Integration of High Capacity Hydrogen and Power-to-X production in the Finnish Energy System

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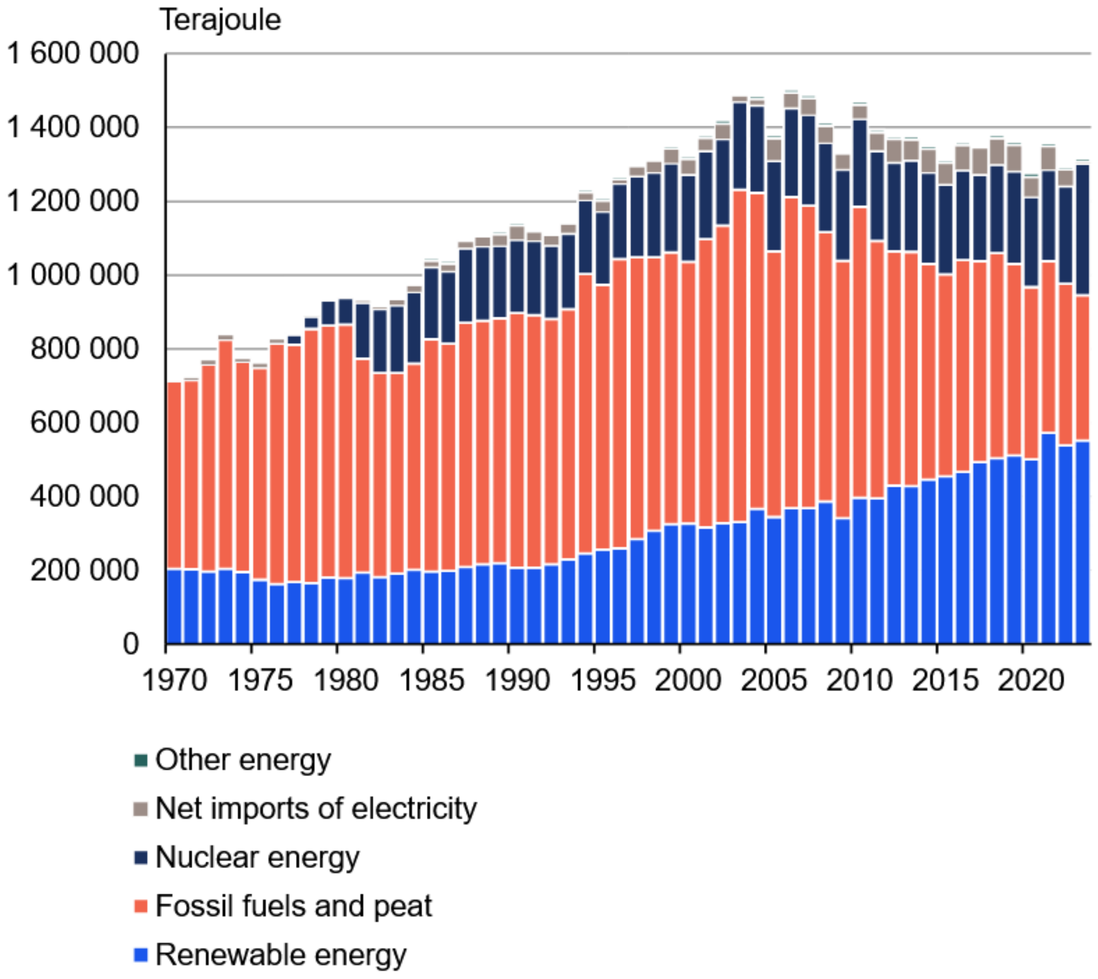
Outline

- Finnish energy system and carbon neutrality
- Regulation for green hydrogen production and operation of H_2 production system
- National resources
- Model based approach
- Regional energy balances and power transmission needs
- Key findings

Power System in Finland

- Total energy consumption of Finland in 2023 was 366 TWh (1.32 milj. TJ)
  - Renewable sources 153 TWh (42%)
    - Hydro, wind, solar PV, biomass
  - Fossil fuels and peat, 109 TWh (30%)
    - Oil based 69.1 TWh
    - Hard coal 18.2 TWh
    - Natural gas 11.9 TWh
    - Peat 6.4 TWh
  - Nuclear energy 99 TWh (27%) -> 32.8 TWh electricity
  - Imported electricity 1.7 TWh (0.5 %)

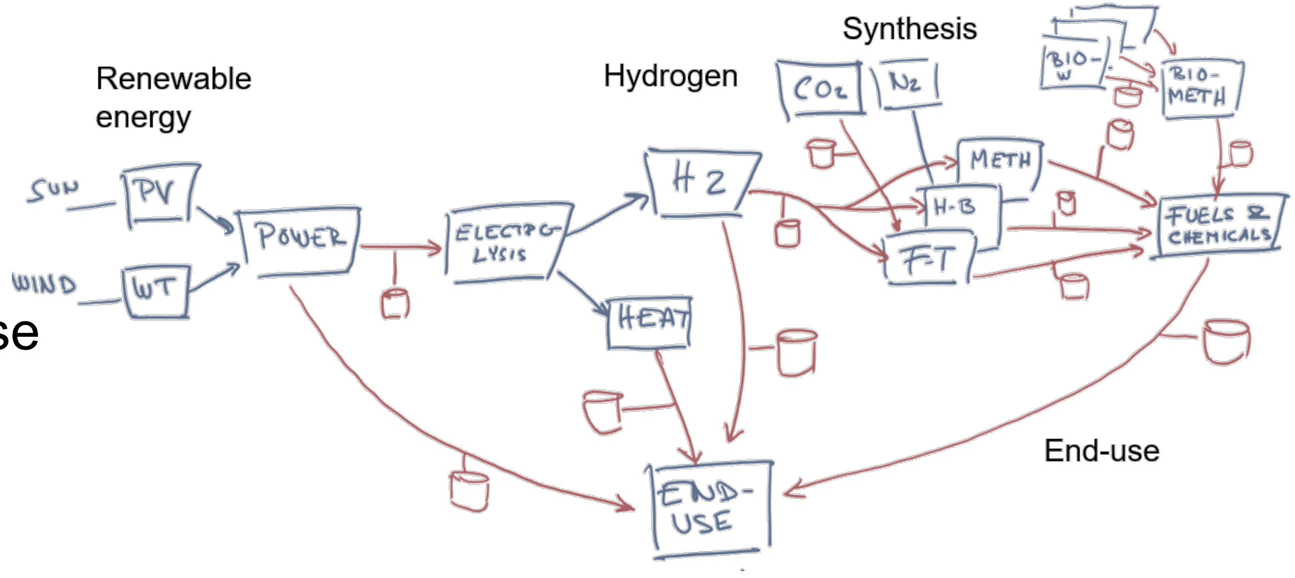
Total energy consumption by energy source, 1970-2023*



Power to X Economy

- Hydrogen or Power to X economy is seen as the most promising way to carry out the energy transition from fossil to a carbon free energy system.
  - Indirect electrification of hard-to-abate sectors in transport and industrial processes
- Electrification requires a huge capacity increase in renewable energy production and energy transmission.
  - Overall need for flexibility will increase as power production becomes more weather dependent

Power to X value chain



For Finland to become energy self-sufficient through PtX economy, the amount on electrical energy would need to at least doubled from 80 TWh to 160 TWh

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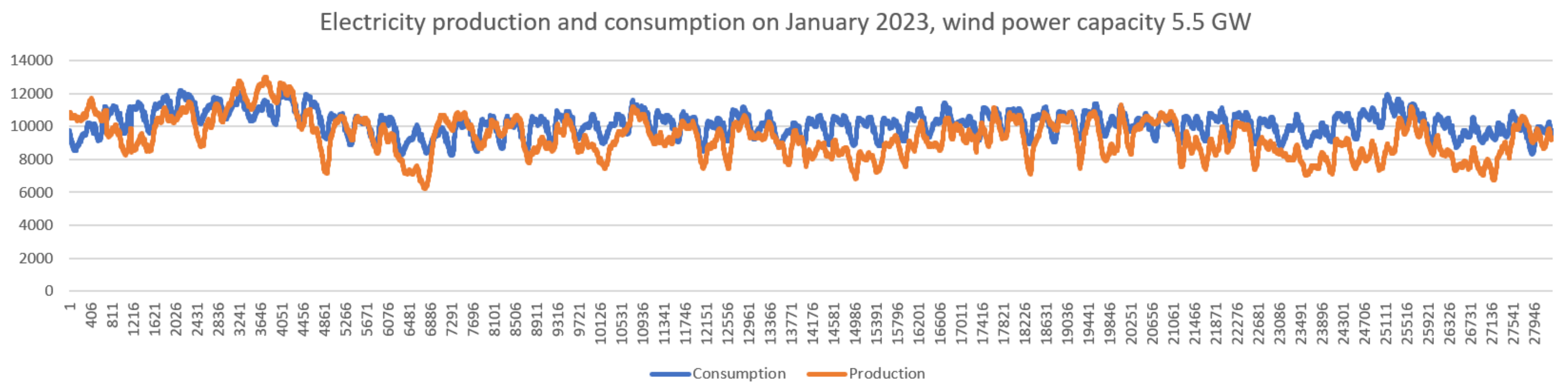
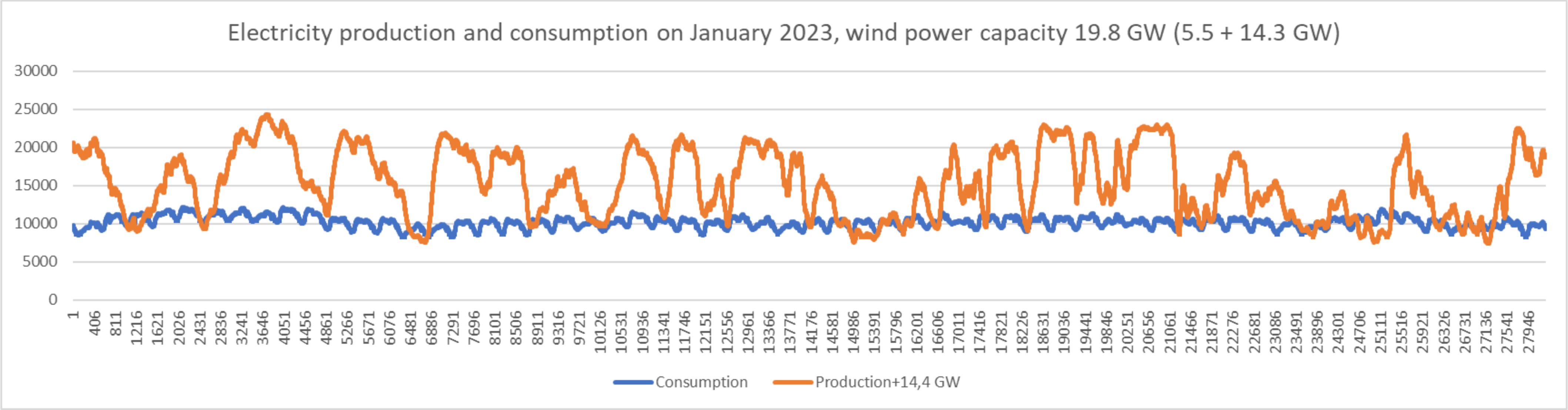
Electric power production and consumption



Deficit 0,4 TWh

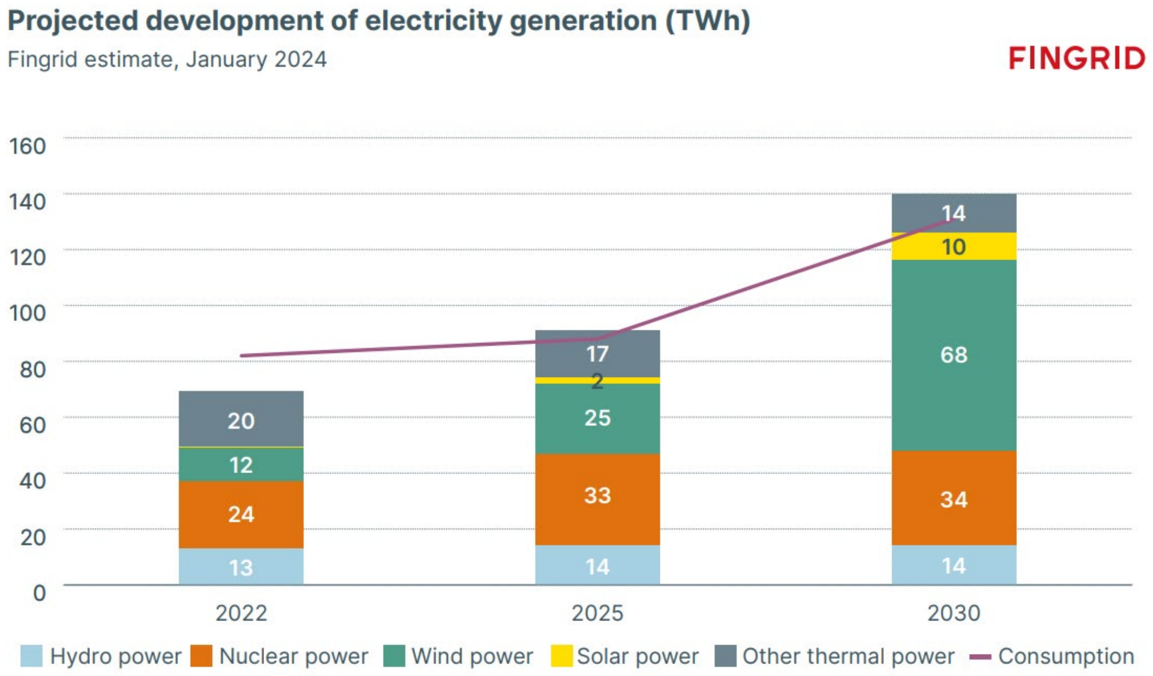


Surplus 2,6 TWh

Regulations for green hydrogen production

EU COMMISSION DELEGATED REGULATION 2023/1184 of 10 February 2023

- In European Union green hydrogen production is regulated to guarantee that:
  - transition to green energy will really have a positive effect on the mitigation of the climate change
  - the integration of hydrogen economy to existing energy system will be as smooth as possible.
- Scale of the transition will be huge -> Integration to existing system must be designed and analyzed carefully –> systemic impacts

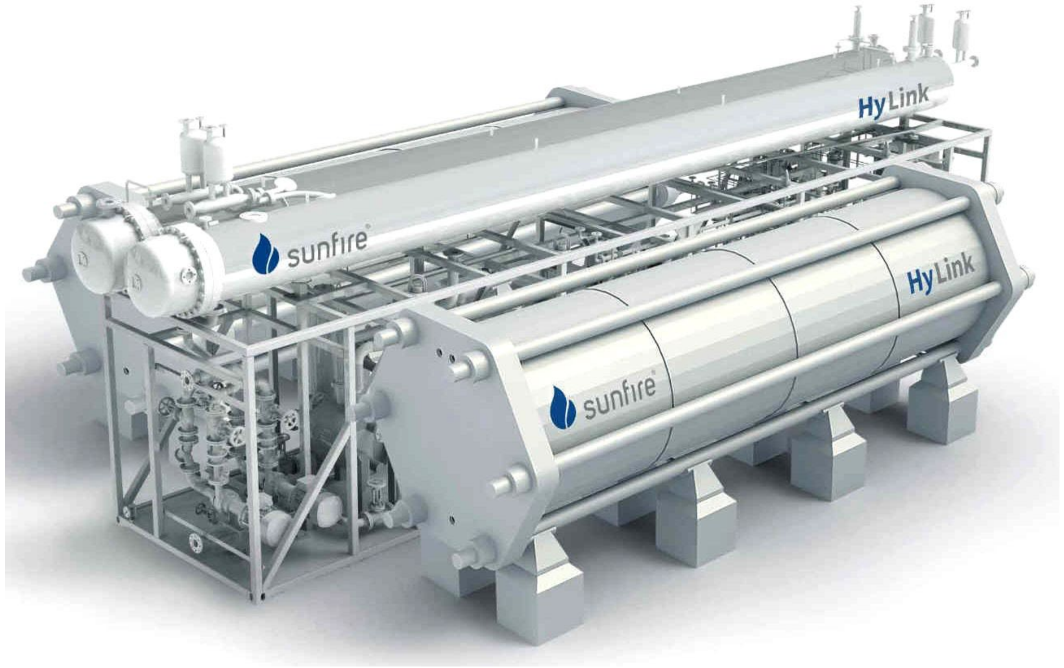


Regulations for green hydrogen production

EU COMMISSION DELEGATED REGULATION 2023/1184 of 10 February 2023

- Detailed rules for the production of renewable liquid and gaseous fuels of non-biological origin (RFNBO)

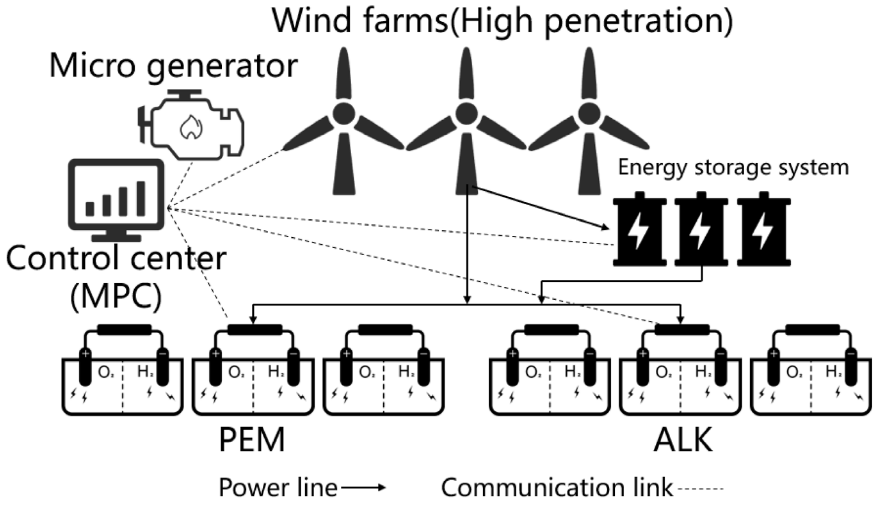
- **The basic rule**: green hydrogen must be produced by splitting water in electrolysis process powered by renewable electricity
    - European Energy Certificate System – The guarantee of the origin of the consumed energy



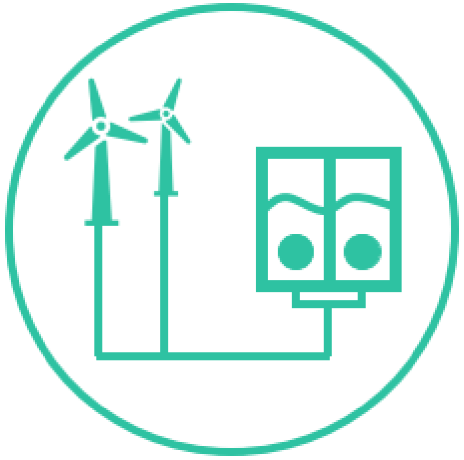
Regulations for green hydrogen production

EU COMMISSION DELEGATED REGULATION 2023/1184 of 10 February 2023

- The most straightforward case is the **direct connection** between renewable energy and RFNBO production.
    - Islanded system, RFNBO production does not utilize grid power at all.



- If grid electricity is used for hydrogen production, there are **four RFNBO producing routes** to ensure that the end product is green

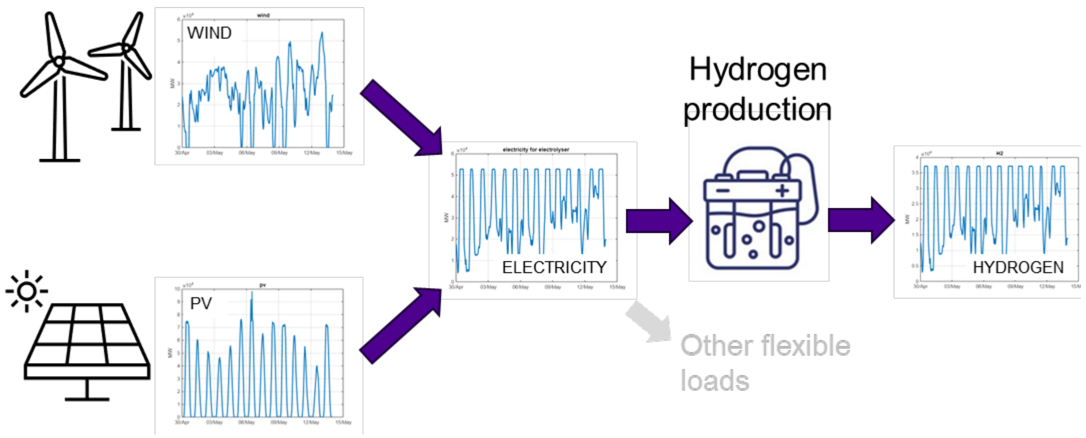


Regulations for green hydrogen production

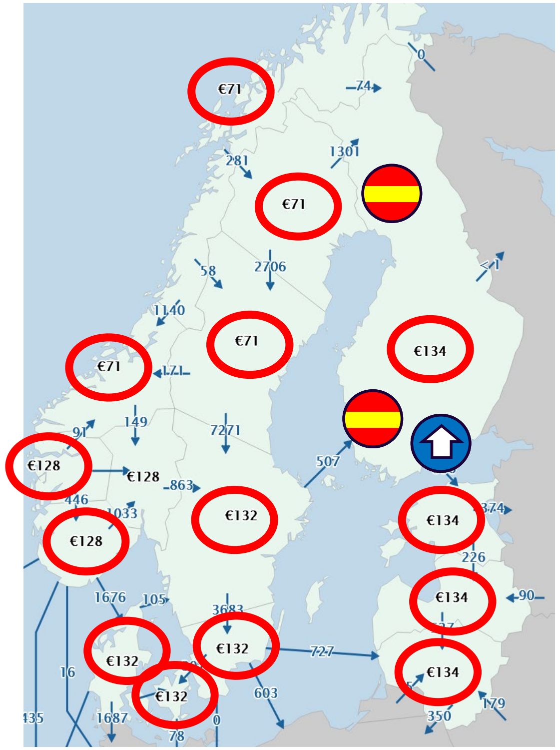
EU COMMISSION DELEGATED REGULATION 2023/1184 of 10 February 2023

- **Route 1.** Grid electricity must fulfill the three following principles
  1. Additionality
     - Parallel investments on VRE and hydrogen production, PPA between electricity producer and consumer
  2. Temporal correlation
     - Electrolyzers synchronized with contracted VRE production in 1 hour energy balance

Electricity production



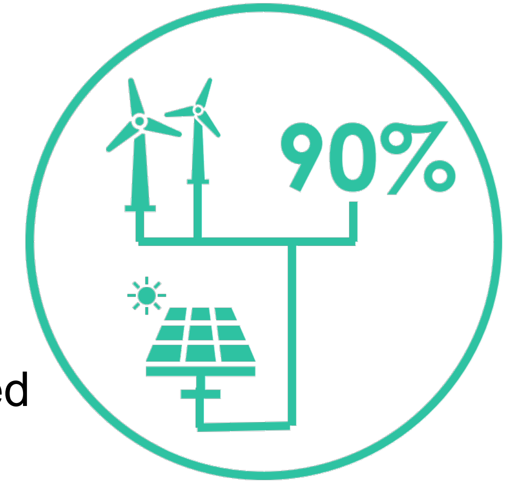
3. Geographical correlation
   - No import from cheaper bidding zone



Regulations for green hydrogen production

EU COMMISSION DELEGATED REGULATION 2023/1184 of 10 February 2023

- **Route 2.** The proportion of renewable energy in the electricity market bidding zone, where RFNBO production takes place, exceeded 90 % during previous year
  - Grid electricity can be used as such for green hydrogen production
  - RFNBO production full load hours must be less or equal than 8760 hours multiplied by the proportion [0,1] of the renewable energy.

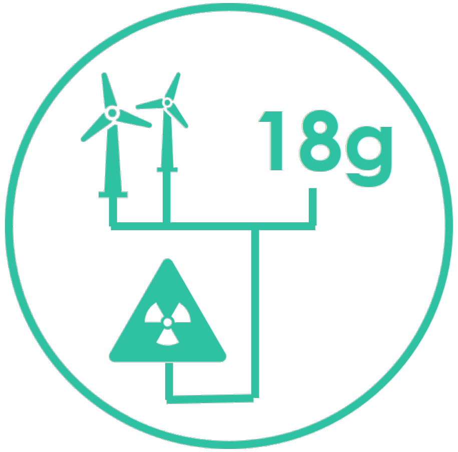


2023 in Finland 42% was nuclear power based

Regulations for green hydrogen production

EU COMMISSION DELEGATED REGULATION 2023/1184 of 10 February 2023

- **Route 3.** The power grid is sufficiently decarbonized
  - If emission intensity of the bidding zone grid is below the value of 65 g CO_{2eq} /kWh, additionality requirement is exempted
  - However, renewable energy needs to be contracted via PPA, and temporal and geographical correlations apply.

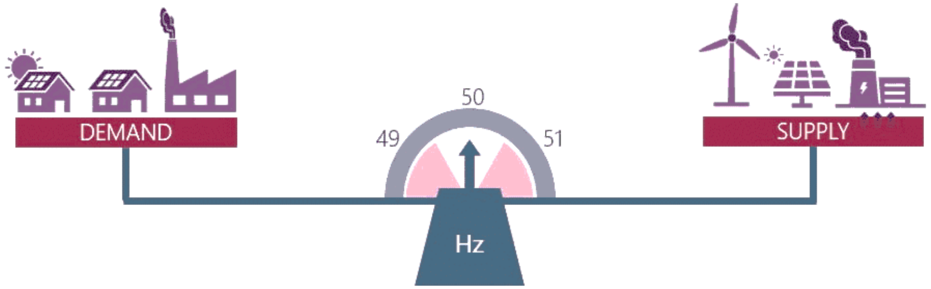


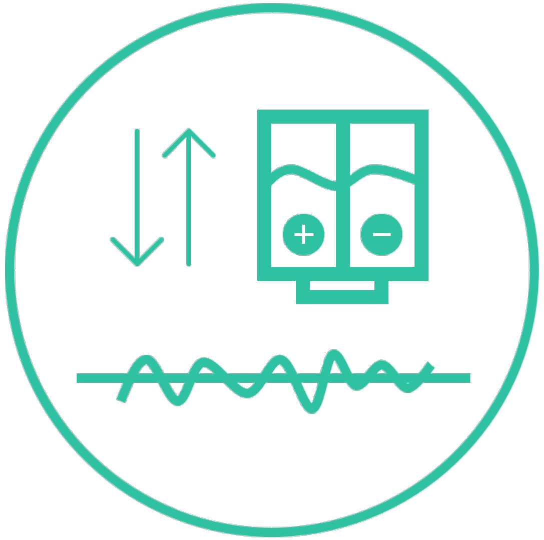
2023 in Finland 33 g CO_{2ekv}/kWh$_e$

Regulations for green hydrogen production

EU COMMISSION DELEGATED REGULATION 2023/1184 of 10 February 2023

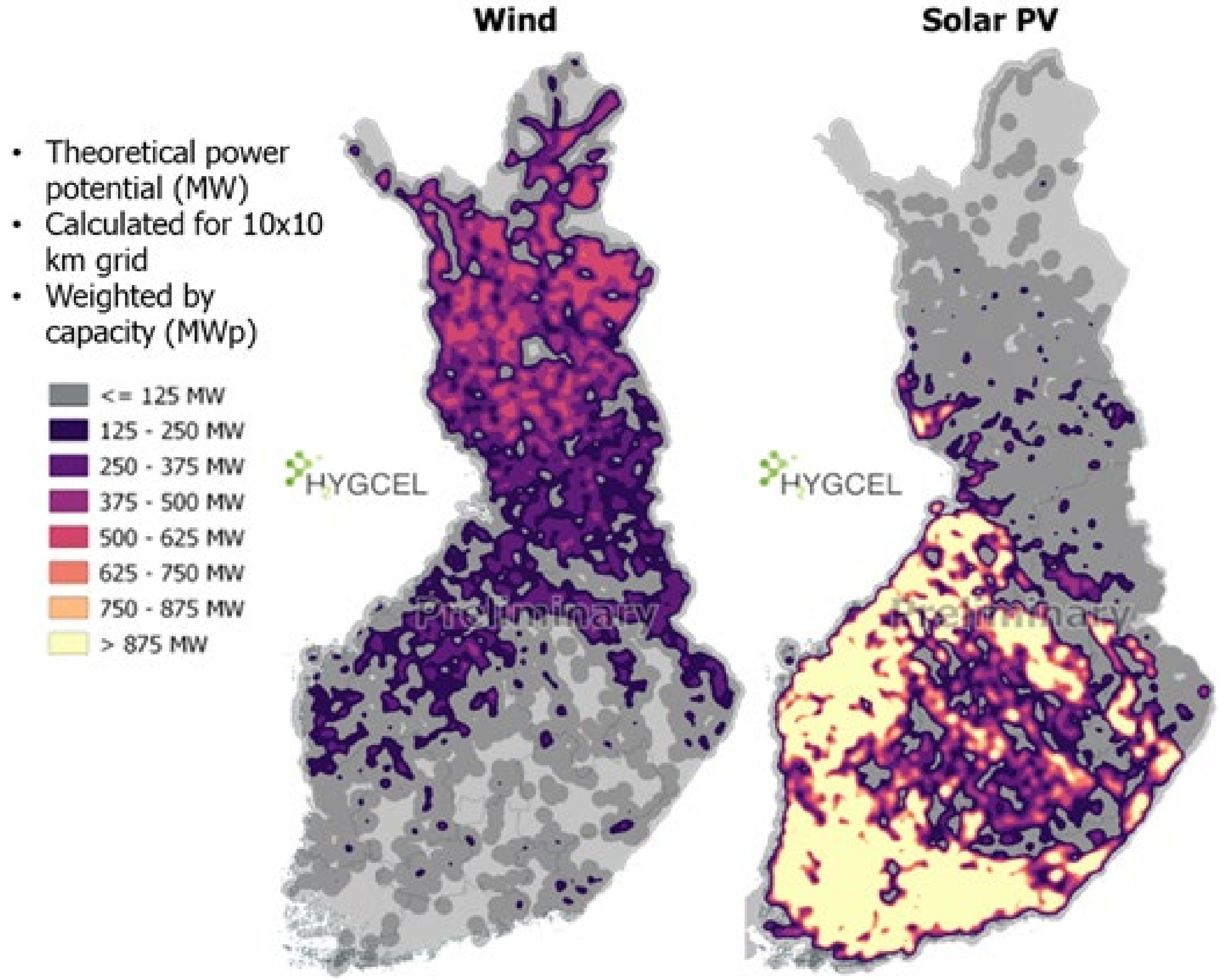
- **Route 4.** The RFNBO production facility improves grid stability.
  - RFNBO producer can prove with the help of the national transmission system operator (TSO) that during an imbalance settlement period (nation dependent) power-generating installations using renewable energy sources were redispatched downwards, and the electricity consumed for RFNBO production reduced the need for redispatching by a corresponding amount.





Where to build?

- The availability of different resources as well as existing energy consumption are divided unevenly in Finland
  - Wind and solar potential
  - Available land area
  - Biogenic CO_2
  - District heating networks (waste heat utilization?)



Hannu Karjunen
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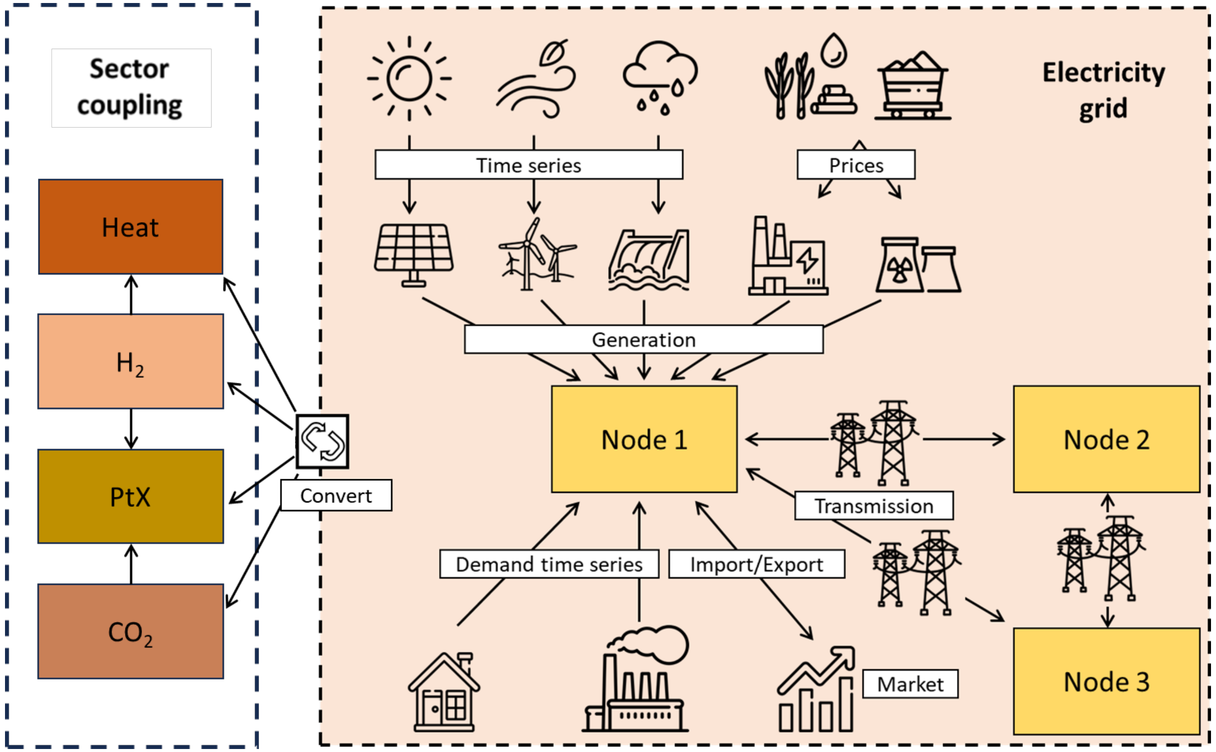
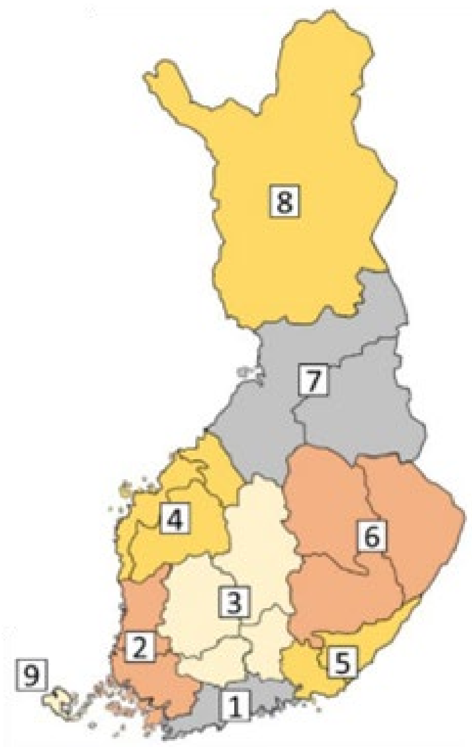
An energy system model of Finland was developed to study future energy needs





- Mathematical model representing the regional structure and operation of the energy system in Finland.
- In the model, Finland is divided into 9 regions.
- The model optimizes the cheapest way to produce the hourly energy demand. Storages and demand response is included.

1. Helistö, N., Kiviluoma, J., Ikäheimo, J., Rasku, T., Rinne, E., O'Dwyer, C., Li, R. and Flynn. D. 2019b. Backbone—An Adaptable Energy Systems Modelling Framework. Energies, vol. 12:17.

Backbone

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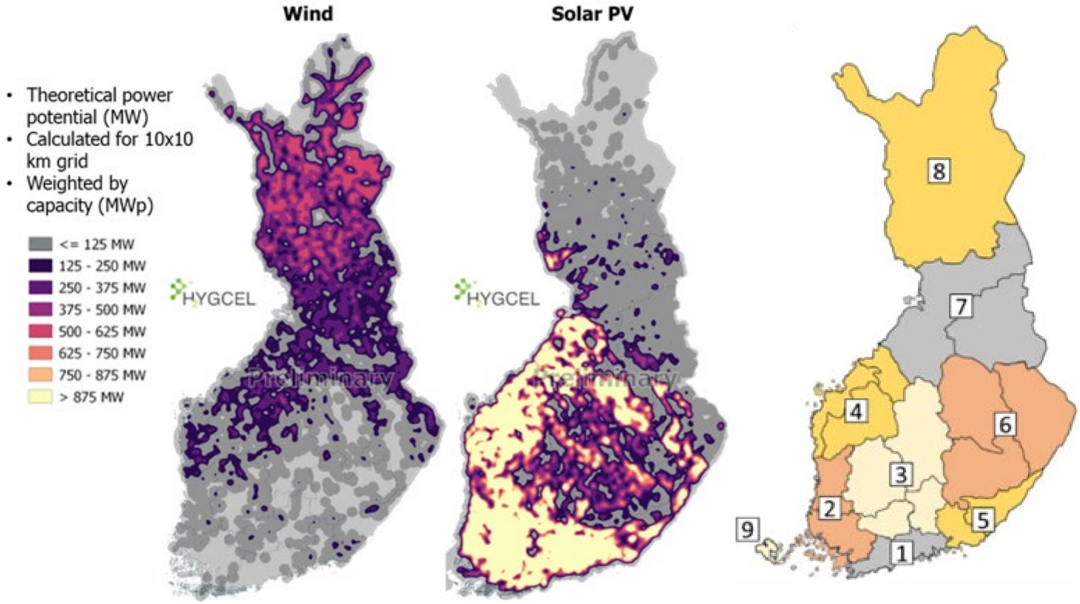
Scenarios

- **Business as usual** (BAU 2035)
  - Finland's energy infrastructure develops by assuming the current publicly announced PtX projects and investments to renewable power production
- **Self-sufficiency** (SS 2035)
  - Finland is headed to energy self-sufficiency by 2050
  - Wind and PV plants are located based on regional potential, different electrolysis locations are studied

GWe	Wind	PV	Electrolysis
2023	6,9	1	-
BAU 2035	35	8	8,9
SS 2035	35	35	17



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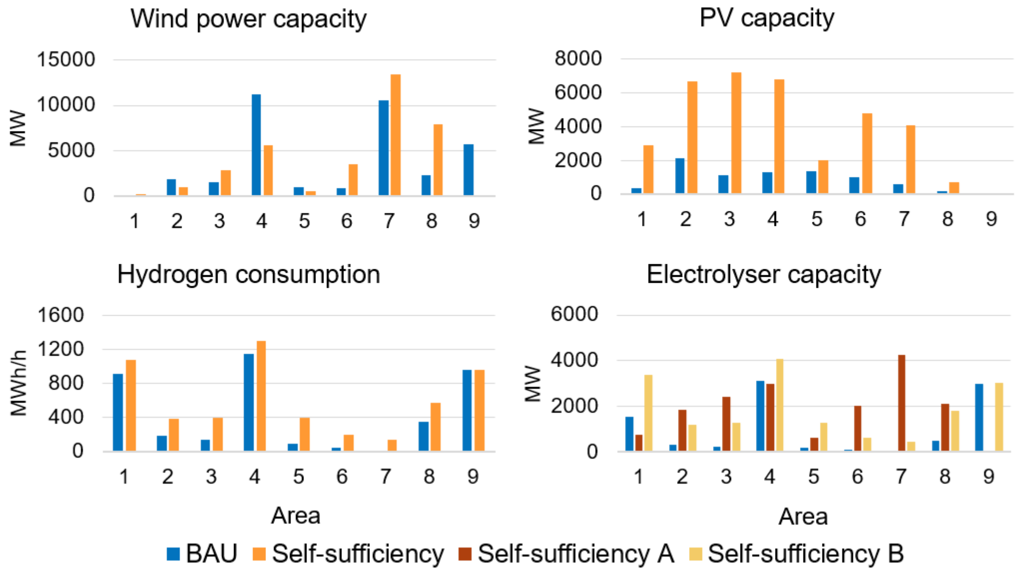

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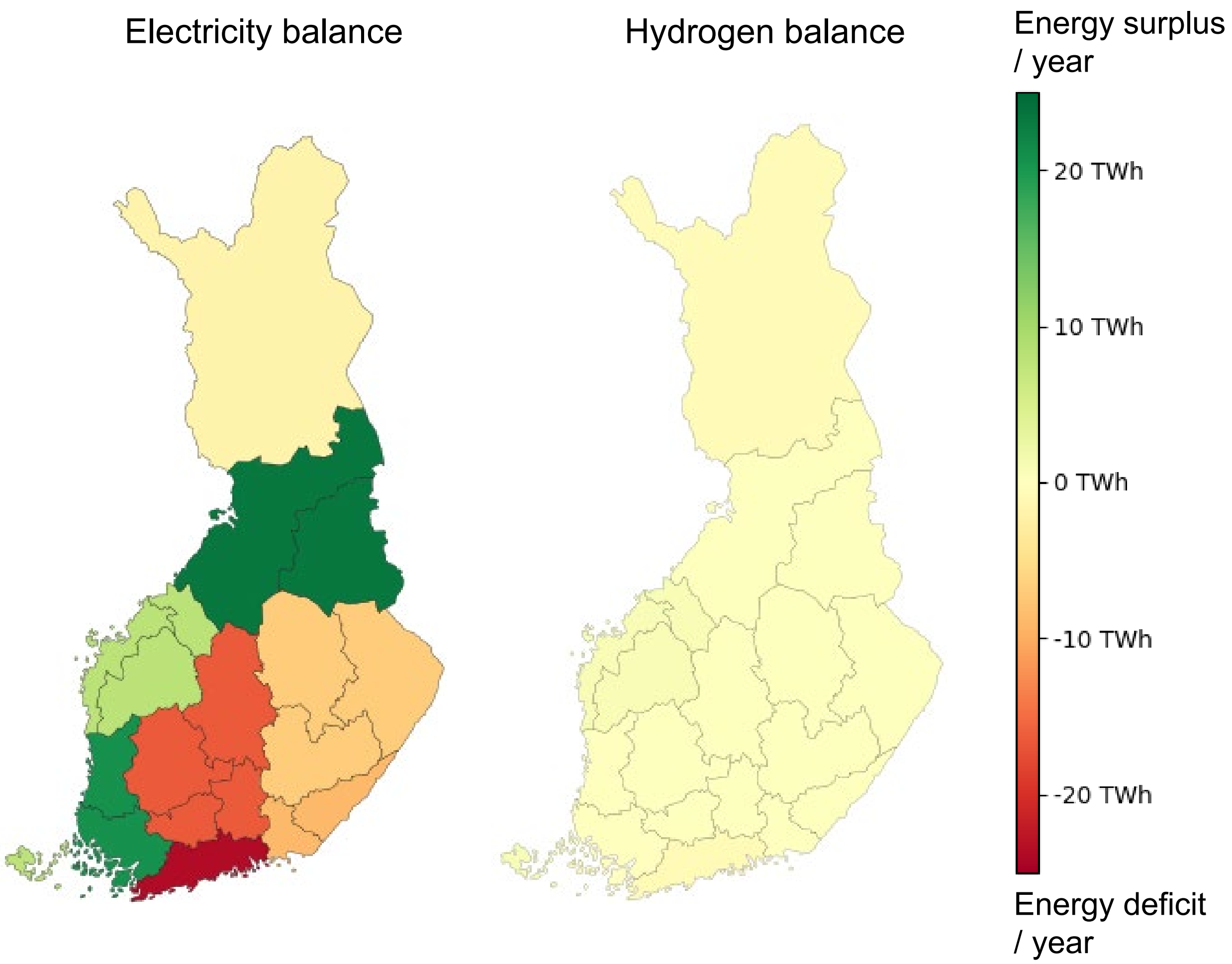
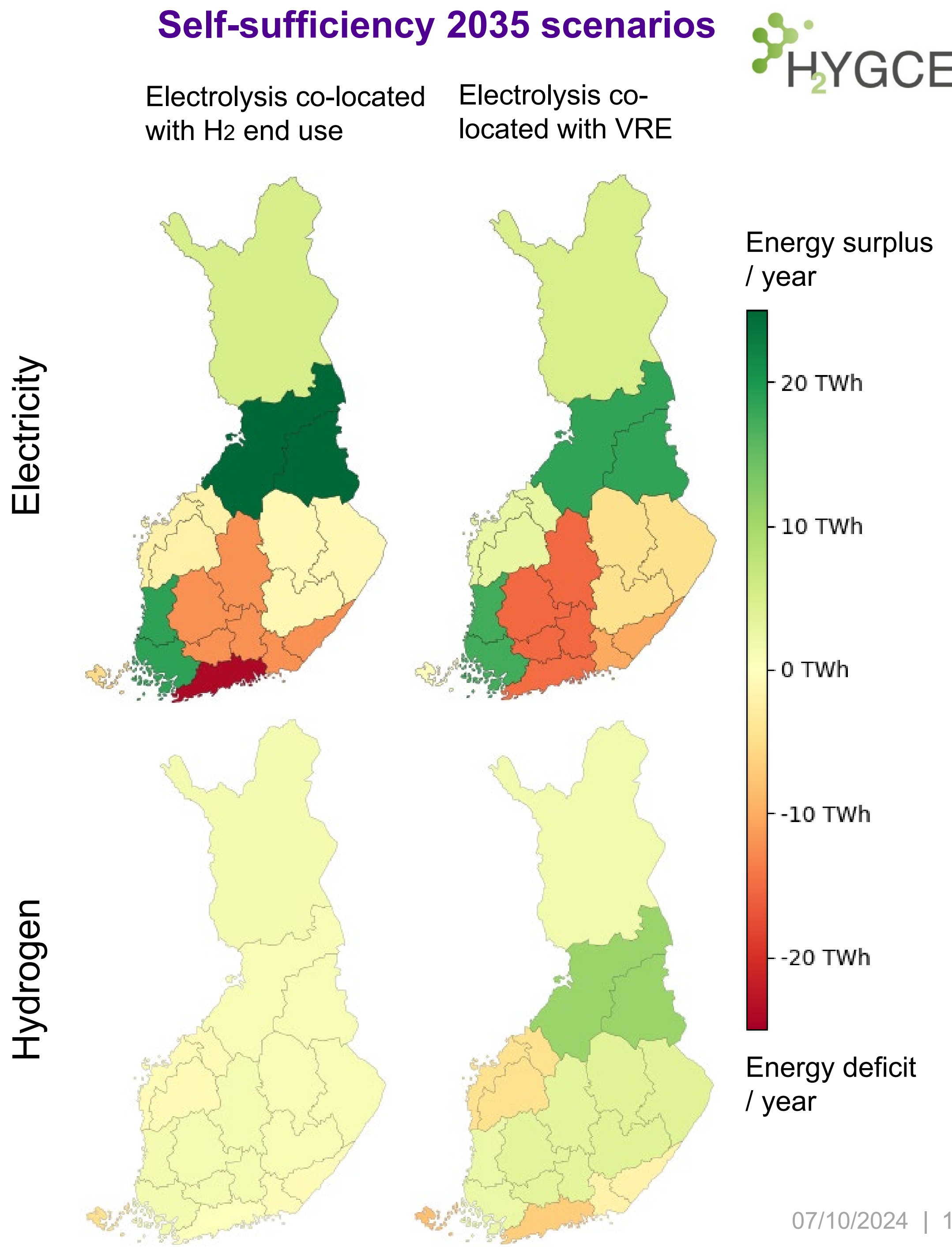
Regional energy imbalances (Business as usual 2035)



- Finland has significant surplus and deficit areas
  - Surplus on the west coast with a lot of wind power investment plans
  - Deficit in south and central Finland in densely populated areas
- Large increase in the grid transmission capacity in comparison to local TSO’s current investment plans until 2033
  - In total, around 50% more transmission capacity between areas needed

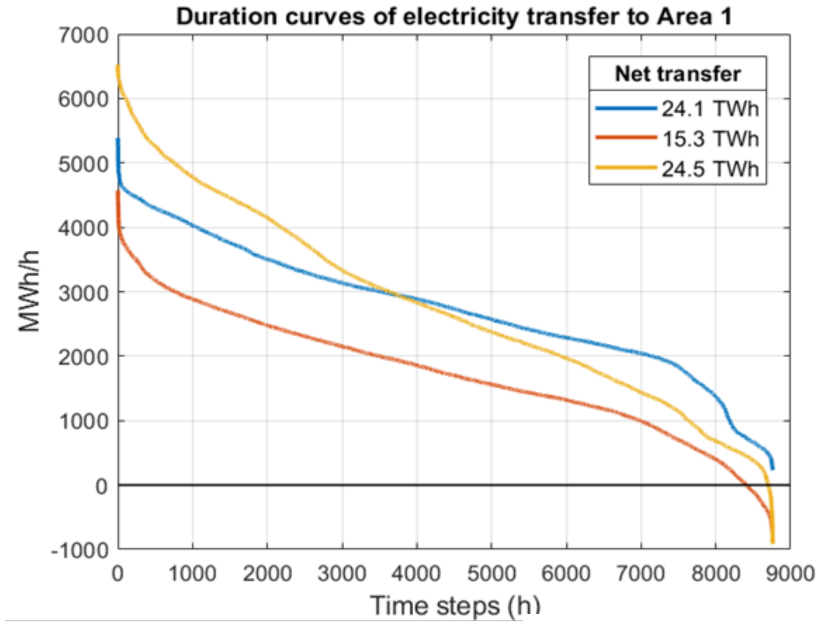
Electrolysis location

- The locations of production capacities affect in what form the energy can be transported: electricity or hydrogen
  - Electrolysers are co-located with the hydrogen consumption → Need to transport electricity to electrolysers
  - Electrolysers are co-located with the renewable energy production capacities → Need to transport hydrogen to consumption areas
- The large need for new electricity transmission capacity can be mitigated by hydrogen transfer, if electrolysis is located close to electricity production

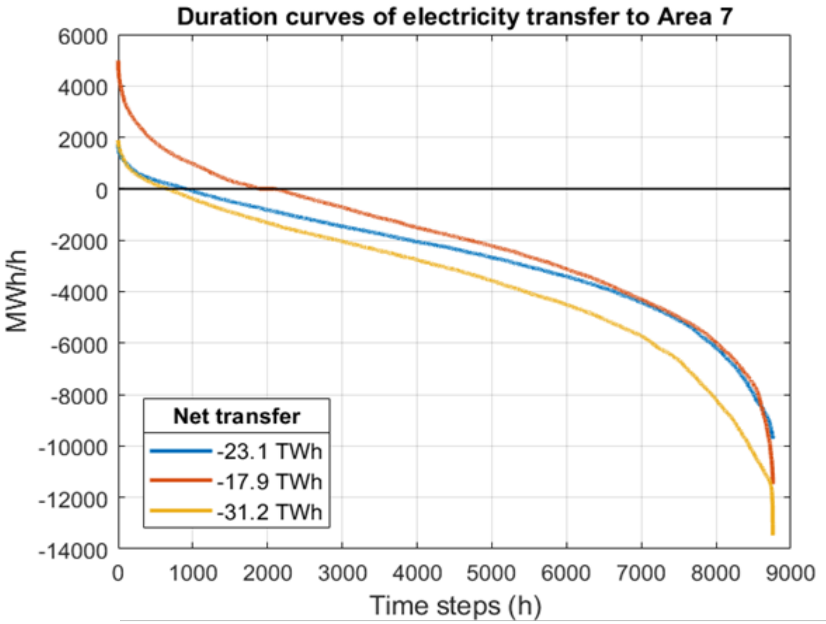


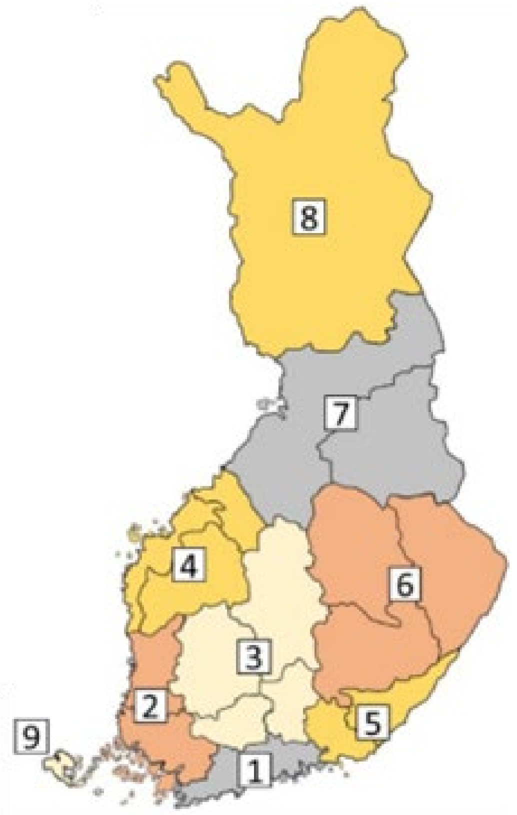
Electricity transmission capacity needs

Main importing region



Main exporting region

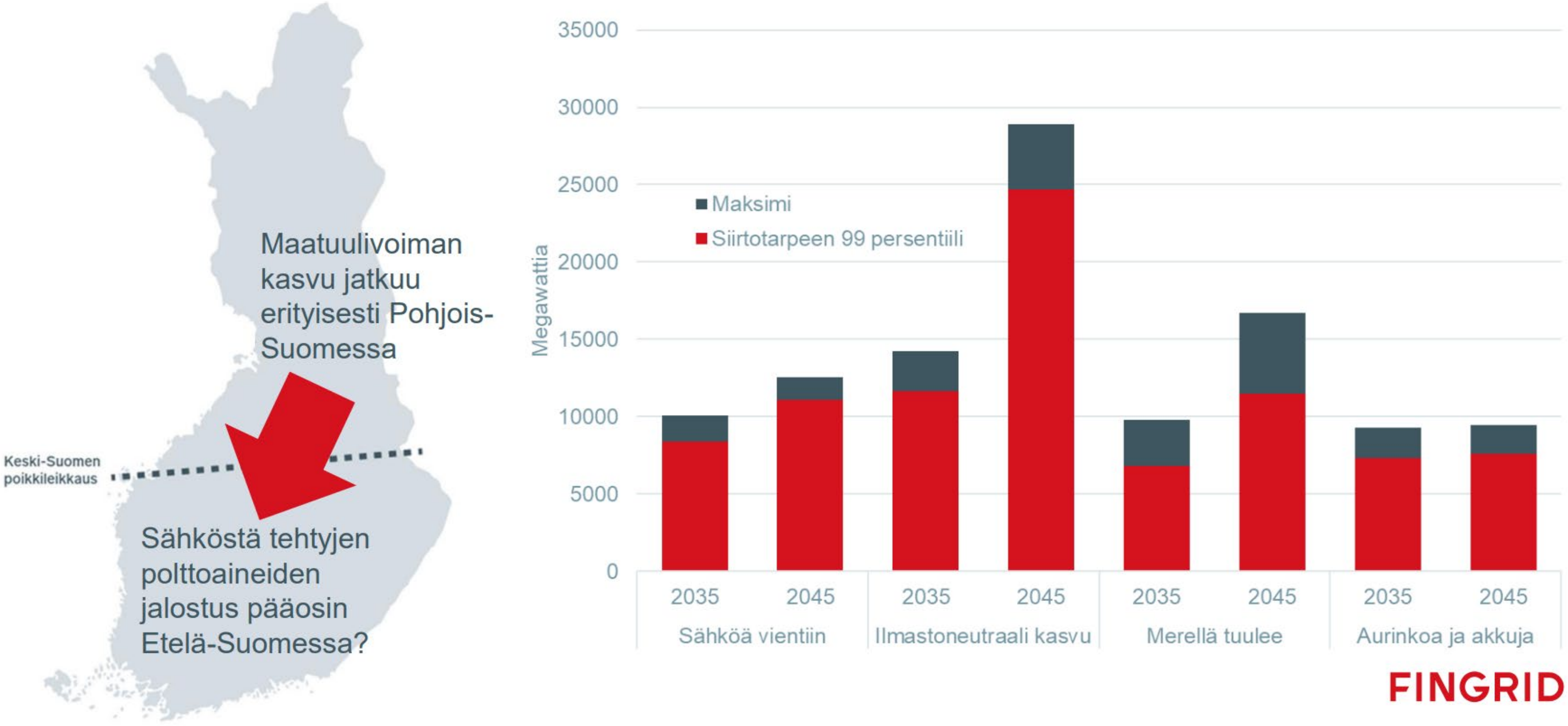




BAU
Self-sufficiency A — Electrolysis co-located with VRE
Self-sufficiency B — Electrolysis co-located with H_2 end use

Siirtotarpeen kasvu jatkuu vuoden 2035 jälkeenkin

Siirto Keski-Suomen poikkileikkauksessa 2035-2045



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Key messages

- EU regulation for green hydrogen production forces hydrogen production to follow variable electricity production
  - Good for power system balance
  - Bad for hydrogen production investment efficiency – low full load hours of operation
- Distributed nature of resources means that Finland has significant energy surplus and energy deficit areas resulting to increasing need for energy transmission.
- Electricity grid reinforcement needs can be reduced by implementing a hydrogen transport infrastructure and utilizing storages and demand response for grid management
  - This applies especially if electrolysis is co-located with renewable electricity production.
- System level storage capacity, hydrogen and PtX, and flexible electrolysis are needed in all scenarios, and it is not dependent on how hydrogen production will be located.