Energy Balances and Transportation Needs in Finland

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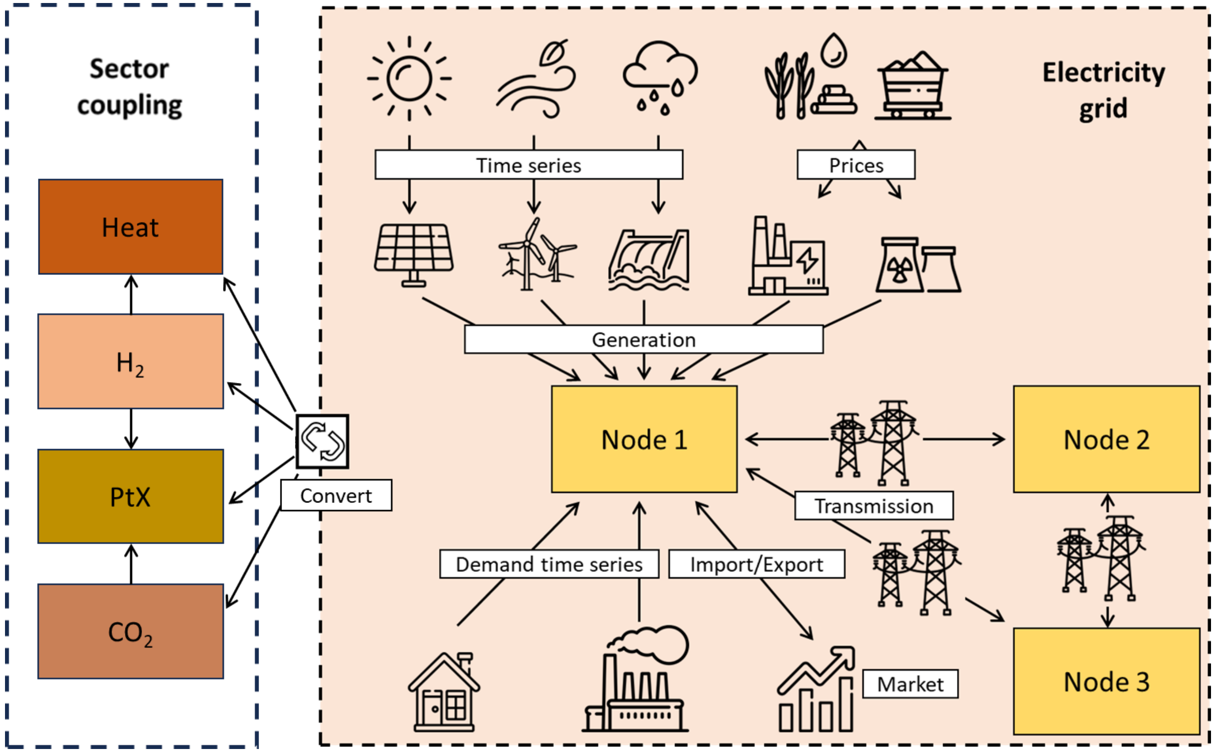
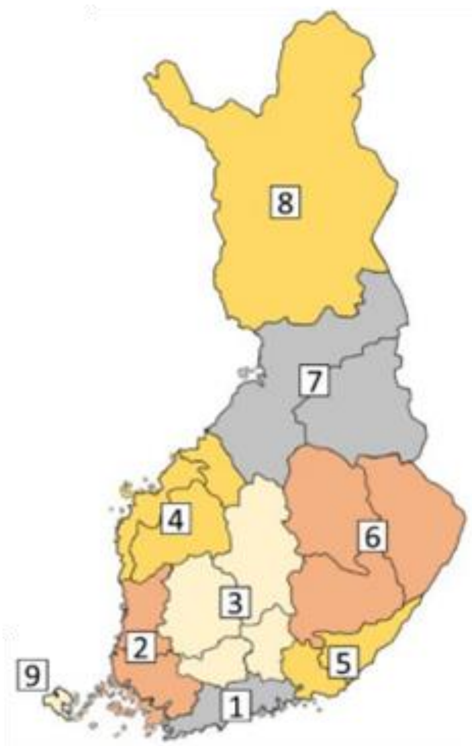
Research Topics & Methods

- Integration of hydrogen / PtX economy in the existing existing system
- Sector integration
- Optimal location and capacities of system components – power generation – power transmission – H_2 / PtX production
- Analysis based on dynamic modelling and simulation of investigated system structures – scenario analysis

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





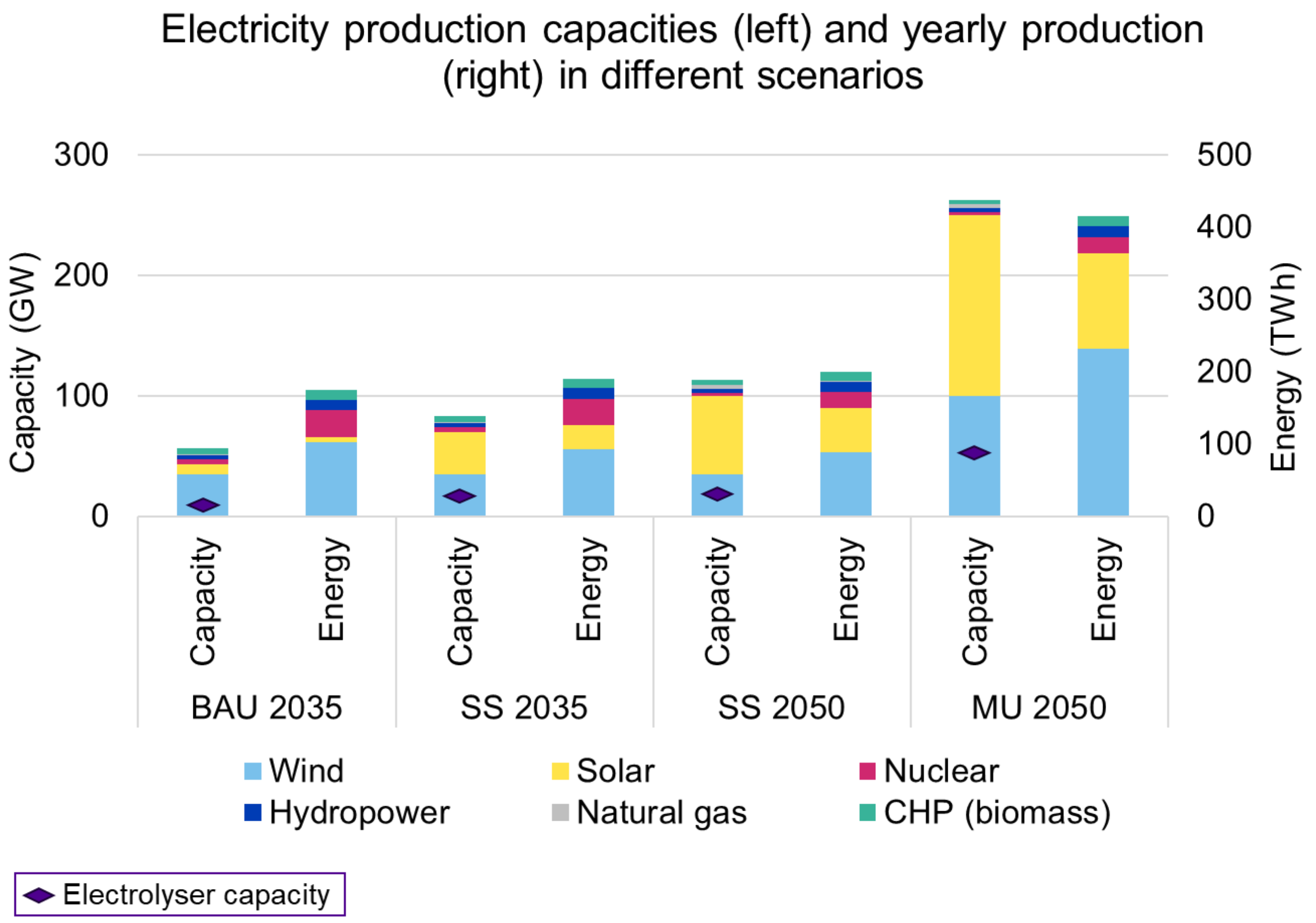
- Mathematical model representing the regional structure and operation of the energy system in Finland.
- In the model, Finland is divided into 9 regions.
- The model optimizes the cheapest way to produce the hourly energy demand. Storages and demand response is included.

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

Three scenarios were modelled

- **Business as usual** (BAU 2035)
  - Finland's energy infrastructure develops by assuming the current publicly announced PtX development and extrapolating that to 2035.
- **Self-sufficiency** (SS 2035 and SS 2050)
  - All the consumed energy is produced in Finland
- **Maximal utilization** (MU 2050)
  - All the consumed energy is produced in Finland
  - Excess electricity is used for manufacturing PtX products for export



Characteristic values of main variables

	BAU2035	SS2035A	SS2035B
Electricity generation (TWh)	173,9	189,3	189,3
Electricity consumption (TWh)	172,2	191,2	190,9
Electricity generation, wind (TWh)	101,2	90,8	90,8
Electricity generation, PV (TWh)	7,7	33,4	33,4
Curtailed VRE generation (TWh)	1,8	2,23	2,24
Imported electricity (TWh)	16,4	19,3	19,5
Exported electricity (TWh)	15,4	14,9	14,8
Peak electricity load (GW)	29,9	36,8	36,9
Electricity to H2 production (TWh)	47,4	68,0	67,7
Maximum H2 storage capacity used (TWh)	2,5	8,1	7,9

Remarkable increase in electrification

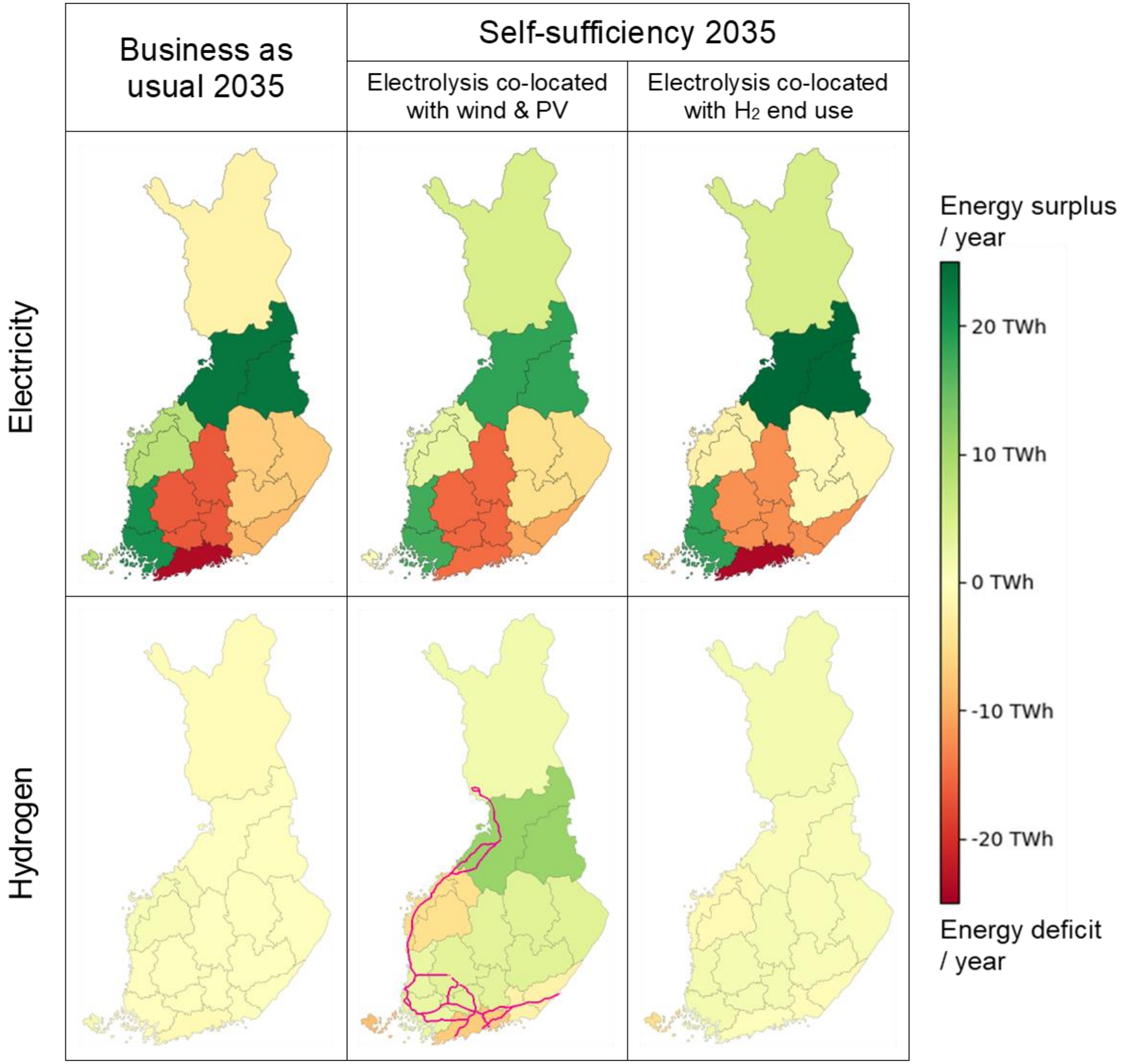
~1 %

~10 % of electricity generation

Price sensitive

5-12 % of H_2 prod.
H_2 demand is not flexible

Modelling reveals regional imbalances



- The distributed nature of renewable energy resources and energy demand leads to regional imbalances: Finland has significant energy surplus and energy deficit areas.
- Modelled locations of production units (wind, PV, electrolysis, PtX) influence energy transport needs from one area to another
- Electricity grid reinforcement needs can be reduced by implementing a hydrogen transport infrastructure
  - This applies if electrolysis is regionally co-located with renewable electricity production

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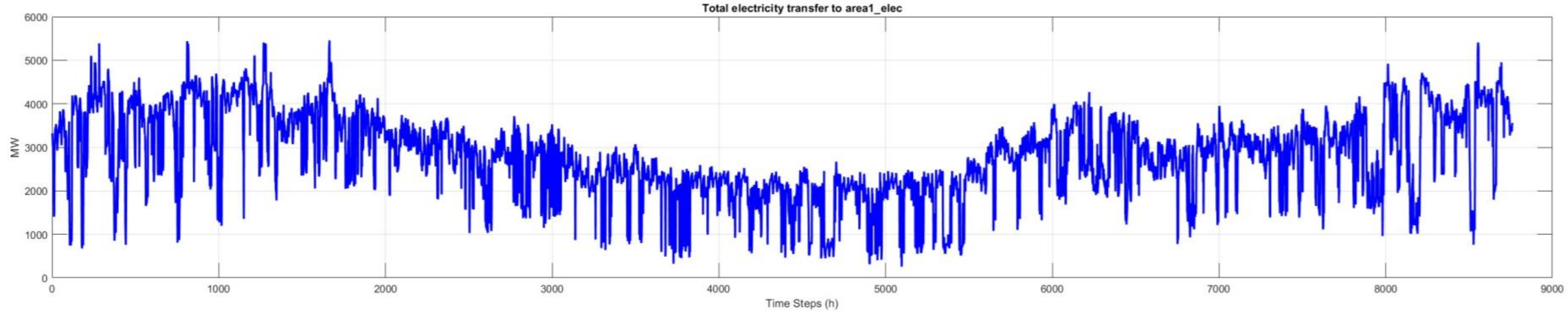
Business as Usual 2035, Examples of electricity transfer

Total electricity transfer to region 1, the biggest deficit region

6 000

MW

0

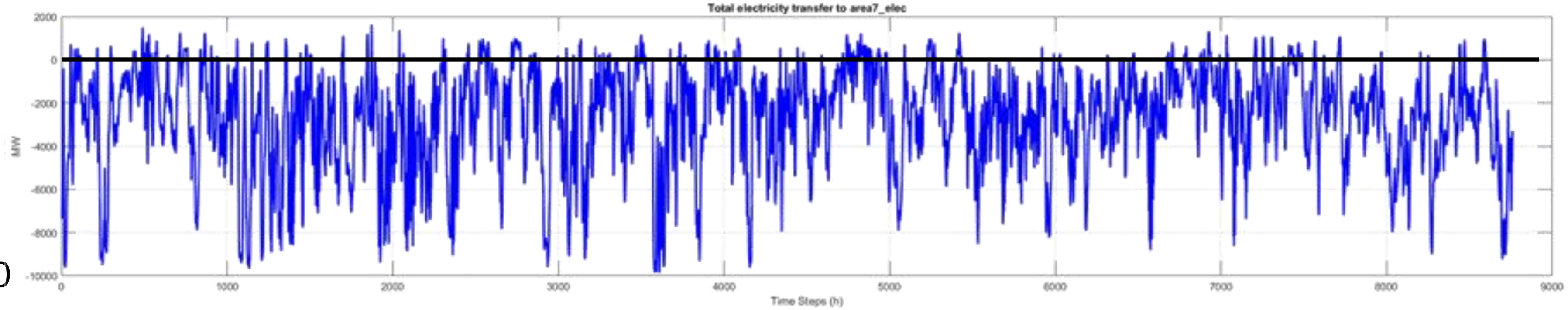


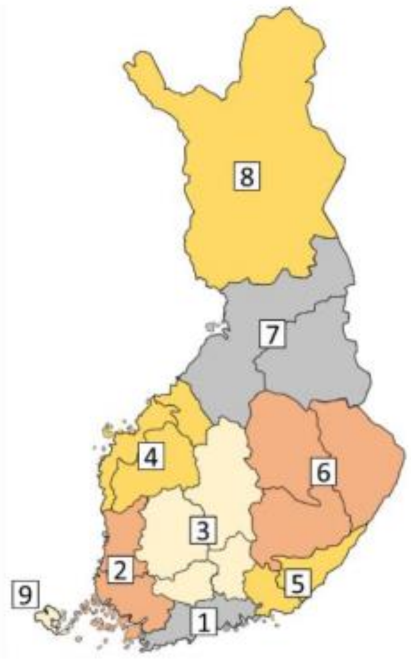
Total electricity transfer from region 7, the biggest surplus region

2 000

MW

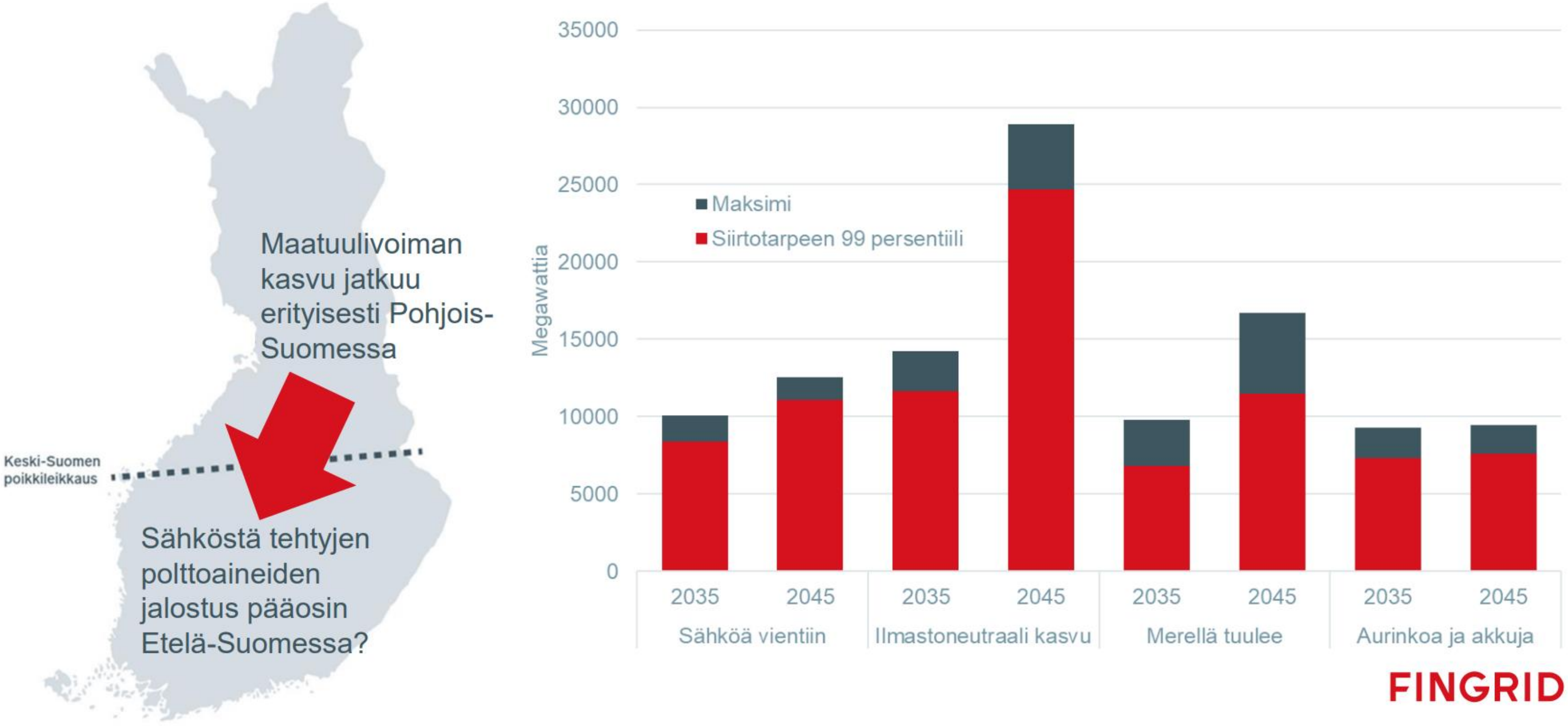
-10 000





Siirtotarpeen kasvu jatkuu vuoden 2035 jälkeenkin

Siirto Keski-Suomen poikkileikkauksessa 2035-2045



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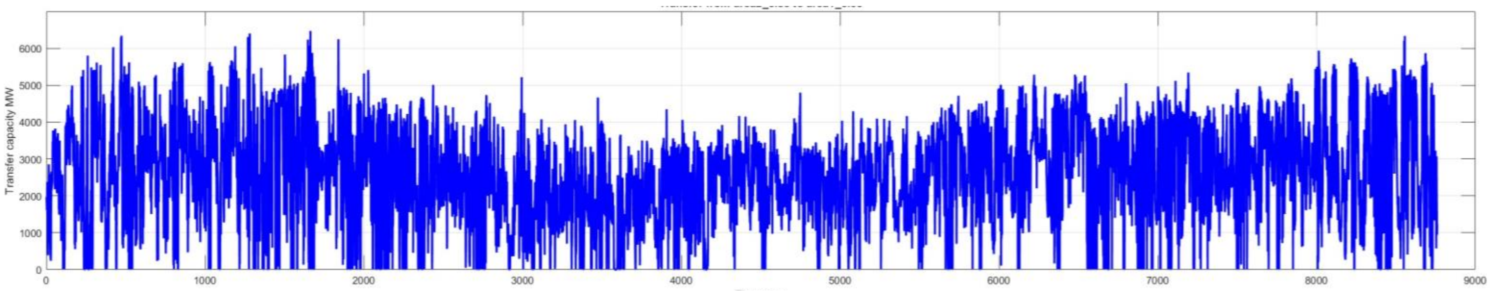
Business as Usual 2035, Examples of electricity transfer

Transfer from region 2 to region 1

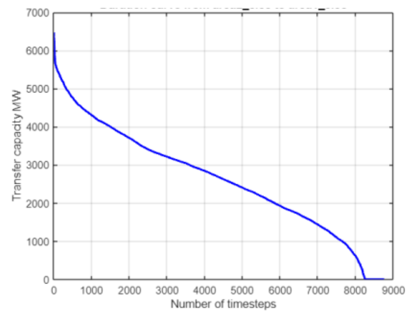
7 000

MW

0



Transfer Duration Curves

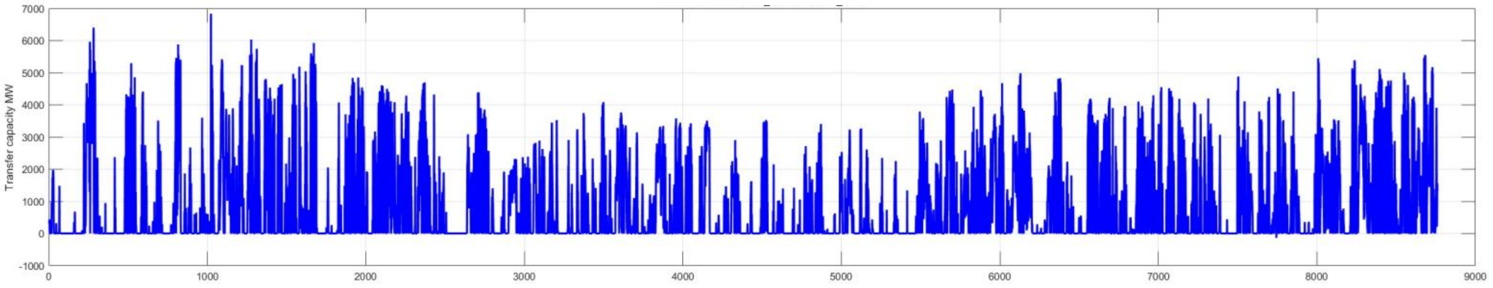


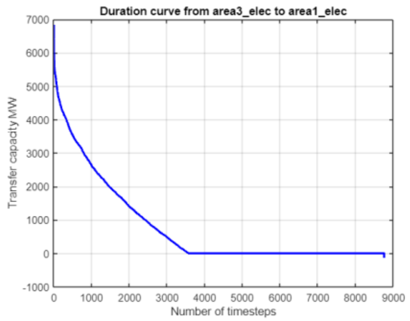
Transfer from region 3 to region 1

7 000

MW

-1 000



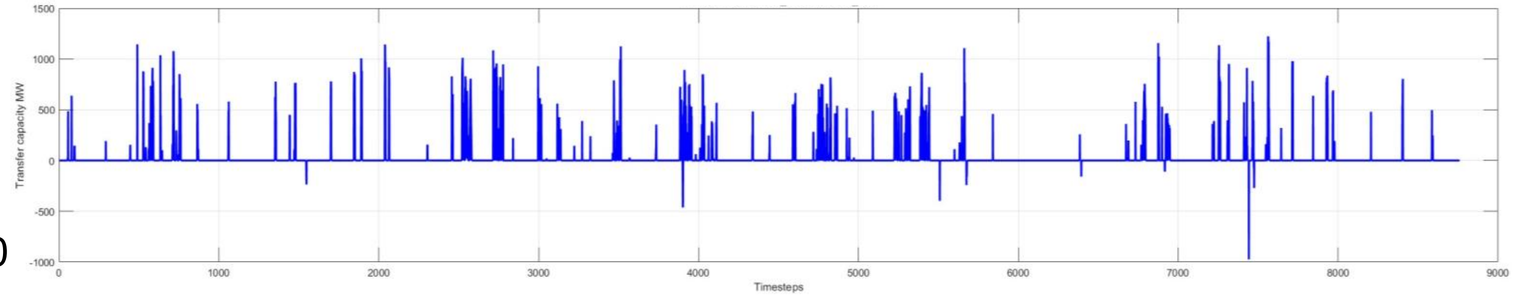


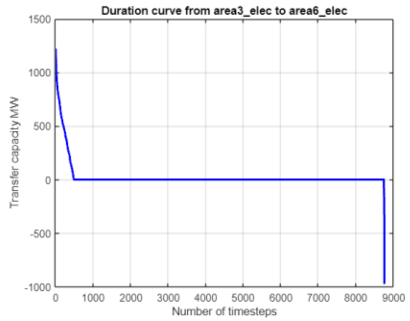
Transfer from region 3 to region 6

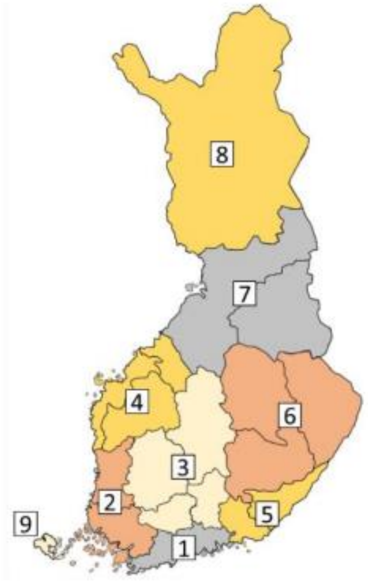
1 500

MW

-1 000

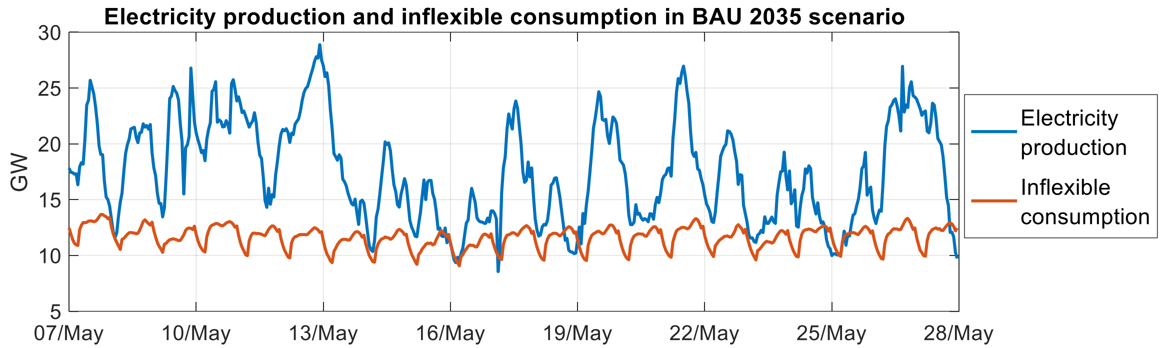


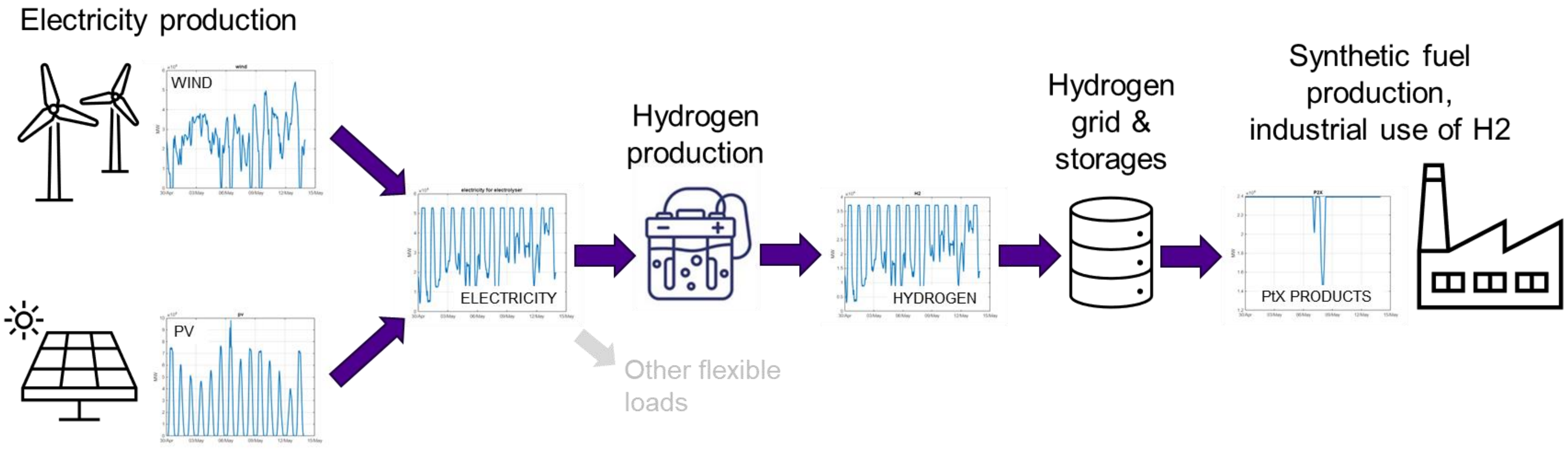




Flexibility needed in the value chain

- The energy system needs flexible loads (i.e., flexible consumption) to balance the high variability of renewable electricity production
- To utilize all variable renewable electricity production potential, hydrogen production must be flexible and **buffered with storages**.
- Insufficient buffer storage capacity reduces hydrogen production volumes (i.e., potential will be lost).
- The energy system needs buffer storage capacity to cope with the temporal variations of green electricity production and this will not depend on the locations of hydrogen production units.





Flexibility resources

- Flexible operation of electrolyzers - Are they really flexible in long run?
  - Part load operation efficiency
  - Modular units – start up costs and - times
  - Expected lifetime vs. variable operation
  - Economic challenges – full load hours vs. invested capacity
- Flexible operation of PtX synthetization processes – requires R&D in process technology
- Storages
  - Operation strategy of hydropower storages (water value)
  - Hydrogen and PtX (ammonia & synthetic hydrocarbons) product storages (hydrogen value)
    - Optimization in relation with electrolyzer capacity, PtX flexibility and end product price
  - Battery energy storages (BES) are not economically feasible for buffering variable electricity production in order to increase full load hours of operation of electrolyzers
    - Investment costs for BES much higher compared with over investing to electrolyzer capacity

Demonstration of Effects of BES and Electrolyzer Capacities on H_2 Production and Storage Use

- Wind power park, P_N 200 MW connected with an electrolyzer plant
- Three electrolyzer designs:
  - 163 MW (FLH 4000 h)
  - 109.3 MW (FLH 6000 h)
  - 93.7 MW (FLH 7000 h)
- Reference case 163 MW electrolyzer with no BES produces 139 230 MWh H_2 in four months
- 109.3 MW electrolyzer can produce same amount of H_2 if connected with **3 433 MWh** BES
- 93.7 MW electrolyzer can produce same amount of H_2 if connected with **7 294 MWh** BES

Demonstration of Effects of BES and Electrolyzer Capacities on H_2 Production and Storage Use

- With investment costs
  - Electrolyzer 1 M USD/MWe electrolyzer capacity
  - BES 0.25 M USD/MWh* BES capacity Investment costs for these three designs:
  - 163 MW electrolyzer with no BES, **163 M USD**
  - 109.3 MW electrolyzer with 3 433 MWh BES, **967 M USD**
  - 93.7 MW electrolyzer with 7 294 MWh BES, **1 917 M USD**
- Using these investment costs, with the same 163 M USD costs you can get:
  - 163 MW electrolyzer with no BES, H_2 production **139 230 MWh**
  - 109.3 MW electrolyzer with 218.8 MWh BES, H_2 production **125 663 MWh**
  - 93.7 MW electrolyzer with 281.2 MWh BES, H_2 production **118 171 MWh**

* Source: IRENA - ELECTRICITY STORAGE AND RENEWABLES: COSTS AND MARKETS TO 2030

Finland’s distributed resources create regional energy imbalances and transportation needs

Key messages

- Distributed nature of resources means that Finland has significant energy surplus and energy deficit areas.
- 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.
  - Battery electricity storages are not feasible for regional balancing

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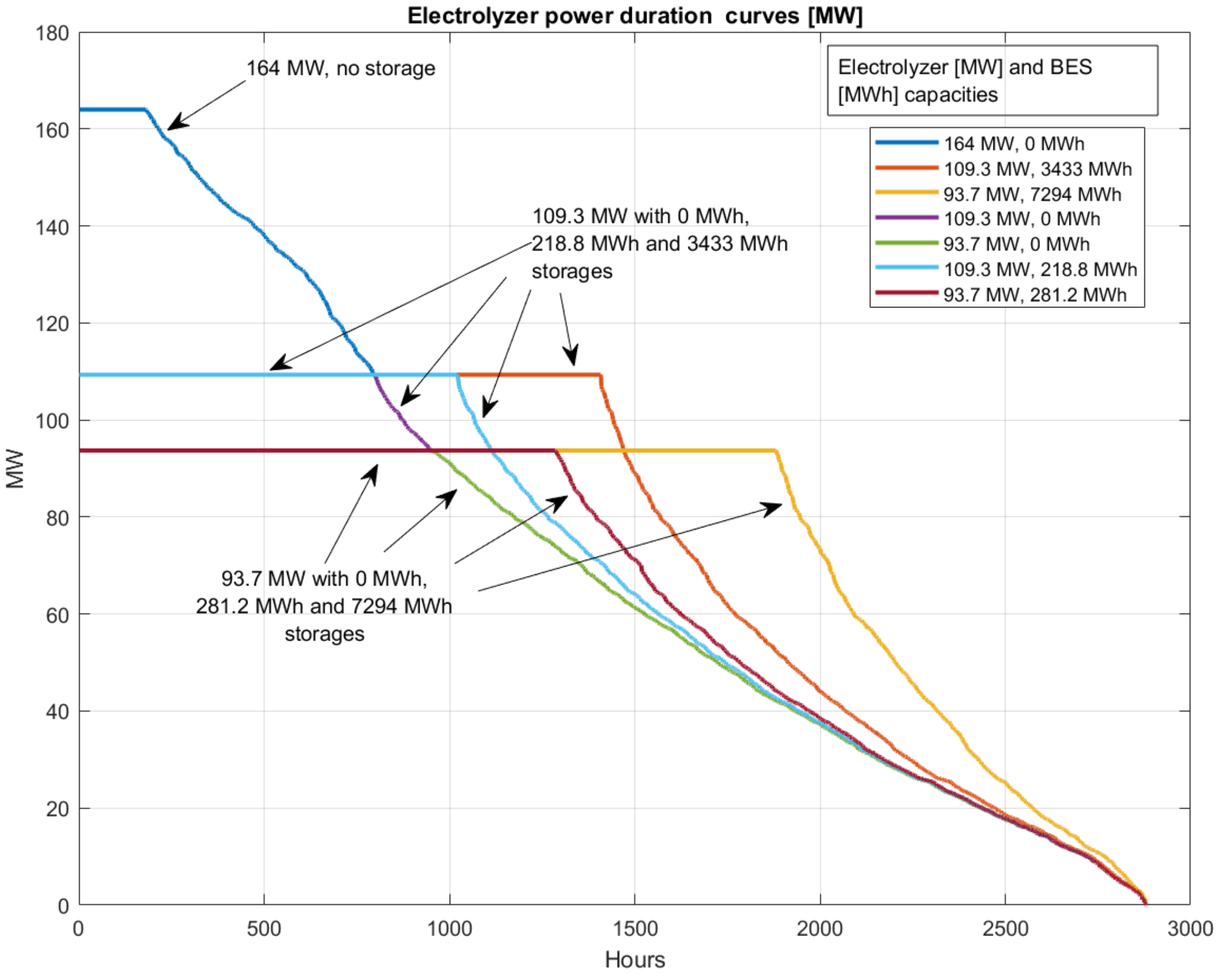
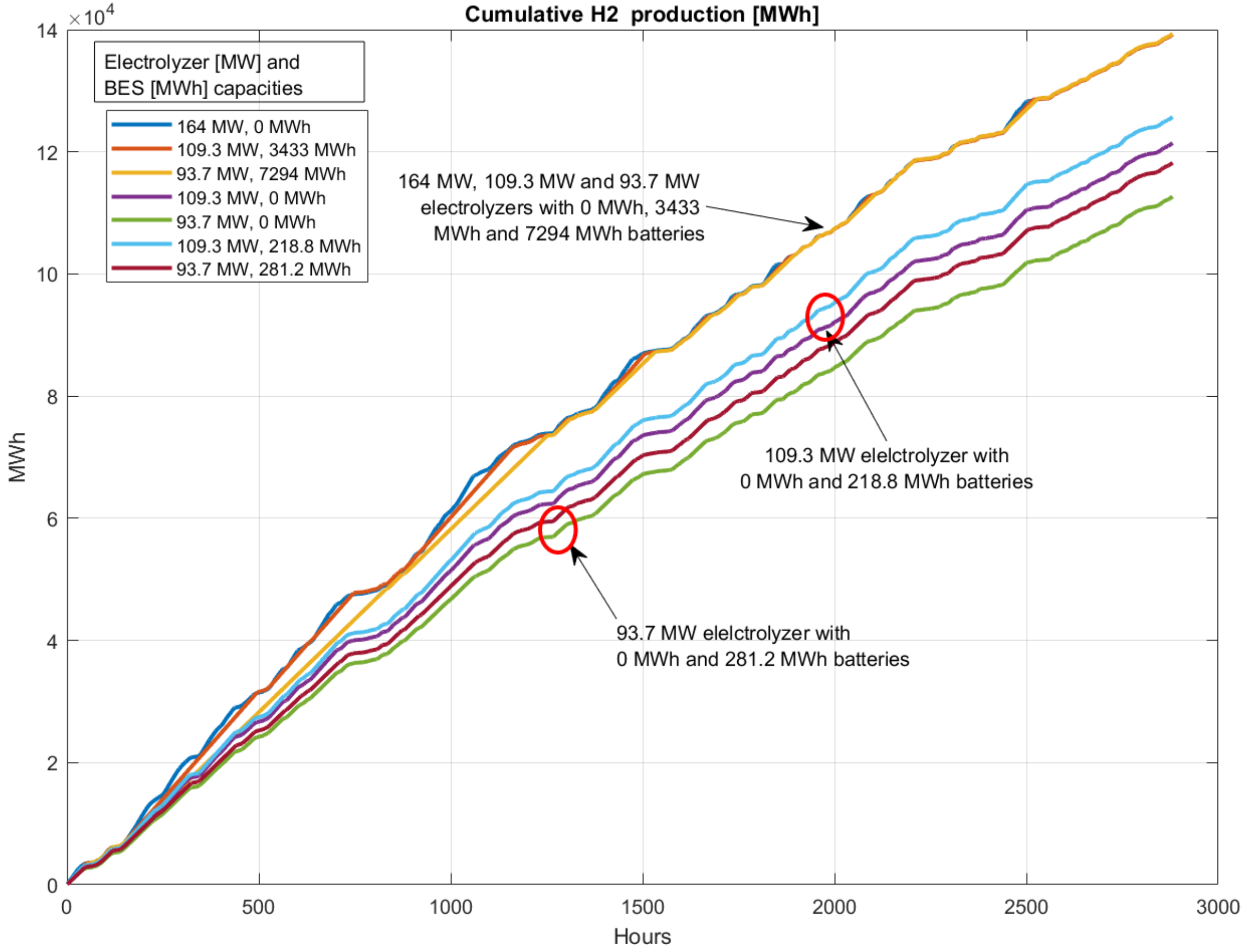


- H2 production equal by
  - 164 MW electrolyzer
    - Investment costs 164 M USD
  - 109 MW electrolyzer & 3 433 MWh BES
    - Investment costs 967 M USD
  - 93.7 MW electrolyzer & 7 294 MWh BES
    - Investment costs 1 917 M USD



Cumulative H2 production [MWh]
×10^4
14
12
10
8
6
4
2
0
MWh
0
500
1000
1500
2000
2500
3000
Hours
Electrolyzer [MW] and
BES [MWh] capacities
164 MW, 0 MWh
109.3 MW, 3433 MWh
93.7 MW, 7294 MWh
109.3 MW, 0 MWh
93.7 MW, 0 MWh
109.3 MW, 218.8 MWh
93.7 MW, 281.2 MWh
164 MW, 109.3 MW and 93.7 MW
electrolyzers with 0 MWh, 3433
MWh and 7294 MWh batteries
109.3 MW elelctrolyzer with
0 MWh and 218.8 MWh batteries
93.7 MW elelctrolyzer with
0 MWh and 281.2 MWh batteries

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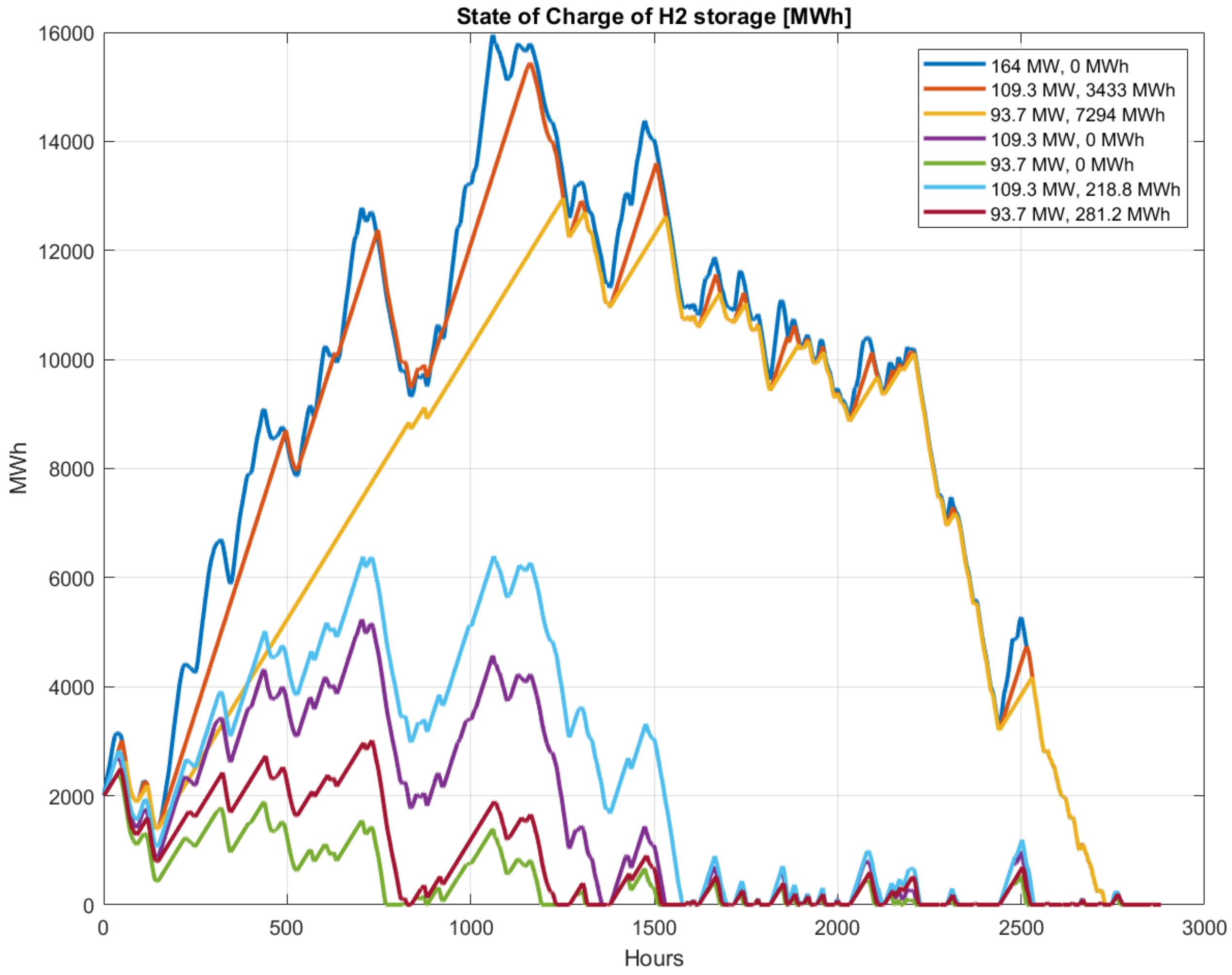

• H2 supply after buffer storage to PtX production with different electrolyzer and storage combinations