Impact of Sector Coupling on the Cost Efficiency of Net Zero Carbon Energy Systems

IEA Wind TEM#113 on Net Zero Power System Studies, Dublin, Ireland

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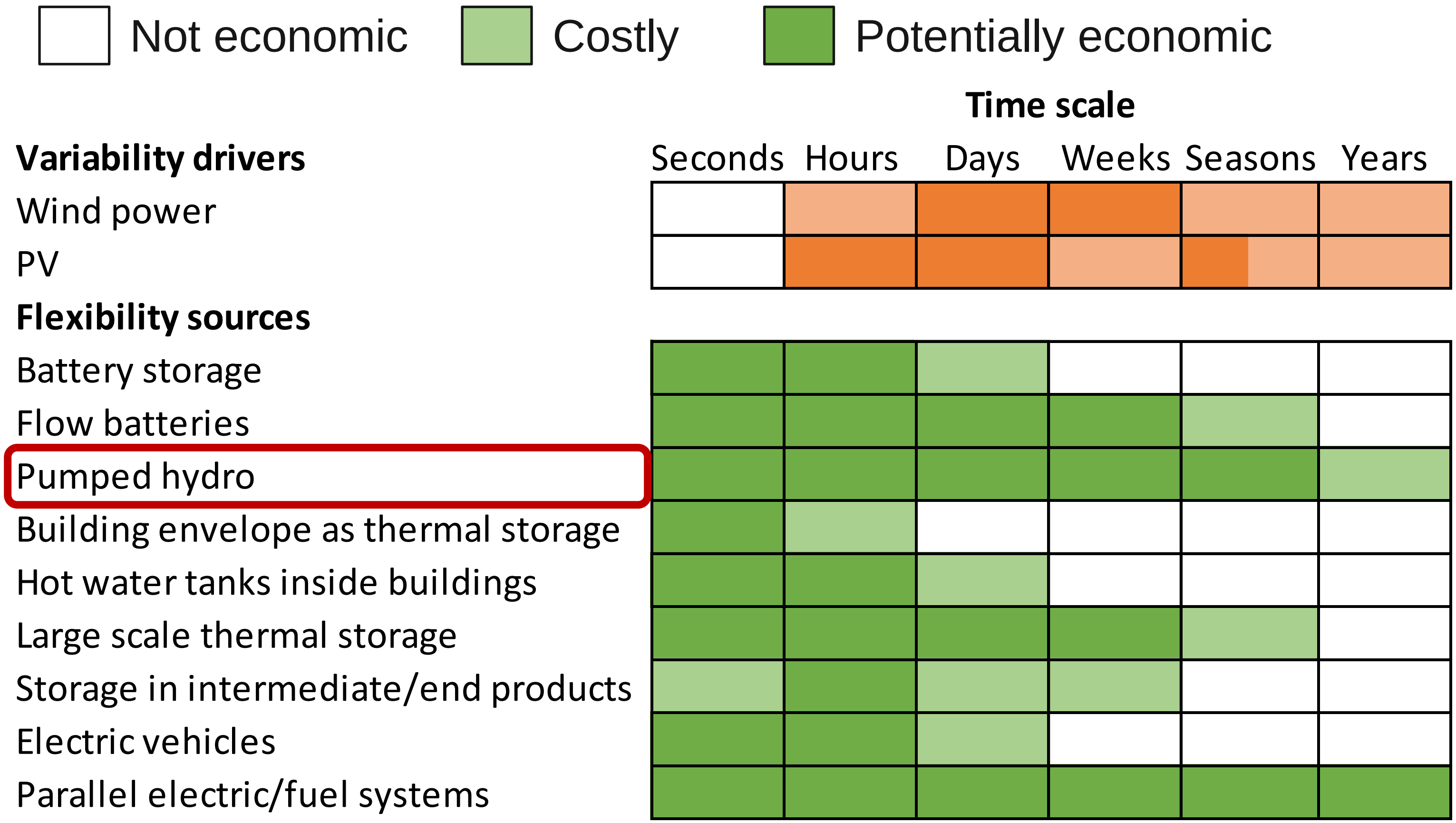
Principal scientist

Lot of new electricity demand expected

- Energy end-use is ~3 x current electricity demand
- Electric vehicles, heat pumps, etc. are more efficient than fuel based alternatives
  - Electrification will roughly double the electricity demand
- <u>How flexible that new demand could be?</u>



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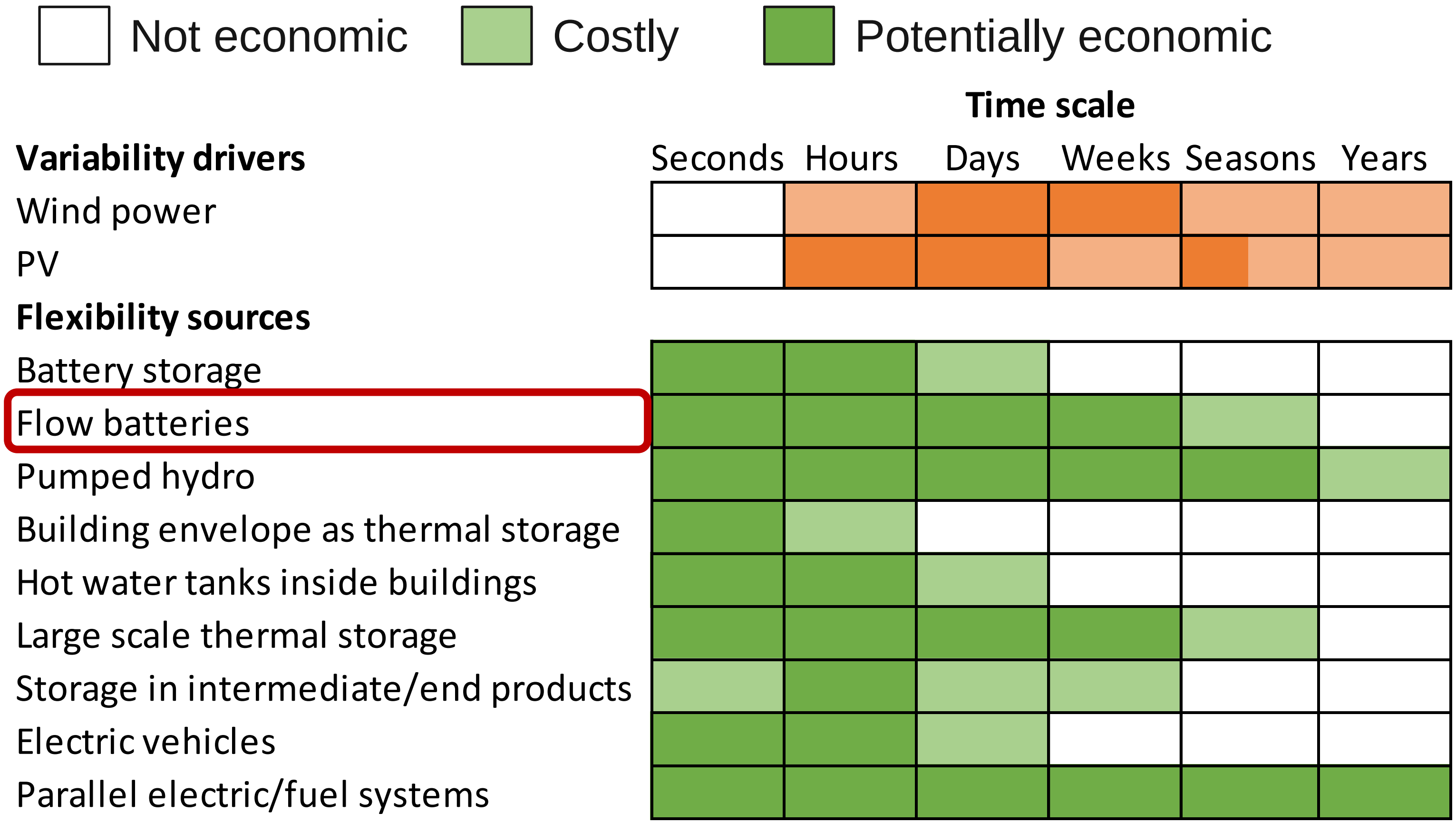

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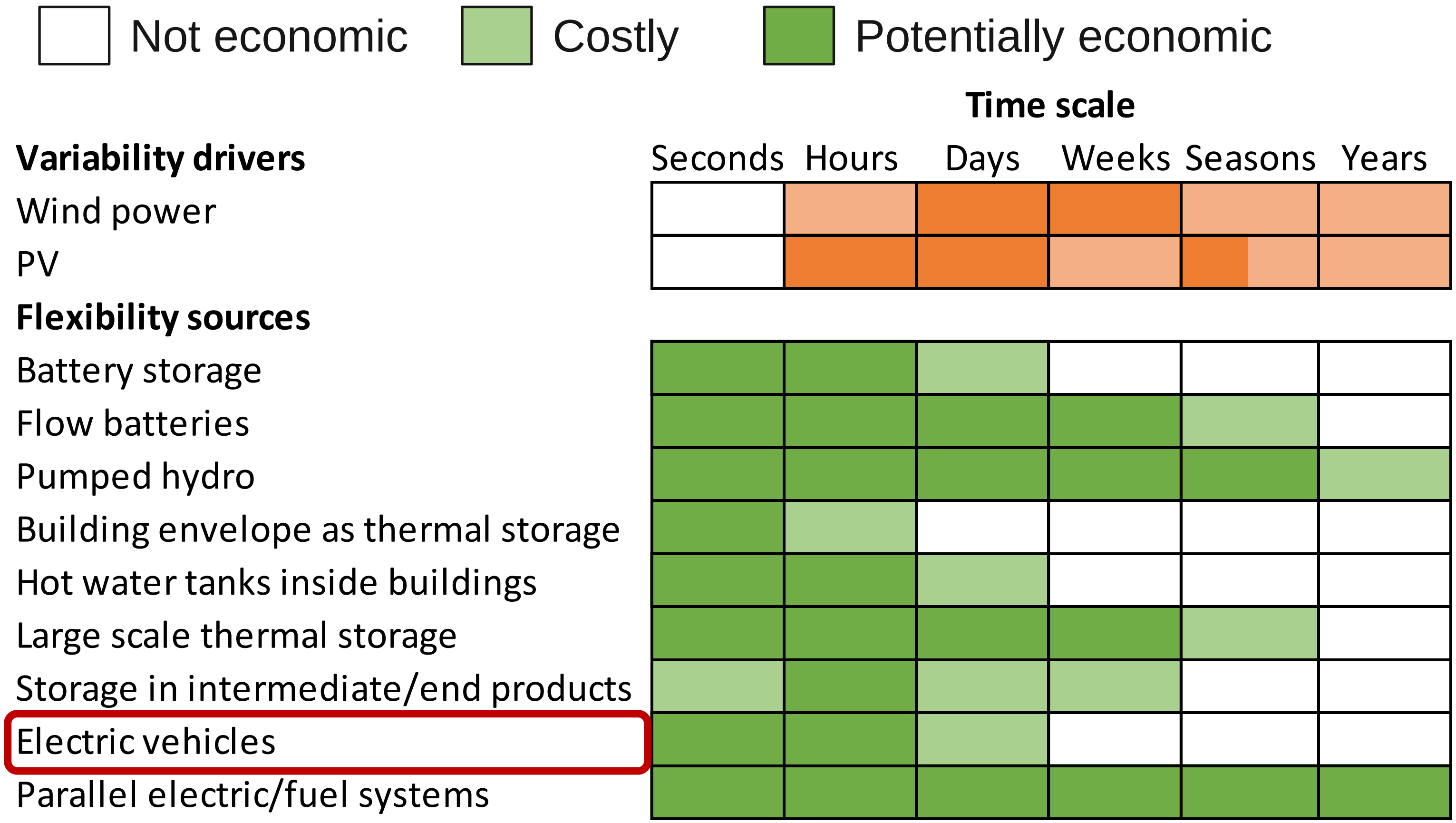

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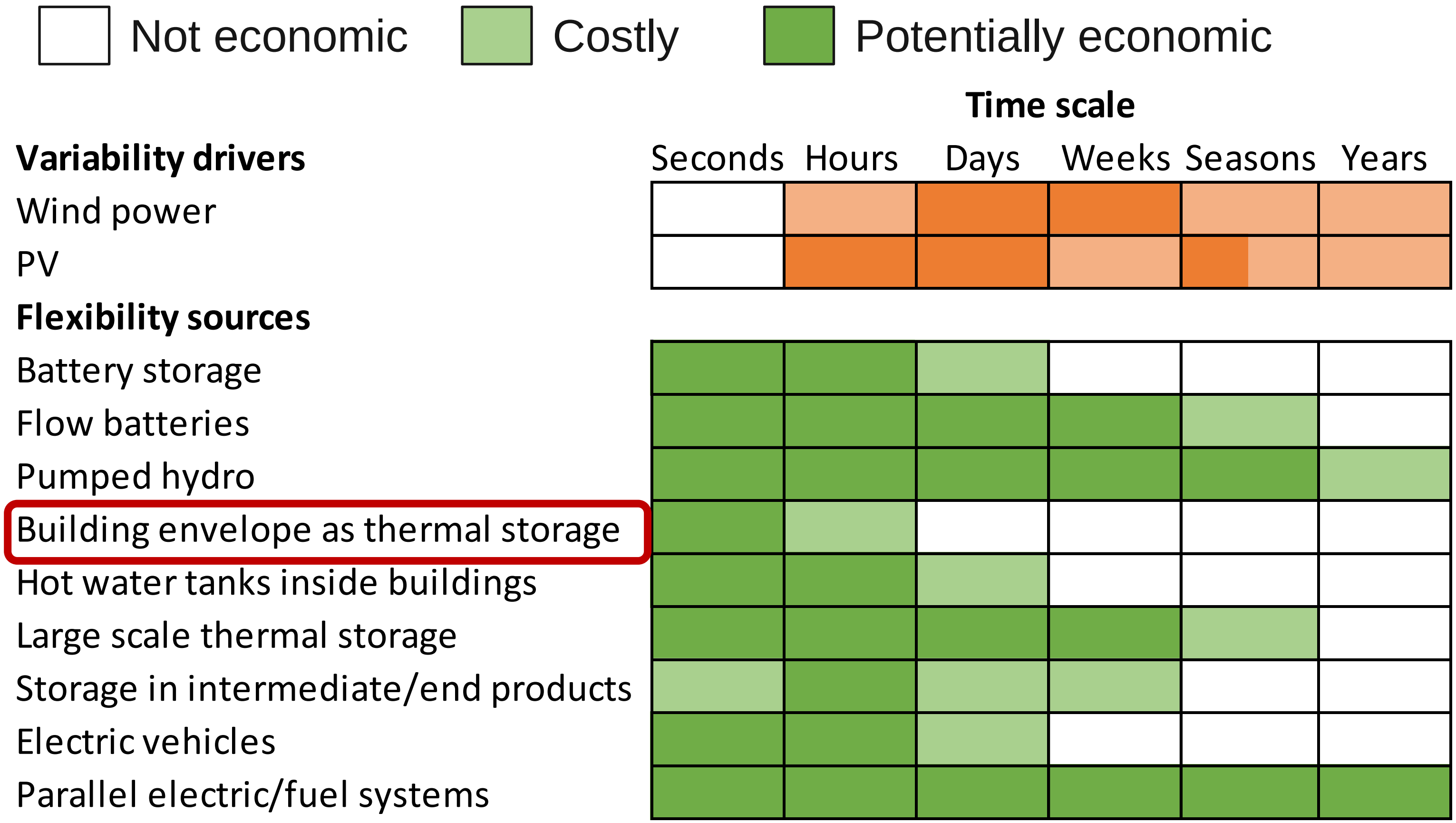

VTT

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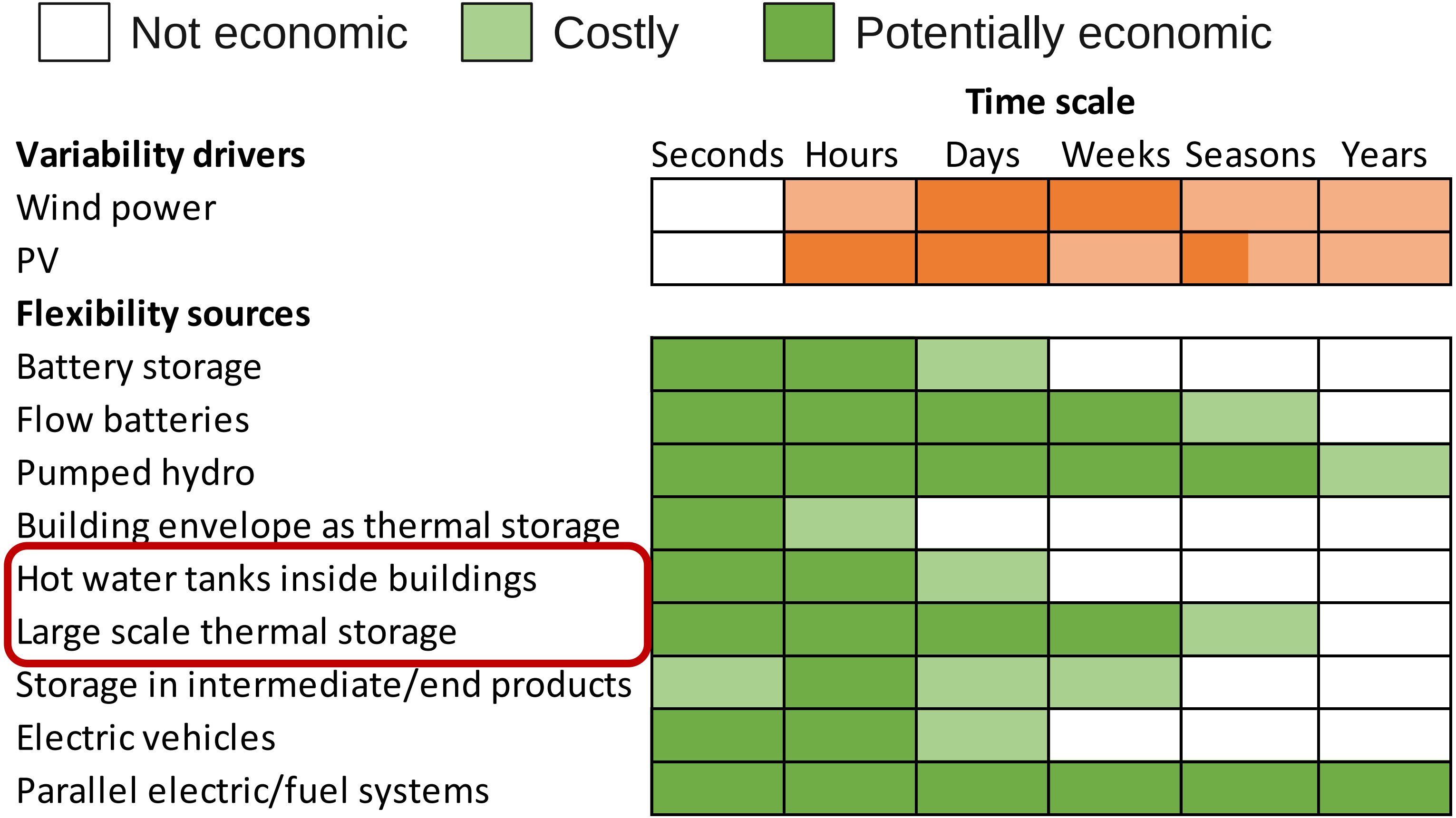

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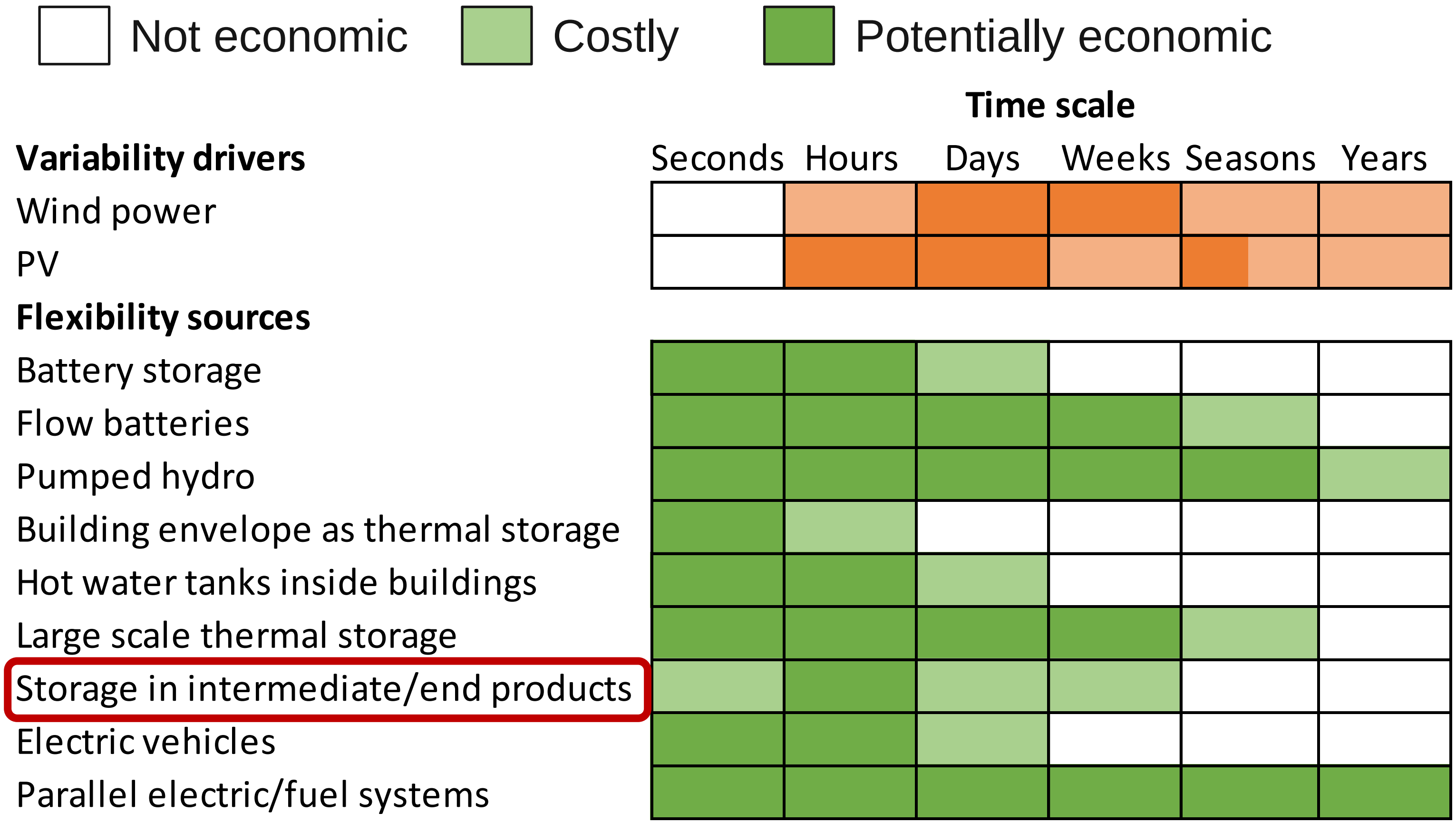

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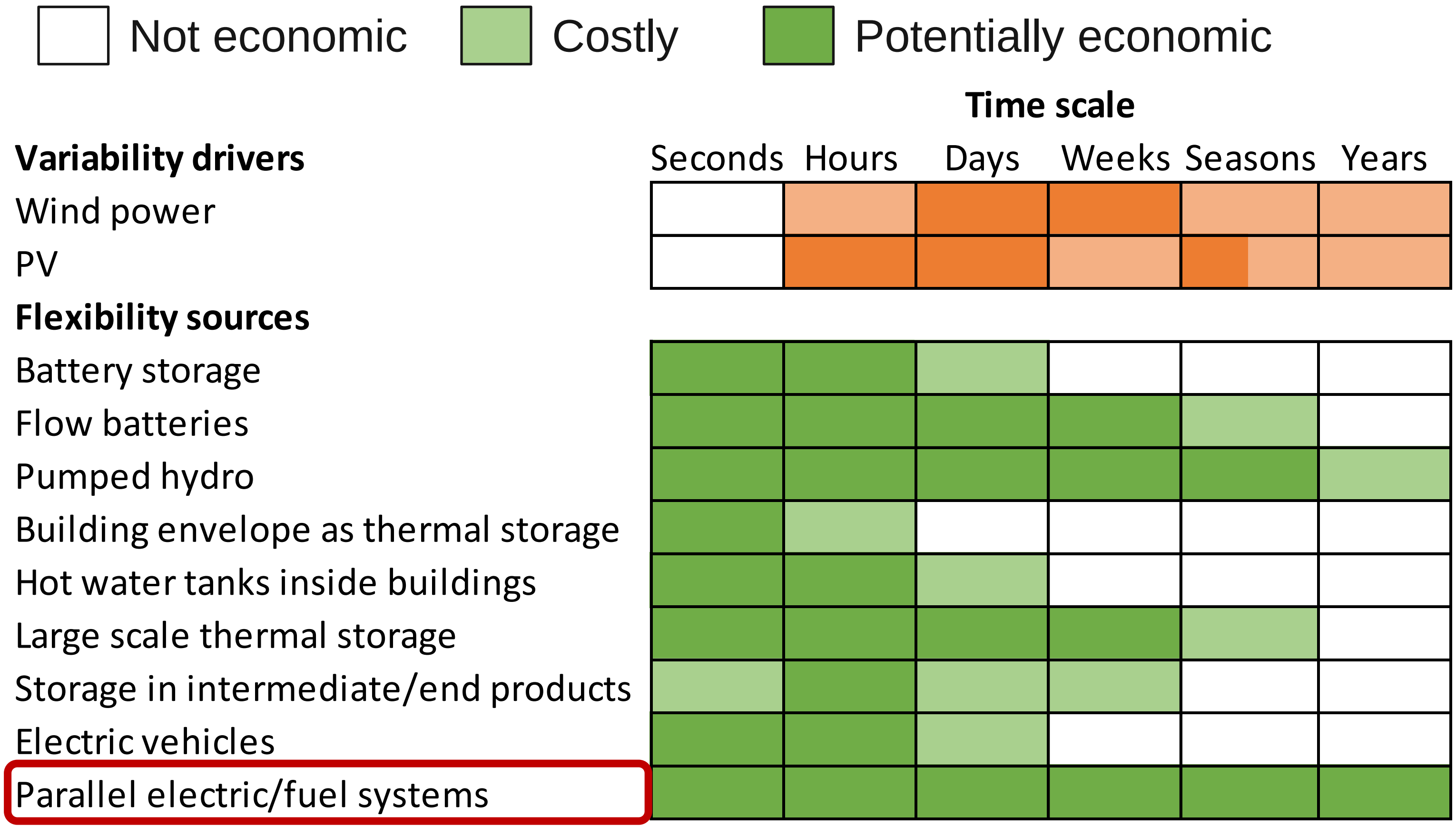

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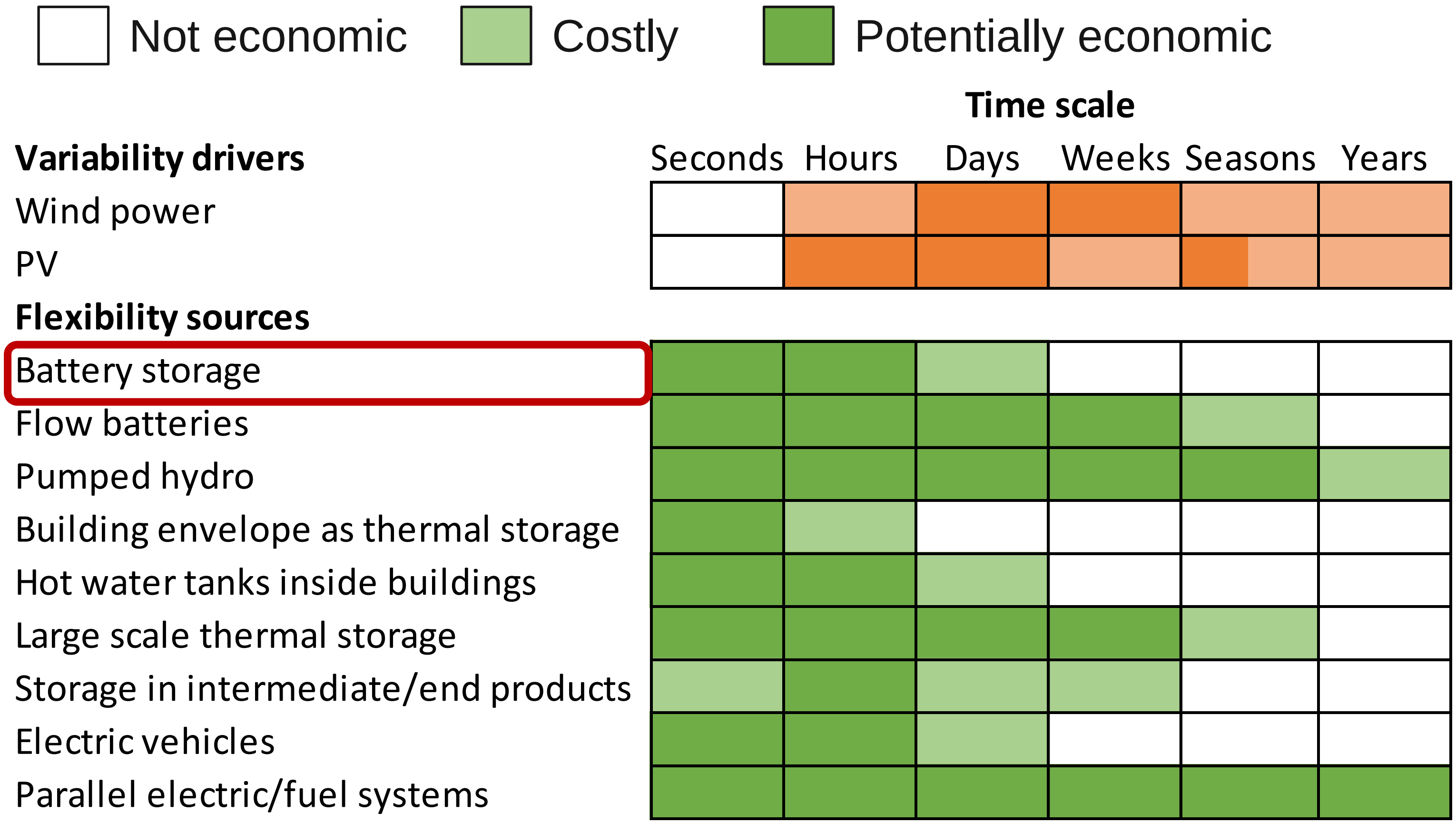

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IEA & VTT

Managing seasonal and inter-annual variability of renewables in reference systems

Dr Ilkka Hannula, Senior Energy Analyst, IEA
Dr Juha Kiviluoma, Principal Scientist, VTT

IEA Wind, Task 25
Tue 8 Nov 2022

VTT team includes Tomi J. Lindroos and Jussi Ikäheimo

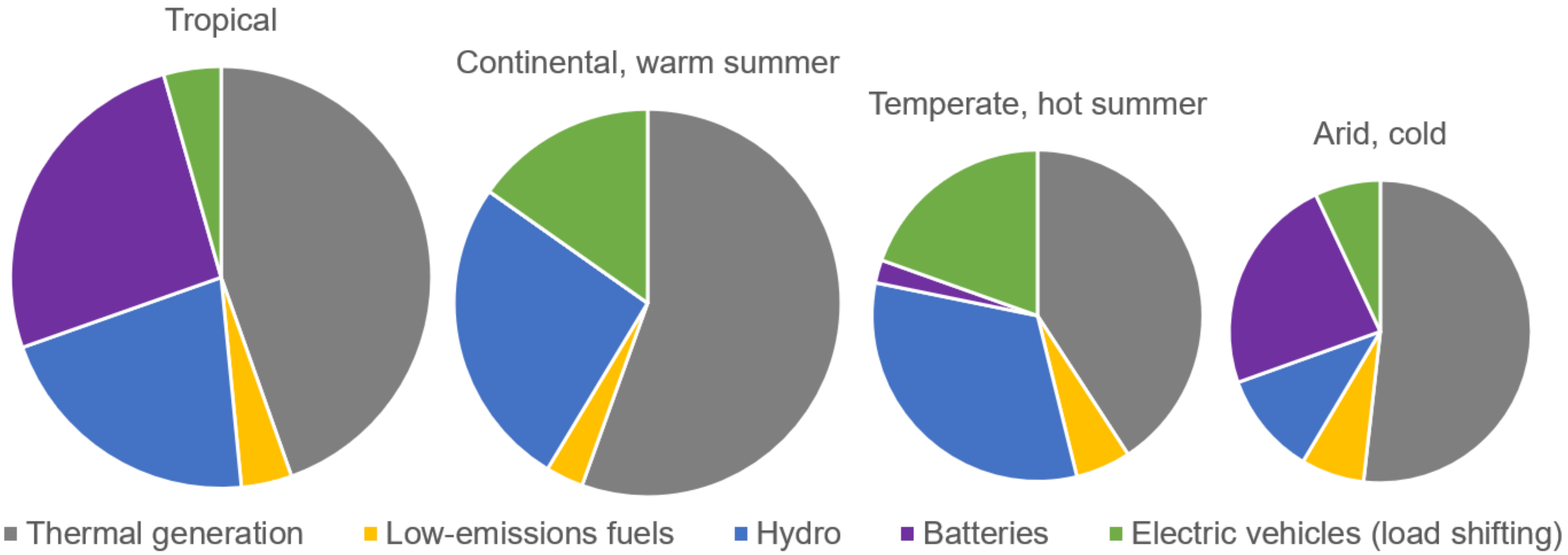
International Energy Agency

Climatic reference systems

- For exploring the impact of climatic zones (and hence different renewable energy resources and profiles) on cost optimal **energy** systems
- Planning level
- Geographically simple model to allow energy sectors, many scenario runs and/or multi-year time series
- Joint IEA – VTT work to support IEA World Energy Outlook (inter-annual variations)
- Initial work at VTT funded by Business Finland and Wihuri Foundation: Article (J Ikäheimo, TJ Lindroos, J Kiviluoma) exploring feasibility of electrofuels

Thermal plants are an important source of flexibility in high VRE systems

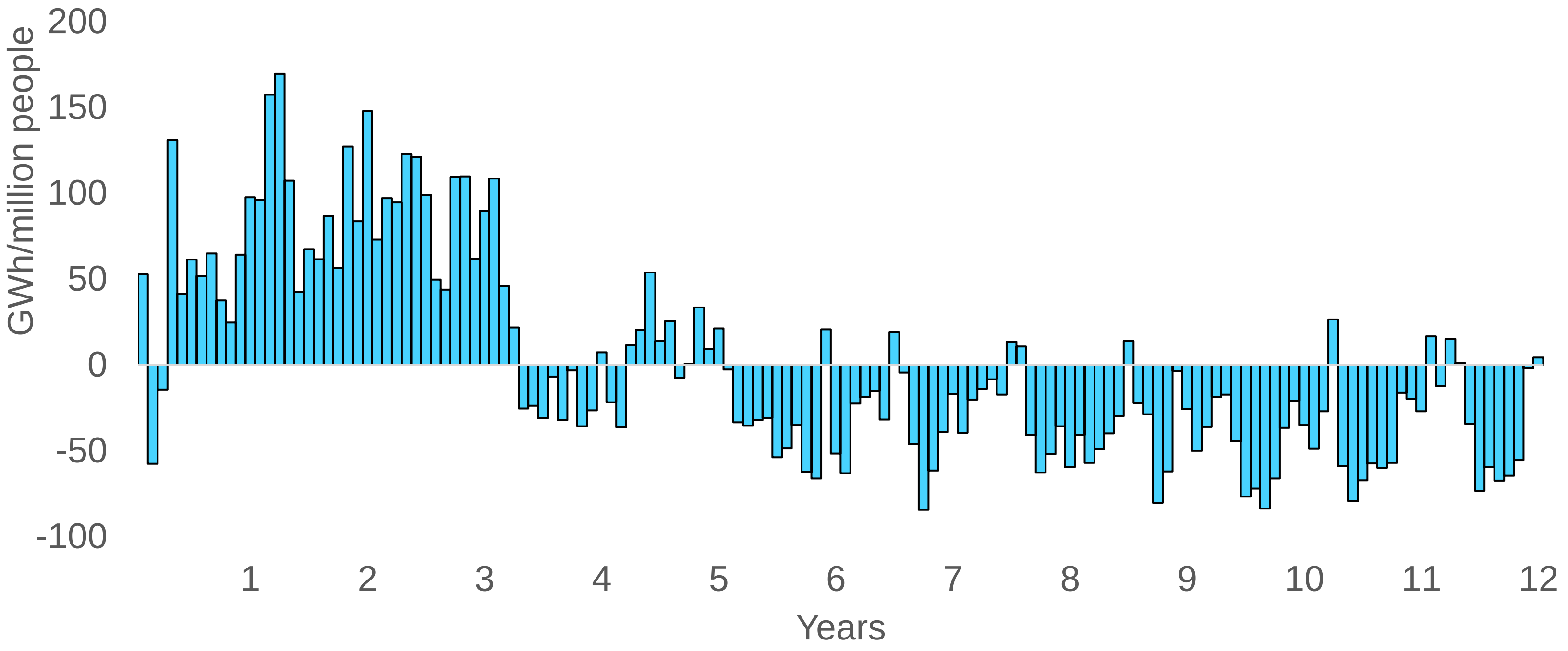
Main technologies responsible for supplying annual electricity storages in the analysed climate zones.



VRE share 70-80% of annual generation with legacy fossil-fired plants and fossil fuel supply chains. Despite high share of thermal generation, the potential to use low-emissions fuels produced from domestic resources remains limited due to high cost.

Hydro drives inter-annual variation in the continental reference system

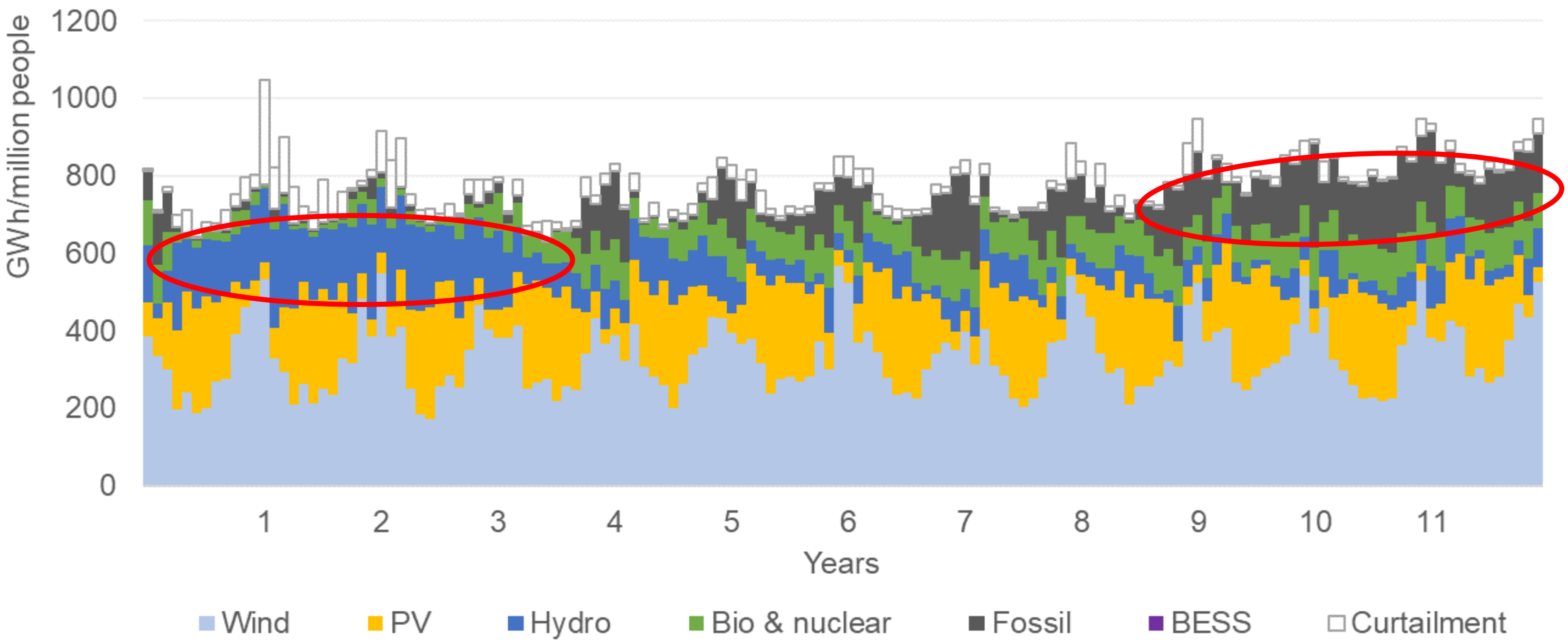
Difference in monthly hydropower generation compared to 12-yr average for the continental (warm summer) reference system.



The complied dataset shows particularly challenging period with several consecutive years of low hydropower generation compared to the monthly average of 95 GWh/million people over the 12 year period.

Inter-annual variation is met with legacy thermal capacity in this ref. system

Monthly generation by technology over a period of 12 years in the continental (warm summer) reference system.



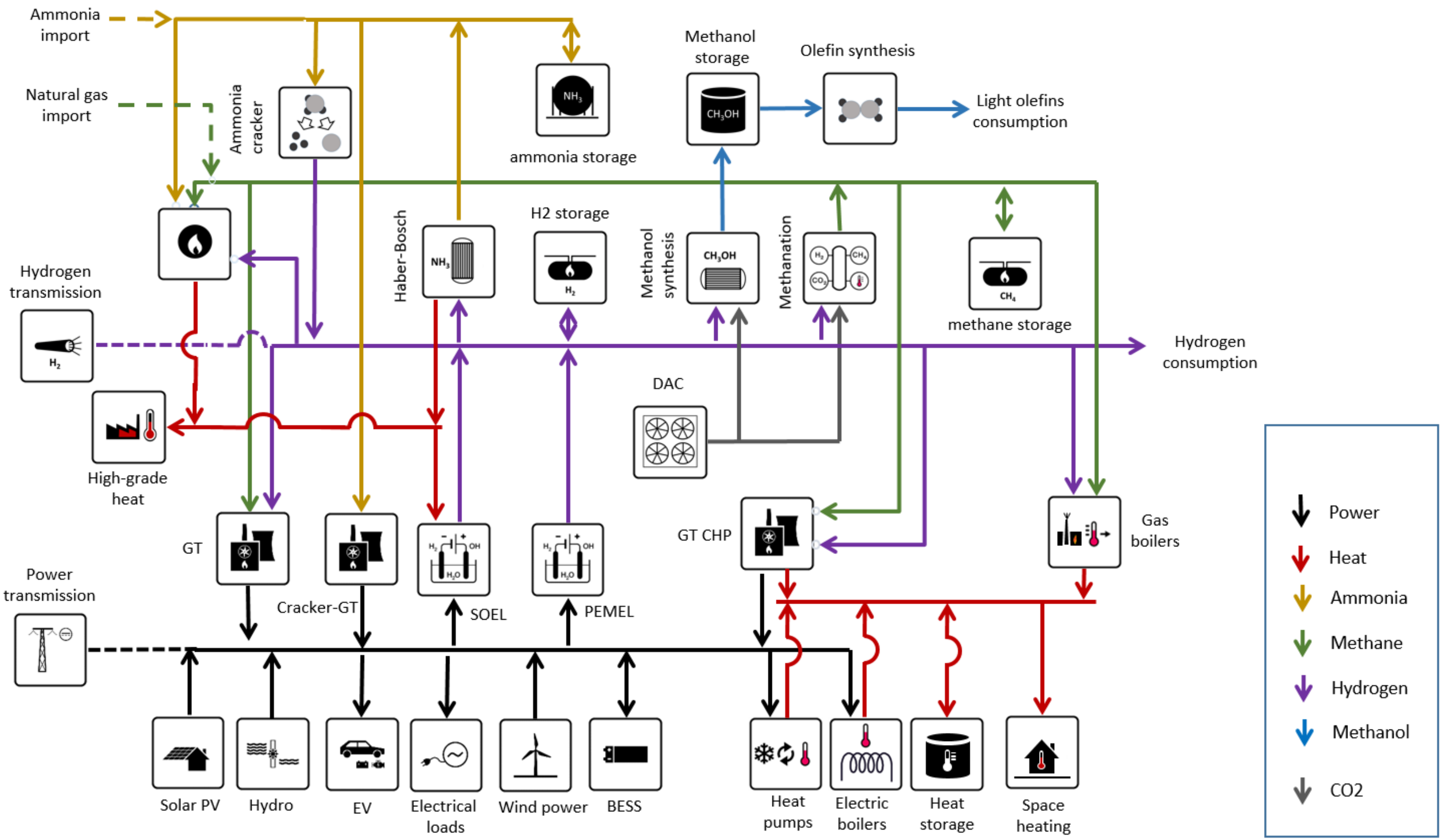
System dispatches first existing low-emission thermal capacity followed by existing fossil fuel capacity to meet the net load during consecutive years of low hydrogeneration.

VTT work on electrofuels

- Multiple electrofuel pathways in the same model
- 38 conversion or storage technologies (as investment options)
- Exogenous demand for electricity, space heating, H2, olefyns, ammonia, road transport
- Import option for ammonia and natural gas
- Representative periods plus candidate periods
- 5 climatic zones, hydro low/high
- Bioenergy, aviation, maritime and certain industries excluded

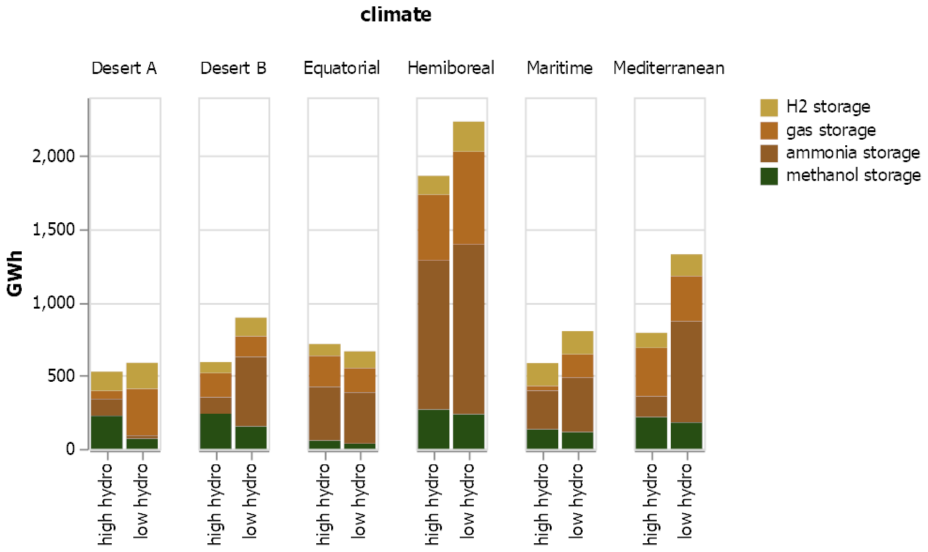
- Ikäheimo J., Lindroos TJ, Kiviluoma J, submitted, Impact of climate and geological storage potential on feasibility of electrofuels

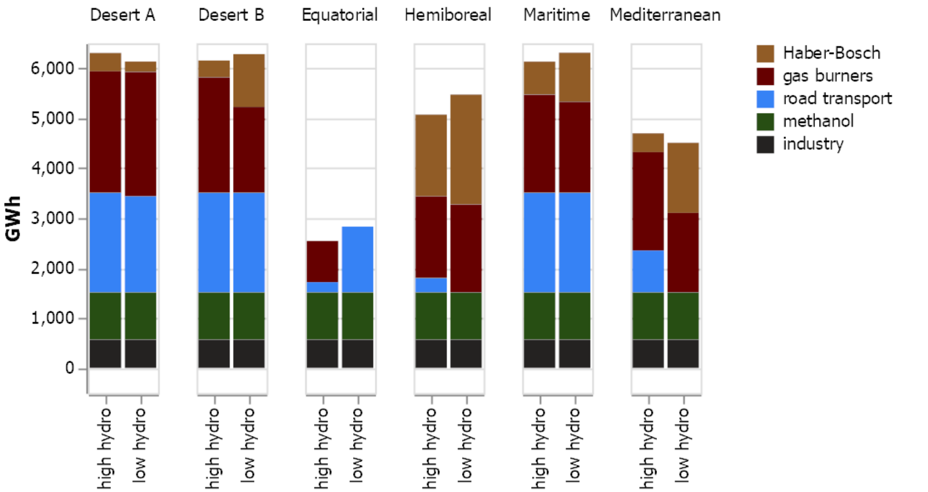
Different electrofuel pathways



Main outcomes

- Electricity consumption increases by 2-3 times
- Wind more important in high latitudes, PV in low latitudes
- Equatorial relies on imports
- All electrofuels used, except liquid methane
- Batteries not used
- Reservoir hydro reduces other storages, but only to a degree
- Cavern storages improved H2 compared to ammonia





Thank you!

- Results from articles
  - IEA & VTT. https://www.iea.org/reports/managing-seasonal-and-interannual-variability-of-renewables
  - Ikäheimo et al. 2023. https://doi.org/10.1016/j.apenergy.2023.121093
- Research team “Design and Operation of Energy Systems” articles
  - https://cris.vtt.fi/en/organisations/does-design-and-operation-of-energy-systems/publications/
- Open source tools and data
  - https://github.com/spine-tools
  - https://gitlab.vtt.fi/backbone/backbone
  - https://github.com/irena-flextool/flextool
  - https://github.com/predicer-tools
  - https://github.com/energy-modelling-workbench
  - https://github.com/vttresearch/north_european_model

Jussi Ikäheimo, Tomi J. Lindroos, Juha Kiviluoma. Impact of climate and geological storage potential on feasibility of hydrogen fuels. Applied Energy 2023, 342:121093. doi: 10.1016/j.apenergy.2023.121093

Juha Kiviluoma *et al*. (2022); Flexibility From the Electrification of Energy: How Heating, Transport, and Industries Can Support a 100% Sustainable Energy System. *IEEE Power and Energy Magazine*, vol. 20, no. 4, pp. 55-65, July-Aug. 2022.

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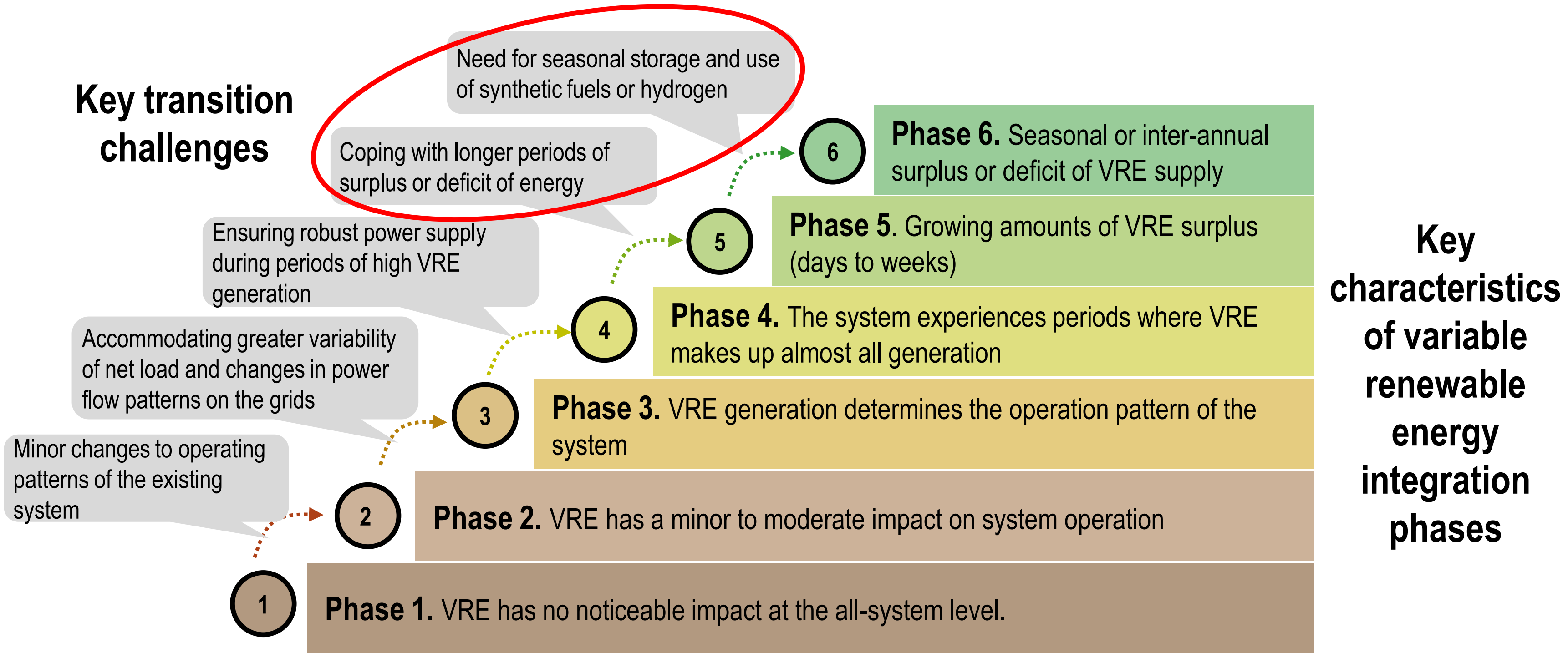
Kiviluoma, Juha; Collantes, Gustavo (2008) Electrification of Energy. Workshop report. Kennedy School of Government, Harvard. April 23rd 2008.

Meibom, Peter; Kiviluoma, Juha; Barth, Rüdiger; Brand, Heike; Weber, Christopher & Larsen, Helge (2007) *Value of electrical boilers and heat pumps for wind power integration*. Wiley, Wind Energy, Vol 10, Issue 4, p. 321-337.

Context for IEA work

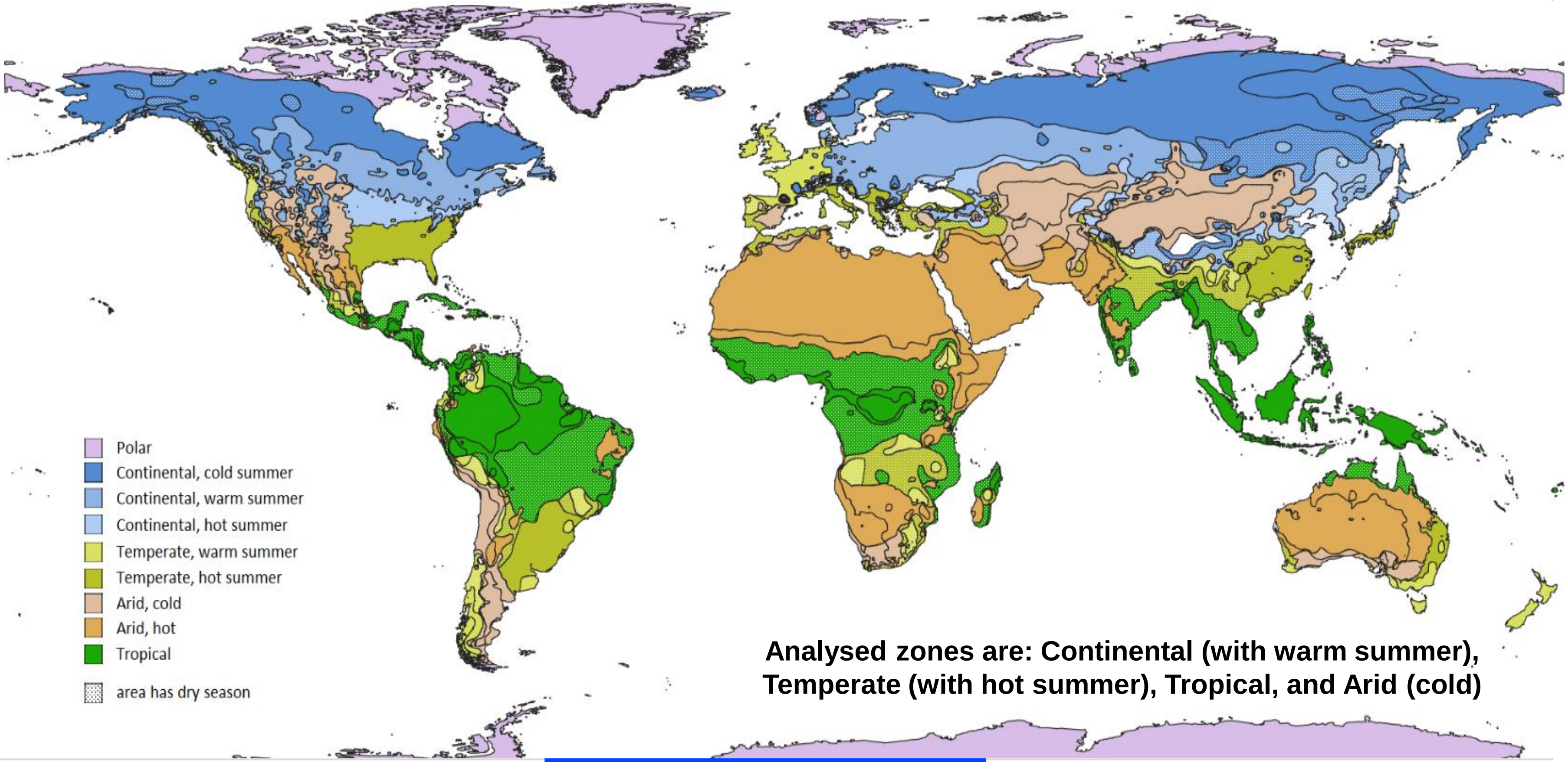
- 2021 study on the Role of low-carbon fuels in power systems:
    - Low-emissions hydrogen and ammonia can play an important role to help ensure electricity security in clean energy transitions.
    - They have important potential in regions where the thermal fleet is young, or the availability of other low-emissions dispatchable resources is constrained.
    - The value of hydrogen and ammonia depends on system contexts and regional conditions.
- Research questions for the ongoing work:
    - What kind of seasonal variation can be expected at very high shares of renewables?
    - How does seasonal variation depend on different climatic conditions?
    - What is the potential role of low-emissions fuels in managing seasonal variation?

Six phases of renewables integration



Several countries and power markets are already in Phase 4, and will be increasingly entering Phases 5 & 6 as countries pursue their net-zero targets.

Current analysis focuses on four key climatic zones



Analysed zones are: Continental (with warm summer), Temperate (with hot summer), Tropical, and Arid (cold)

Seasonal patterns emerge from the interaction of demand and renewables supply

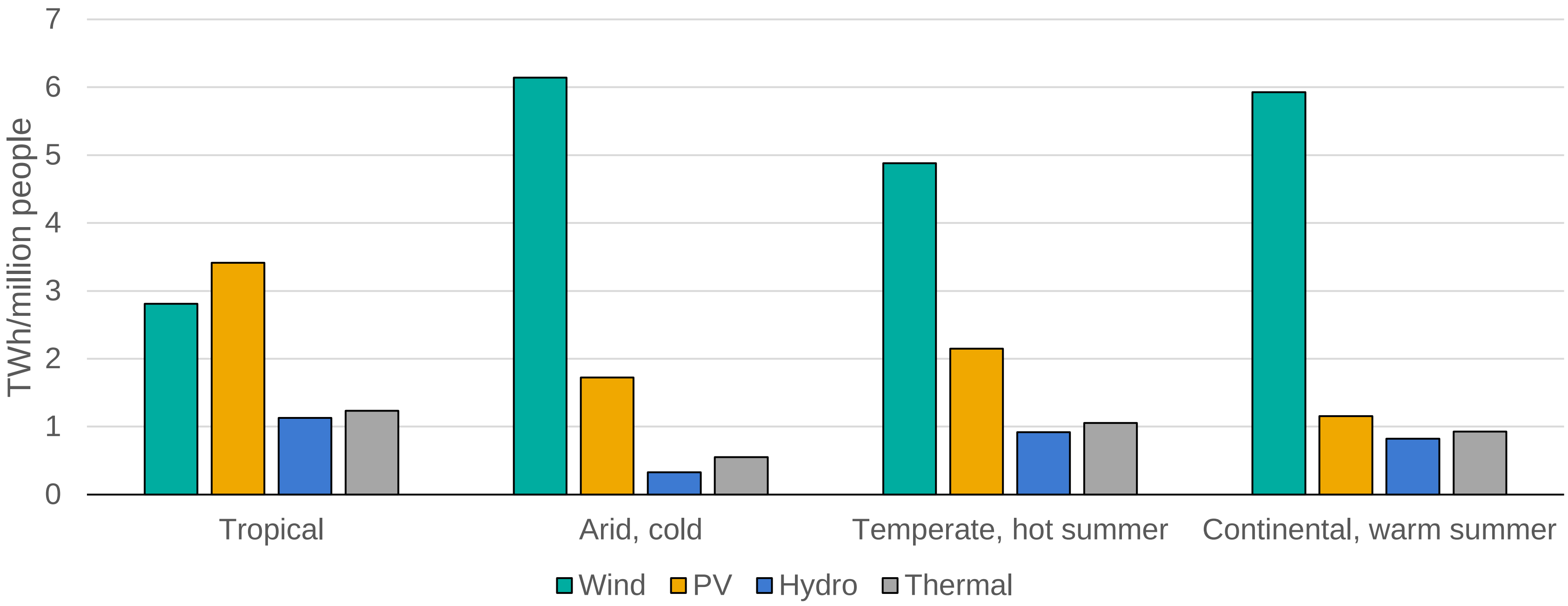
Key seasonal attributes of analysed climate zones.

	Seasonal demand profile	Size of peak load	Hydro availability	Seasonal wind & PV complementarity
Tropical		|	■■■	−
Arid, cold		|	■	−
Continental, warm summer		||	■■■	+
Temperate, hot summer		|||	■■	+

Challenges to integrate renewables over long time periods increase with strong mismatches between energy demand and renewables supply on a seasonal scale.

Climate conditions influence the electricity mix

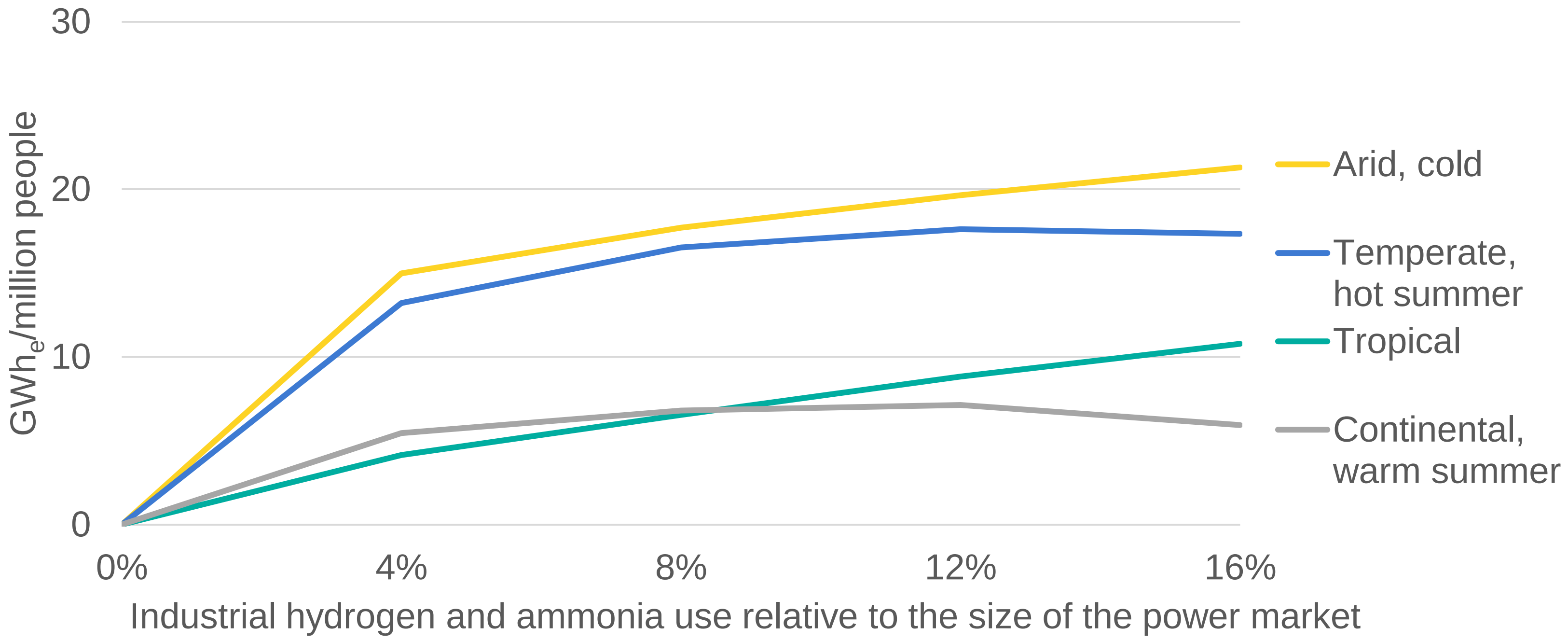
Breakdown of annual domestic electricity generation for the analysed climate zones.



Technologies remain the same, but climatic and energy system conditions govern their contribution. In the results, VRE share is 70-80% with legacy thermal fleets representing 5-15% of annual generation.

Industrial use of low-emissions fuels reduces the cost of co-firing

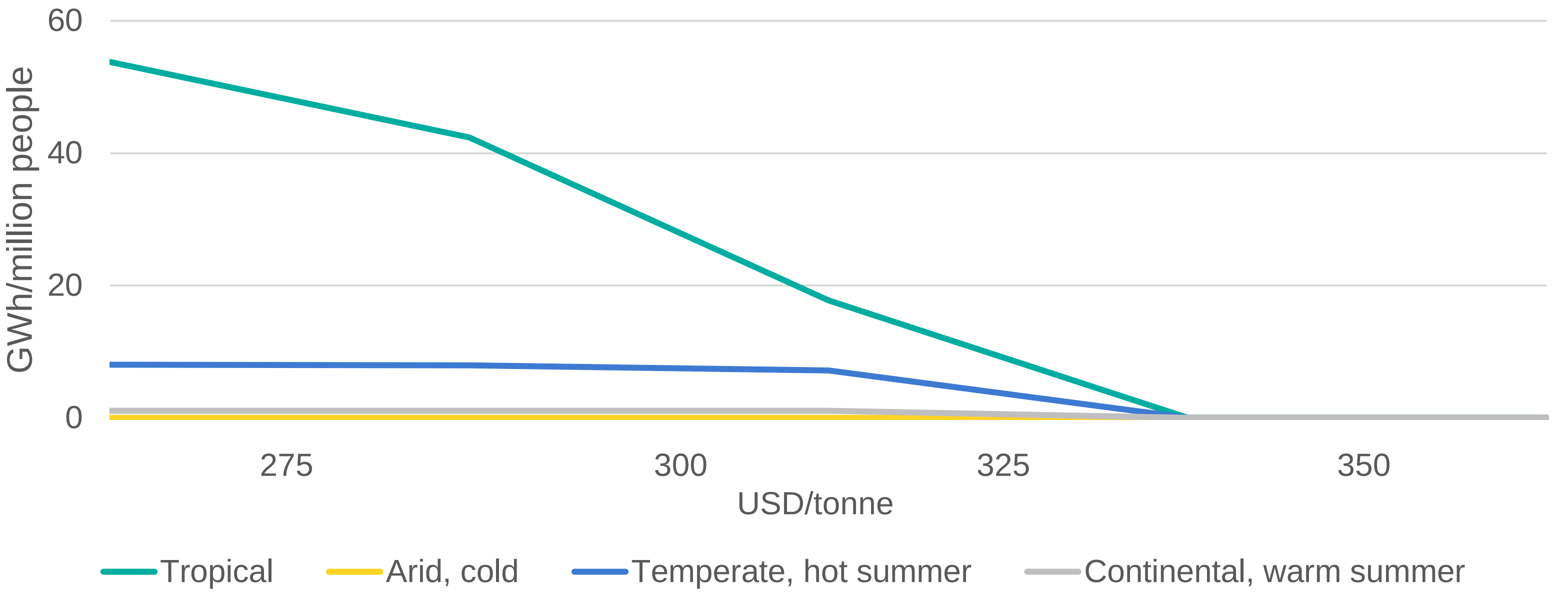
Impact of industrial hydrogen and ammonia use on co-firing in thermal power plants based on domestic renewable resources.



Industrial use of hydrogen and ammonia stimulates investments in the associated supply chain infrastructure, which will lower the cost of low-emission fuels for other uses.

Ammonia supply costs must decrease further to enable international trade

Impact of import cost on the demand of low-emissions ammonia in the analysed climate zones.



Domestic potential to produce and use low-emissions fuels could be enhanced by imports, but the import cost would need to decrease below USD 350/tonne.

Conclusions

- At high shares of renewables, long-duration surpluses and deficits become a key challenge of renewables integration, largely covered by flexibility from thermal power plants (45-60%).
- Low-emissions fuels remain expensive for electricity generation, but are a potential source of low-emissions flexibility. Their value depends on climatic and system contexts.
- Sharing infrastructure investments with industrial users helps to reduce total costs, and helps to create new value chains for the power market.
- At import prices below USD 350/tonne international ammonia trade can connect regions that have low-cost renewable resources with regions where low-emissions fuels have high value.
- At high shares of renewables, consecutive inter-annual deficits can be more difficult to manage than any single year in the studied reference systems.

Next steps

- This is an ongoing work that will be one of IEA's inputs to the Japan G7 in 2023.
- Contribution from RISE still to be added:
  - Analyse the impact of stochastic variation in generation transmission outages and weather on power system adequacy.
  - Analyse the impact of seasonal variability on the need for system services
- Part II of the project will start on Jan 2023. Includes an analysis of the total costs of a regional electricity system that adequately addresses the seasonal and inter-annual variability of renewables.
- Work will ultimately provide input to WEO 2023.