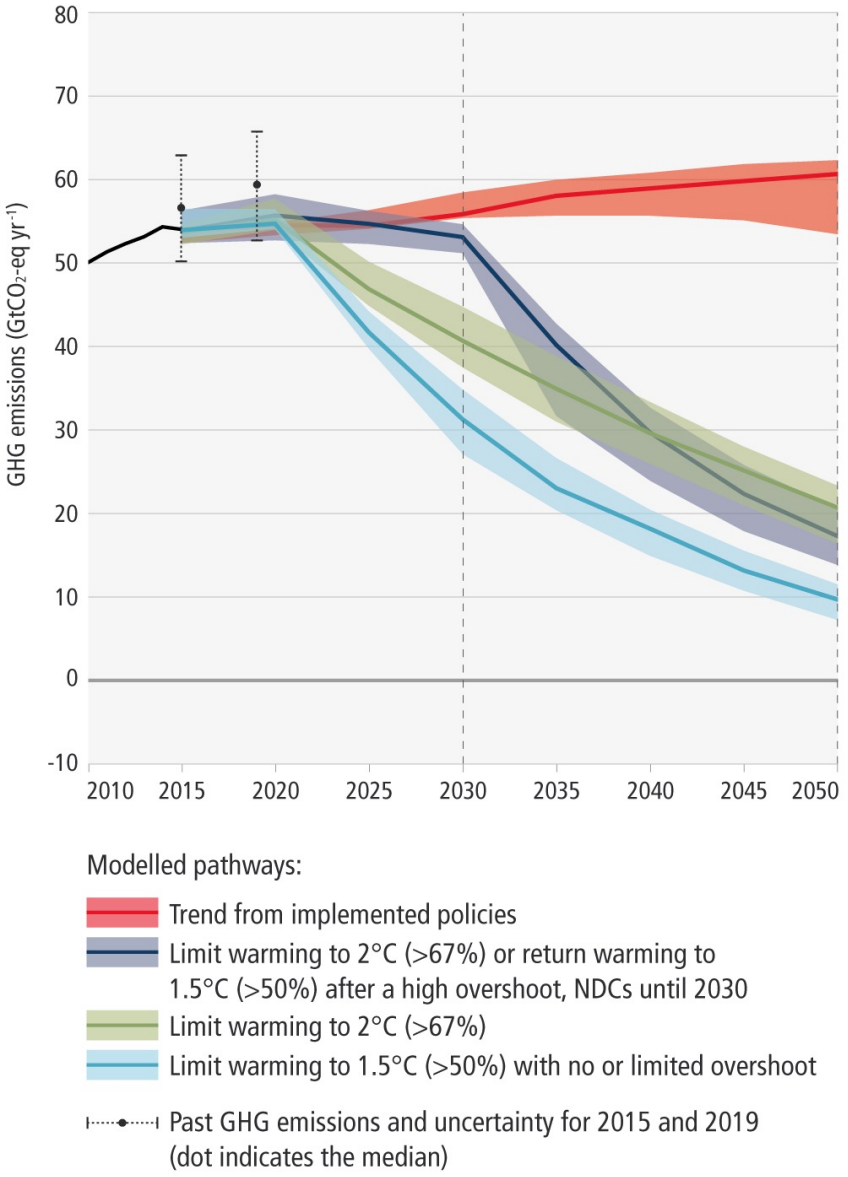
Limiting Global Warming

- Limiting warming to below 2°C will require substantial energy system changes over the next 30 years.
  - This includes reduced fossil fuel consumption, increased production from low- and zero-carbon energy sources, and increased use of electricity and alternative energy carriers.
  - Low-carbon sources produce almost of 100% of global electricity by 2050 in scenarios that limit likely warming to 2°C or below



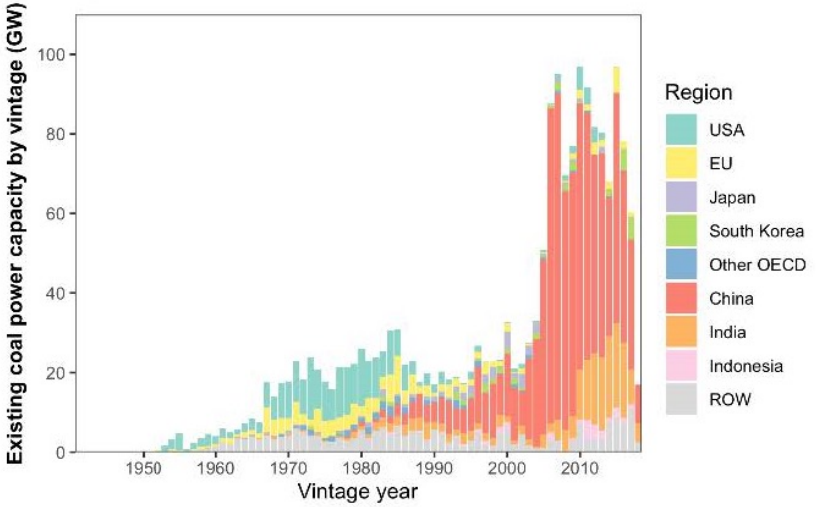
Key Questions

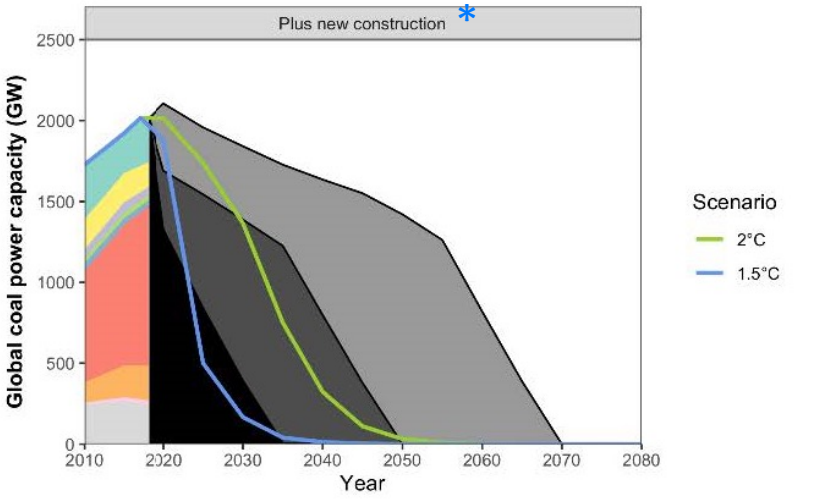
- Will energy systems that emit little or no CO2 be different to those of today?
  - In the future, almost all electricity will be produced from sources that emit little or no CO2, such as solar power, wind power, nuclear power, bioenergy, hydropower, geothermal power, or fossil fuel based in which CO2 is captured and stored.
  - Electricity, hydrogen, bioenergy will replace fossil fuels (e.g. transport, heating, industry).
  - Energy is likely to be used more efficiently than today, for example more efficient buildings that would use less energy, more efficient lights, appliances, greater use or public low-carbon transportation.
  - Fundamental to all of these changes is that low-carbon energy systems will use far less fossil fuel than today.
  - It is important now to improve and test out options that could be useful later on, for example, producing hydrogen from low-carbon sources
  - All of these changes will require new policies, institutions, and even new ways for people to live their lives

Limiting Fossil Fuel Sources

- If investments in coal and other fossil infrastructure continue, energy systems will be locked-in to higher emissions, making it harder to limit warming to well below 2°C.
  - Retirement of these units (need to retire 10 to 25 years earlier than the historical average operating lifetime) is an important factor to limit warming to 1.5°C and likely 2°C.

- Phasing-out coal in the next few decades will present economic, social, and security challenges.
  - These will vary across regions based on the characteristics of existing coal infrastructure, the availability of alternatives, economic development, and technological and institutional lock-in.

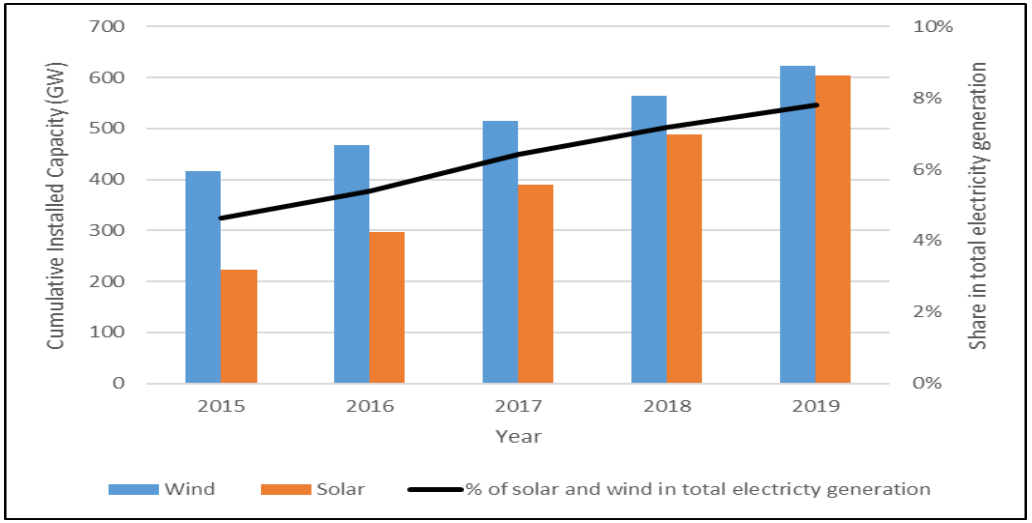


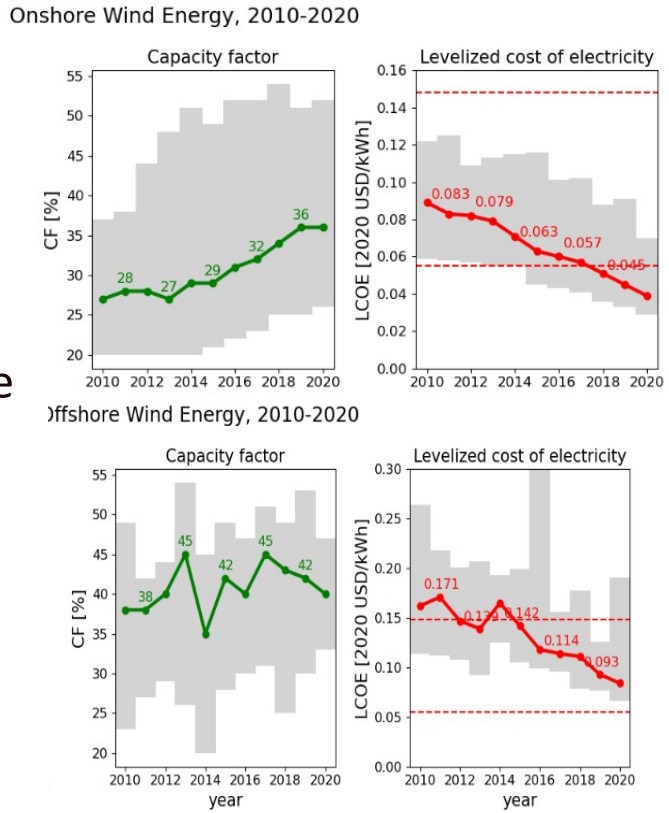


Lifetime of the coal plants Black: 15 years – Dark Grey: 30 years – Light Grey: 50 years

Technology Development

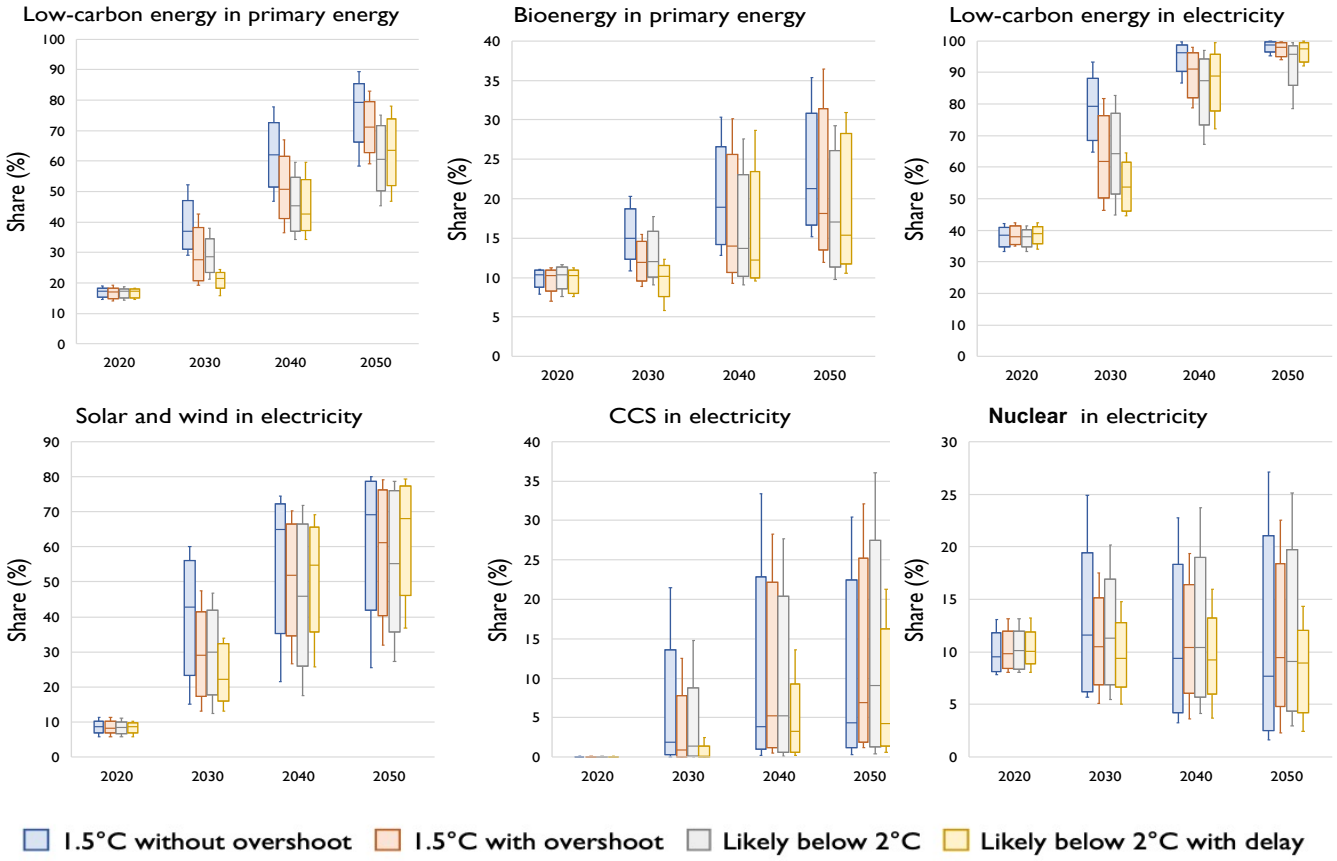
- Costs of RES have reduced rapidly over the last five years, notably solar PV, wind power, and batteries.
  - From 2015 to 2020, the prices of electricity from PV and wind dropped 56% and 45%, respectively, and battery prices dropped by 64%
- Global wind and solar PV capacity and generation have increased rapidly.
  - Policy, societal pressure to limit fossil generation, low interest rates, and cost reductions have all driven wind and solar PV deployment.



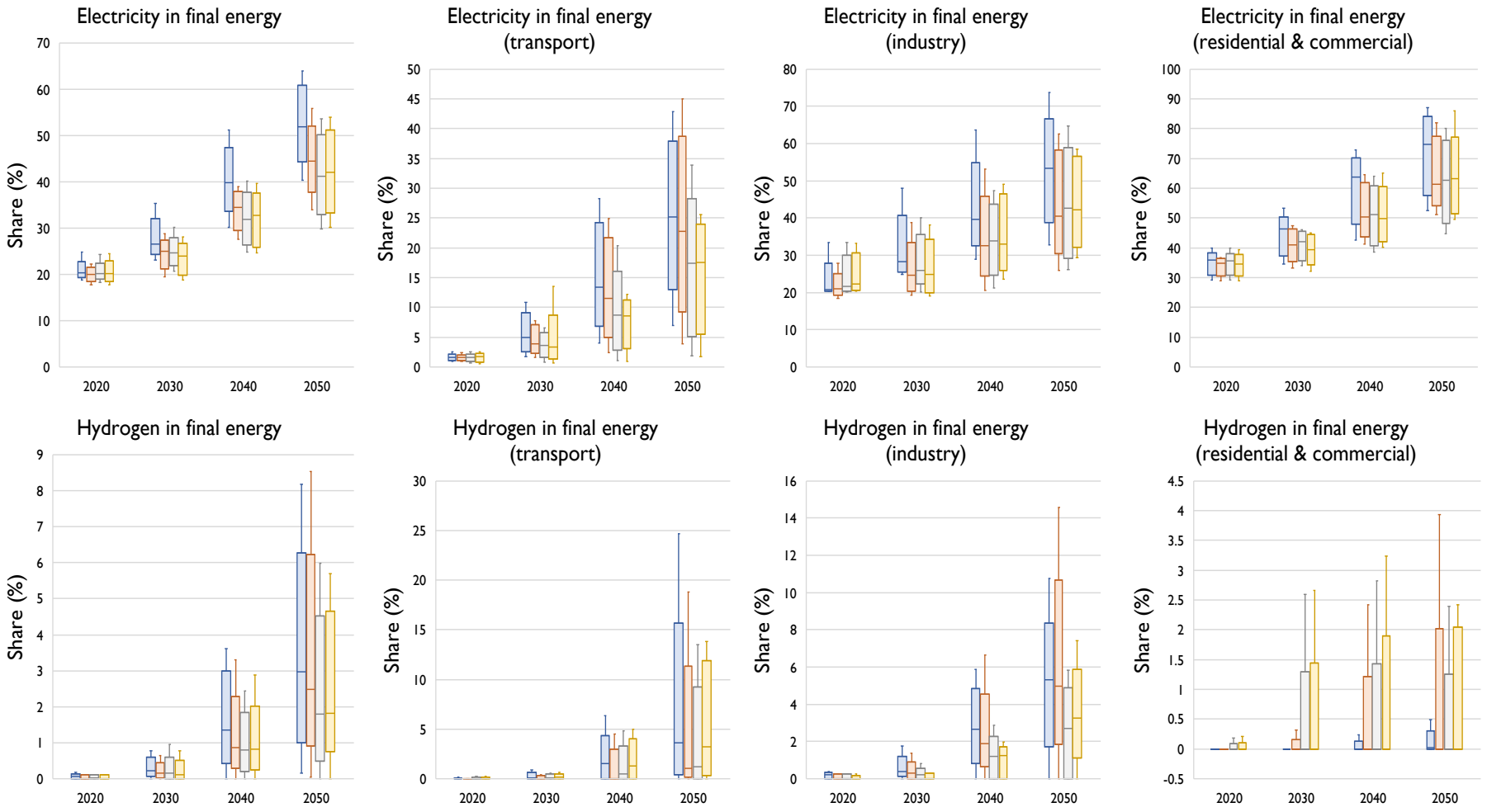


Impact of Climate Change on Energy

- Climate change will affect many future local and national low-carbon energy systems. The impacts, however, are uncertain, particularly at the regional scale.
  - Electricity generation through nuclear power, hydropower, Solar PV and wind. Bioenergy accounts for about a tenth of global primary energy. Carbon capture is used in the oil and gas industry.



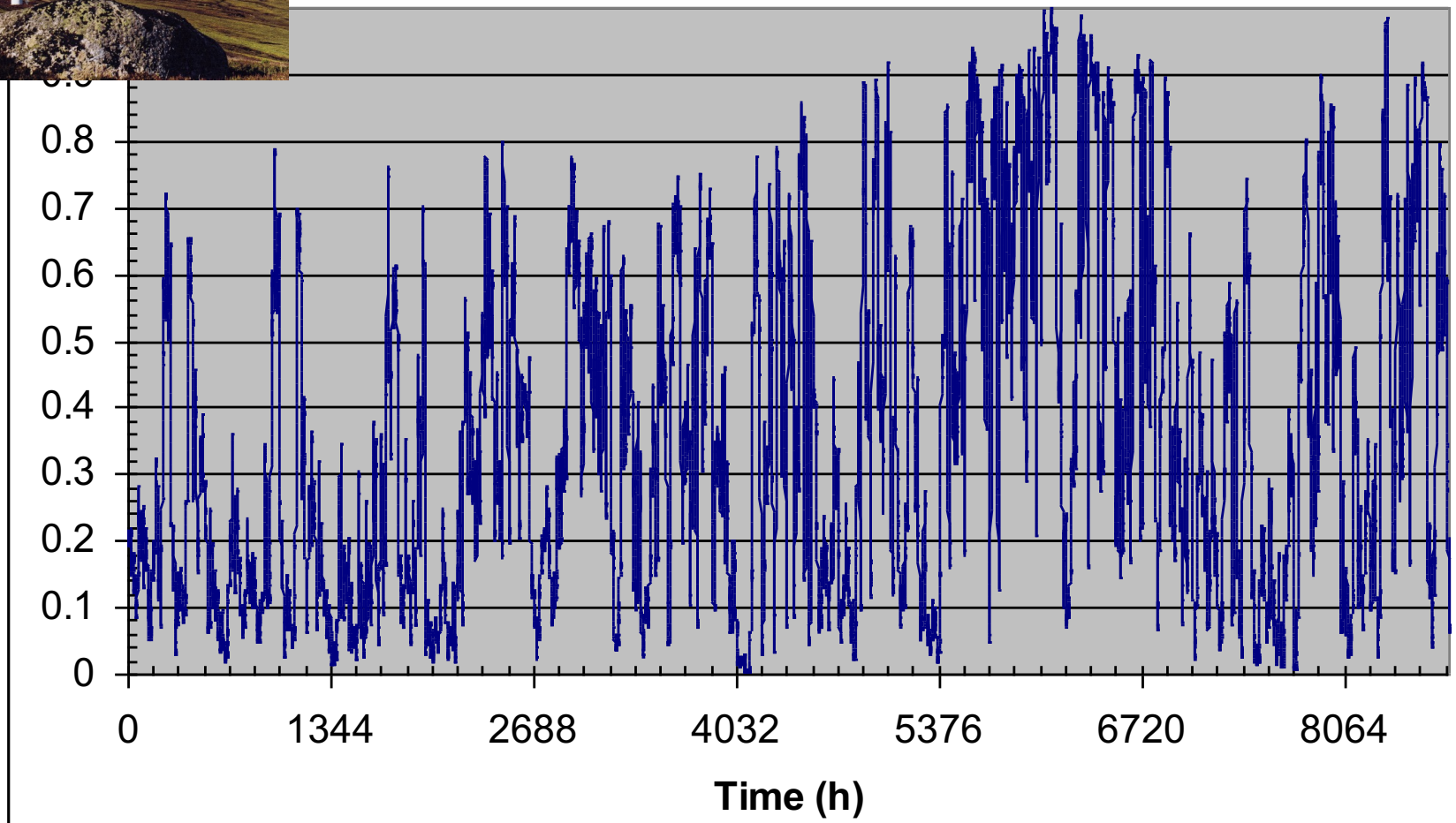
Shares of electricity and hydrogen in final energy



RES - key Question

- Can renewable sources provide all the energy needed for energy systems that emit little or no CO2?
  - Some countries have significant renewable energy resources, whereas others do not, and other energy sources, such as nuclear power or fossil energy in which CO2 emissions are captured and stored (carbon dioxide capture and storage, or CCS) can also contribute to low-carbon energy systems.
  - The energy from sources such as solar, wind, hydropower vary throughout the day, over seasons and years
  - All low-carbon energy sources have other implications for people and countries.
- For all of these reasons, it is unlikely that all low-carbon energy systems around the world will rely entirely on renewable energy sources.

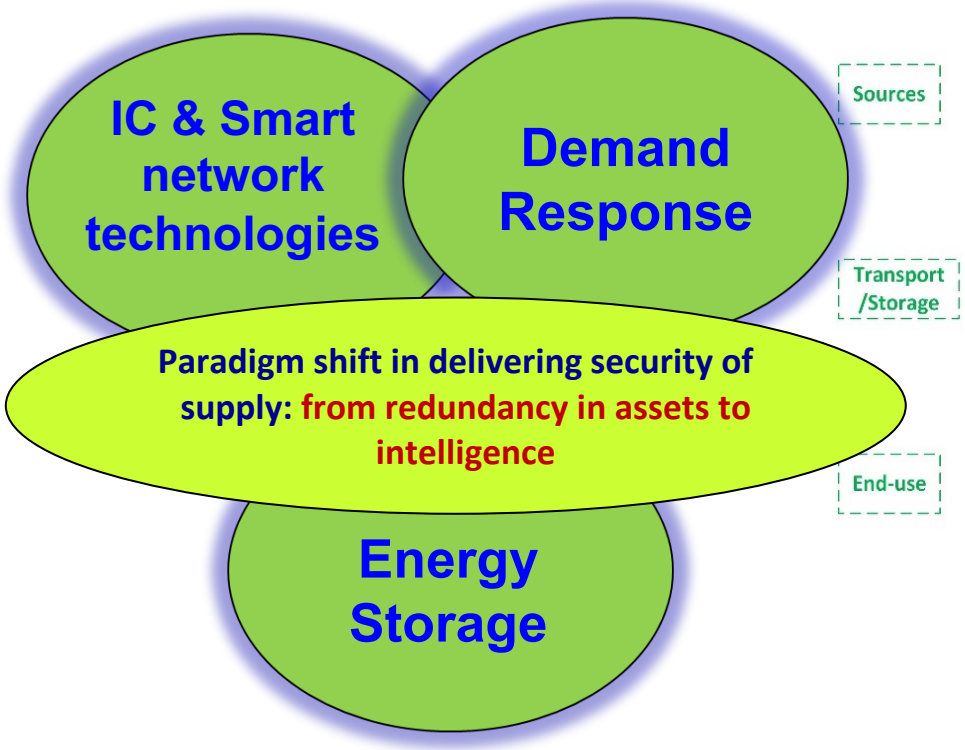
RES dominated system: *operation and planning challenges*

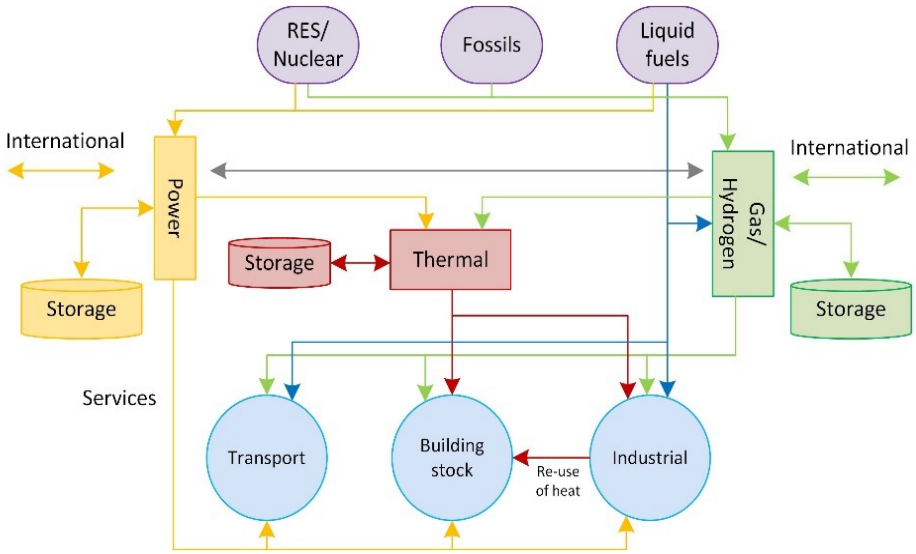


Energy System Integration

- A broad-based approach across the energy sector (and not only electricity system) will be necessary to reduce emissions.
- Enhanced integration across energy system sectors and across scales will lower costs and facilitate low-carbon energy system transitions.

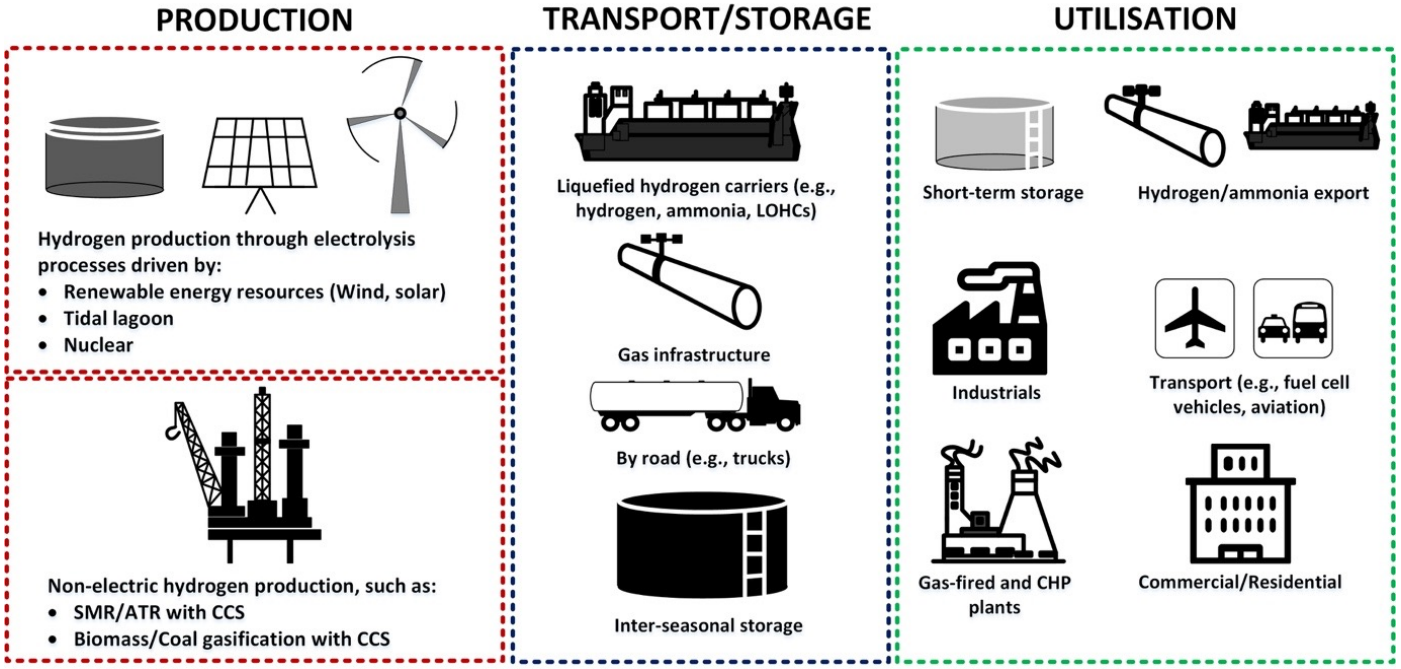
➢ Energy systems can be integrated across district, regional, national, and international scales.





Hydrogen Value Chain

- Advances in low-carbon energy resources and carriers such as next-generation biofuels, hydrogen produced from electrolysis, synthetic fuels, and carbon-neutral ammonia would substantially improve the economics of net-zero energy systems (realizing a hydrogen economy)
  - However, long-term mitigation costs are not well understood and depend on policy design and implementation, and the future costs and availability of technologies.



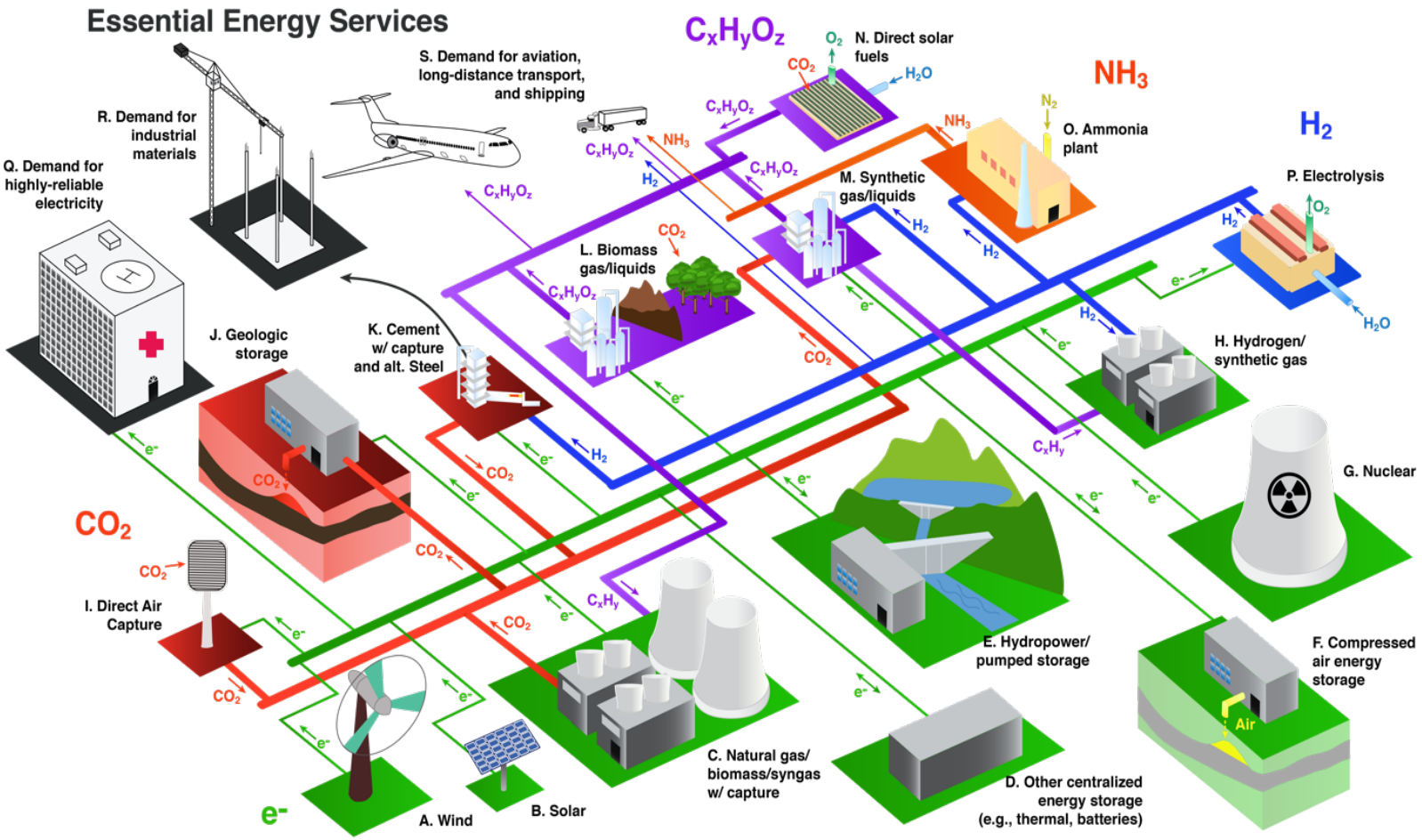
Net-Zero Energy System\1

- Net-zero energy systems will share common characteristics, but the approach in every country will depend on national circumstances. Common characteristics of net-zero energy systems will include:

1. Electricity systems that produce no CO2 or remove CO2 from the atmosphere
2. Greater **energy system integration** across regions and across components of the energy system
3. Widespread electrification of end uses
4. Substantially lower use of fossil fuels than today
5. Use of alternative energy carriers such as **hydrogen**, bioenergy, and ammonia to substitute for fossil fuels
6. More efficient use of energy
7. CO2 removal (e.g., **DAC, BECCS**) to offset any residual emissions

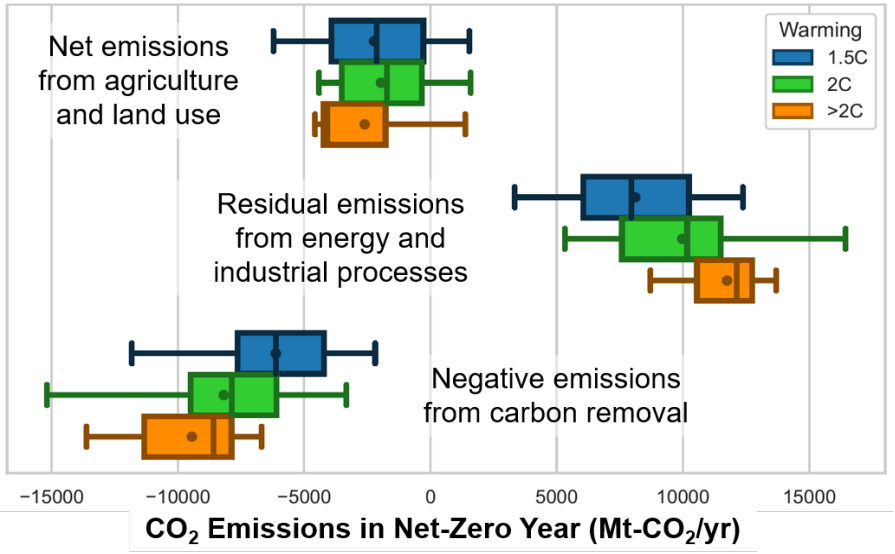
Net-Zero Energy System\2

- Schematic of net-zero emissions energy system, including methods to address difficult-to-electrify sectors

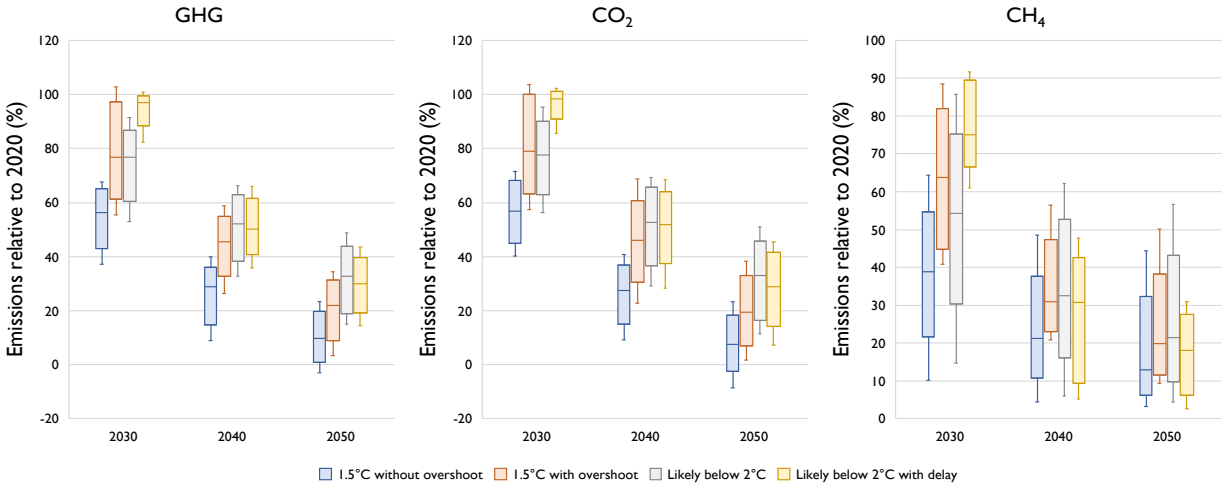


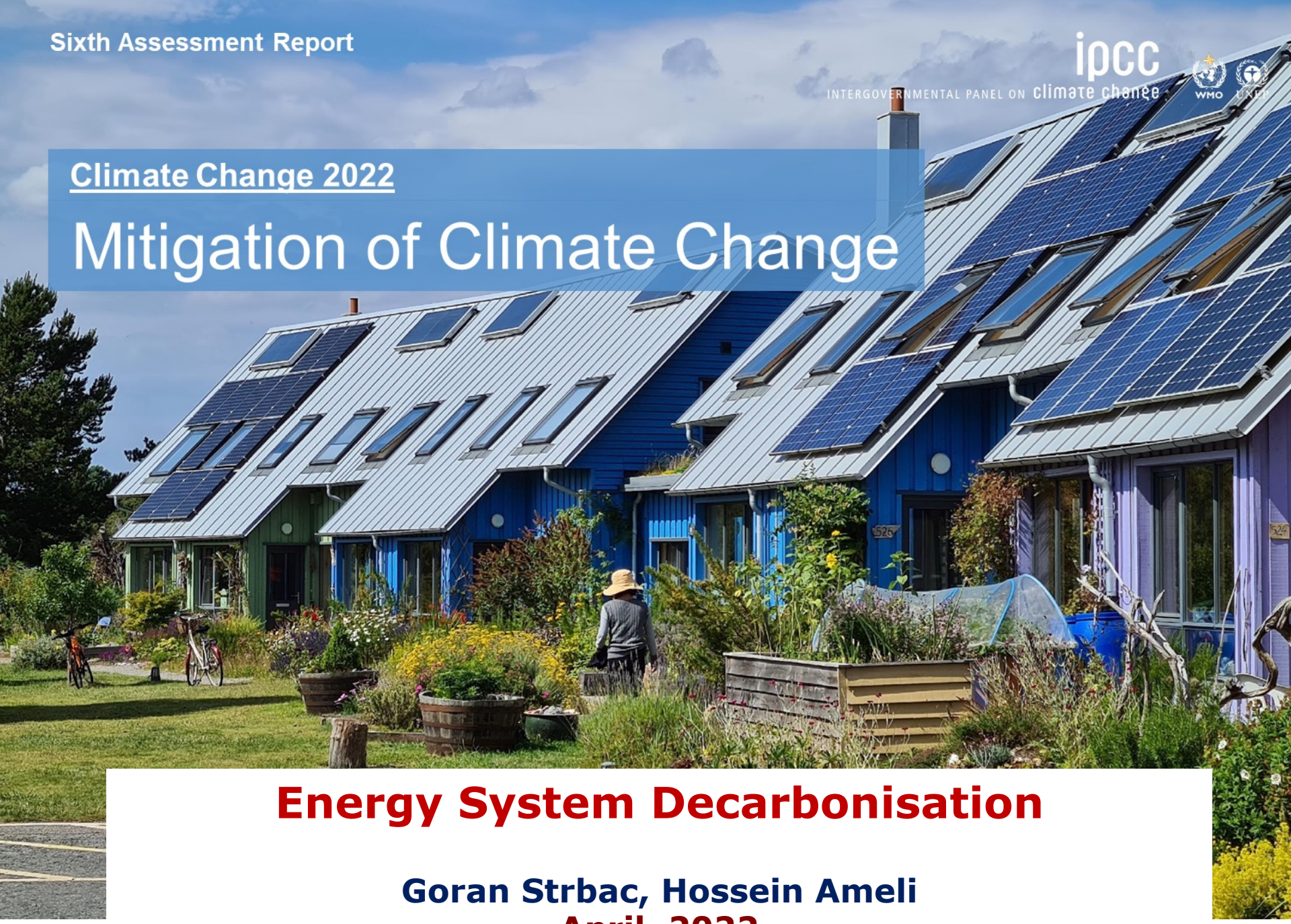
Net-zero scenarios: emissions

- Residual and negative emissions in net-zero scenarios (global energy and industrial CO2 emissions reach net-zero) show global differences across warming levels (blue = <1.5˚C, green = <2.0˚C, orange = >2.0˚C).



- Projected energy sector GHG emissions for the 1.5°C scenarios (without and with overshoot), and likely below 2°C scenarios (without and with delayed policy action) during 2020-2050





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