Designing low emissions, efficient, high renewable energy systems resilient to climate change

TFIAM
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CREDS
Decarbonisation of heat

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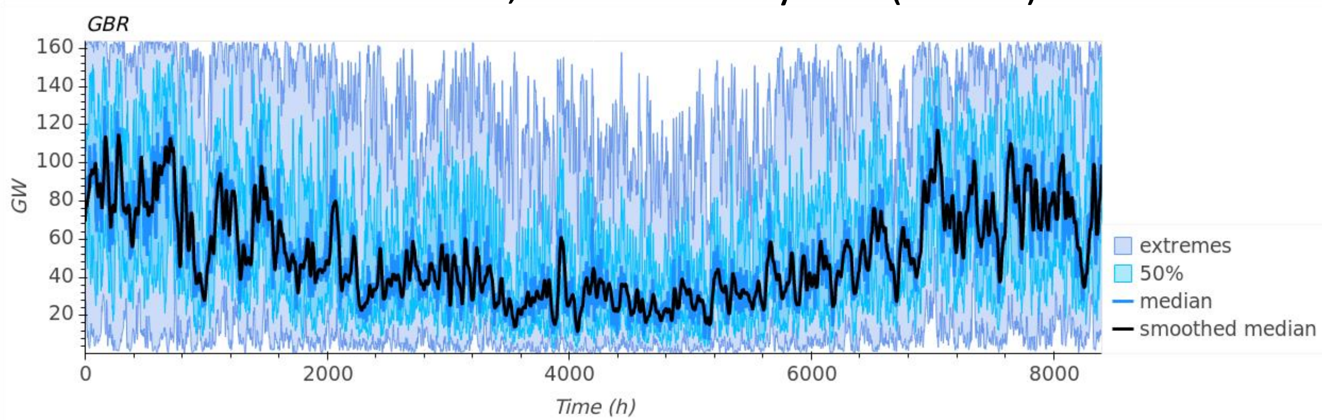
Mismatch between (variable) renewables and (variable) demand

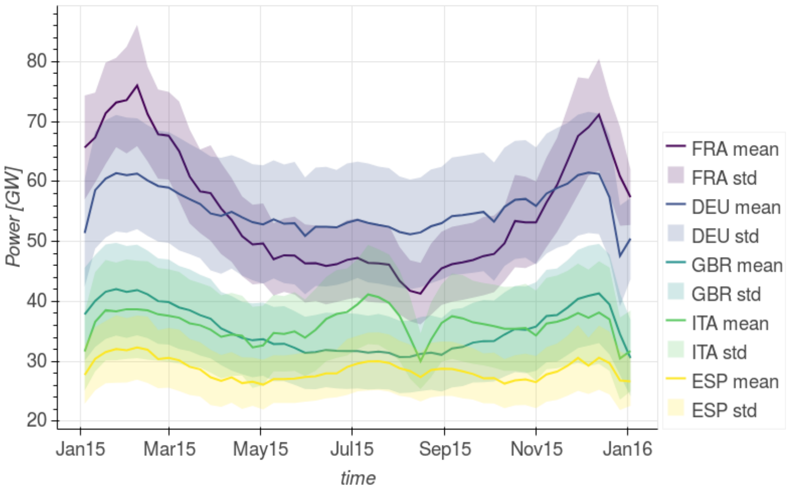
Wind varies across hours, months and years (+-10%):



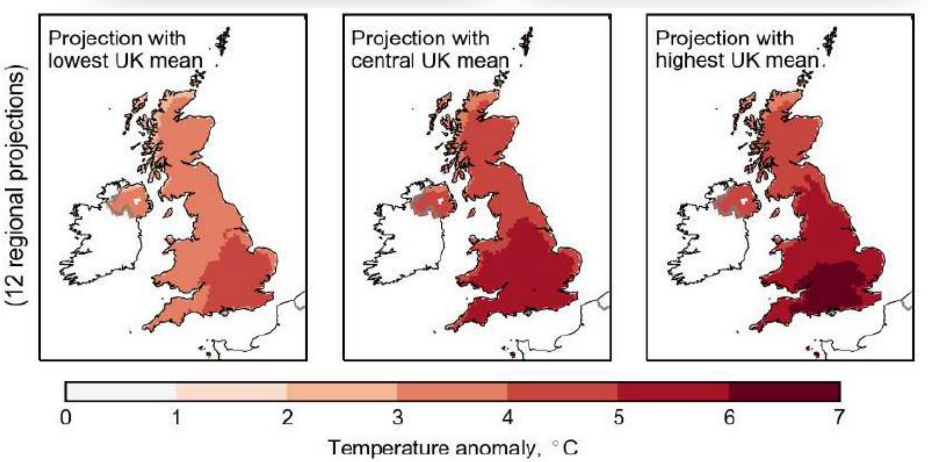
Sources:

- Gallo Cassarino et al. Applied Energy, 2018
- UKCP18 National Climate Projections. MetOffice, 2018

Changes in demand due to weather and human activity:



Increase in the frequency and intensity of extremes: consequences for heating/cooling?



Can either storage or interconnections meet demand on its own?

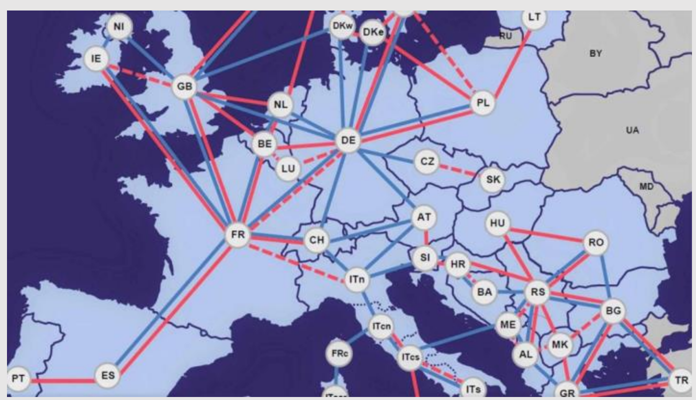
Storage

- ✓ Available immediately
- ✓ Near demand
- ✓ Long term
- ✓ High capacity
- ✓ Multiple vectors

- × Space constraints
- × Expensive

Interconnections

- ✓ Smooth demands and renewables
- ✓ Reduce storage
- ✓ Reduce curtailment and installed capacity
- ✓ Security through interdependence and diversity

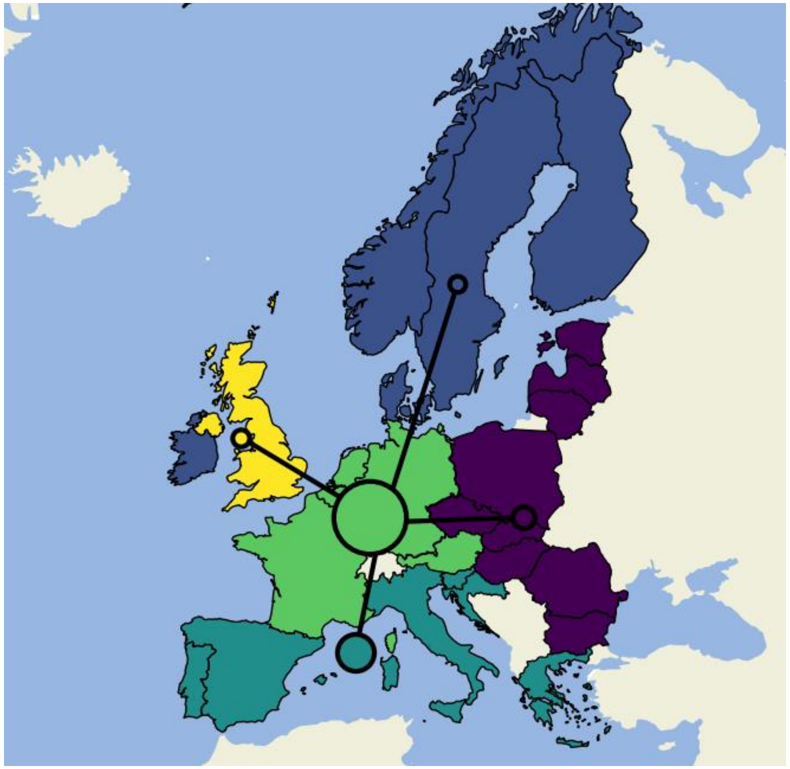


- × Depends on surplus/deficit
- × Only electricity

ESTIMO – Energy Space Time Integrated Model Optimiser

Objective: near zero net greenhouse gas emission at least cost.

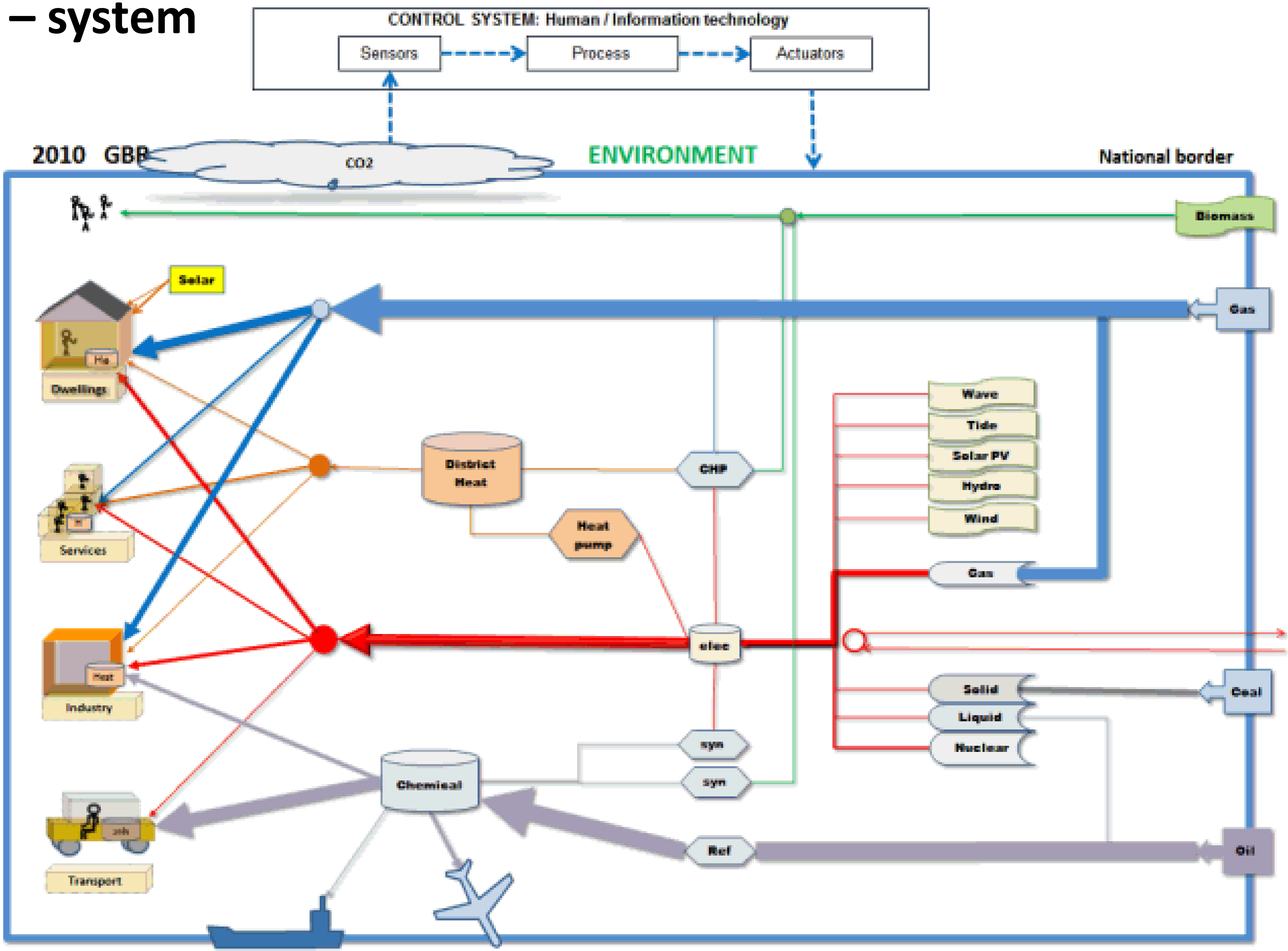
Problems:
- Mismatch between demand and ***variable*** renewable generation.
- With ***climate change***, the heat:cool ratio will be different and we need to design systems resilient to these uncertainties.



What is the **optimal mix of storage and transmission** for balancing demand and supplies in **highly electrified**, renewable systems given the possible impacts of **climate change**?

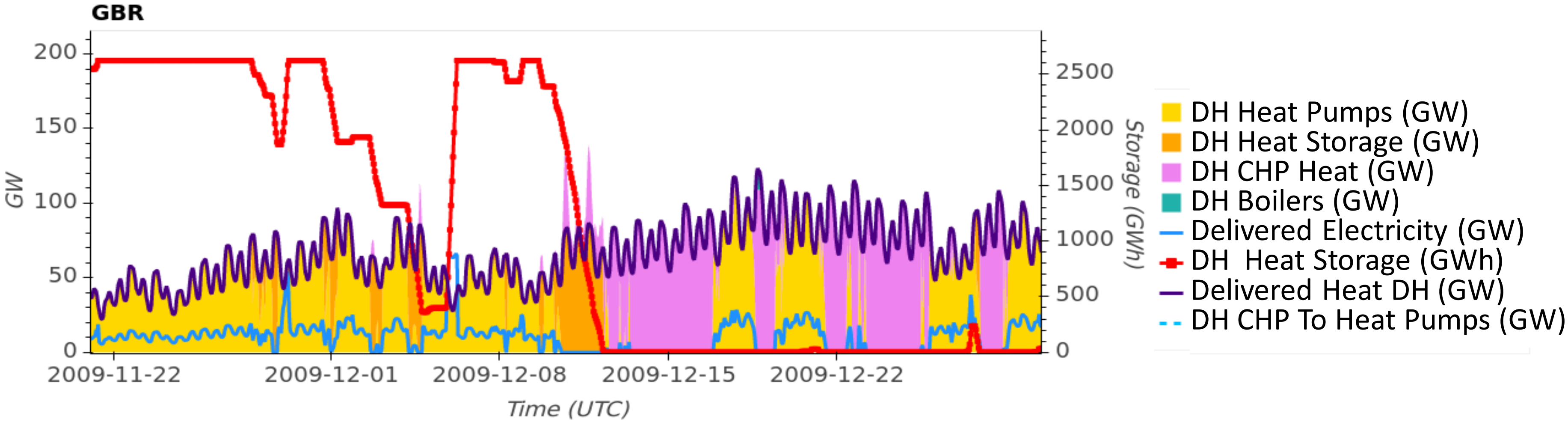
- 30+ countries at hourly time step
- 37 years of weather data (hourly, at 0.5 degree lat/lon resolution)
- multiple scenarios for demand & supply

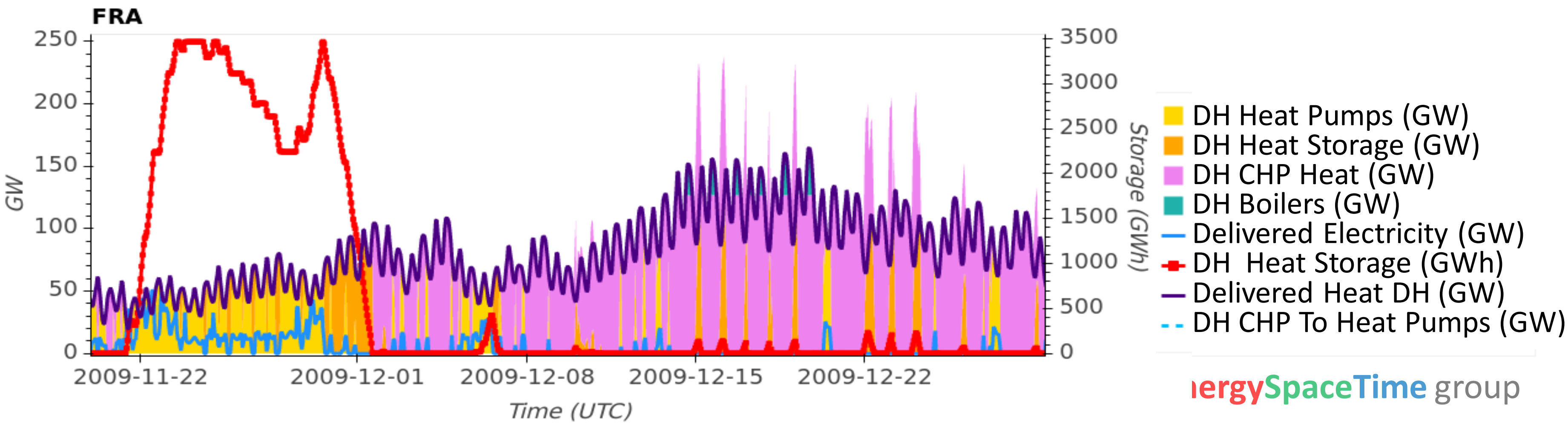
ESTIMO – system



ESTIMO – district heating (hourly simulation)

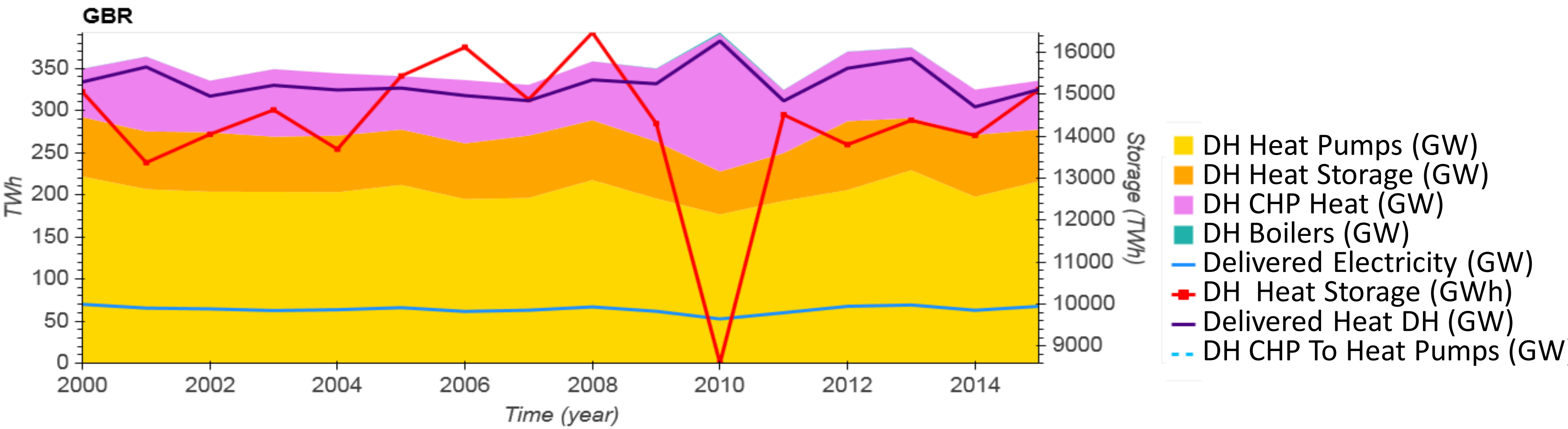
DH heat sources (HP, CHP, boiler) varying with demand and renewable surplus. District heat a valuable subsystem for managing larger system. Flows are different in GBR and FRA because of time difference and weather.

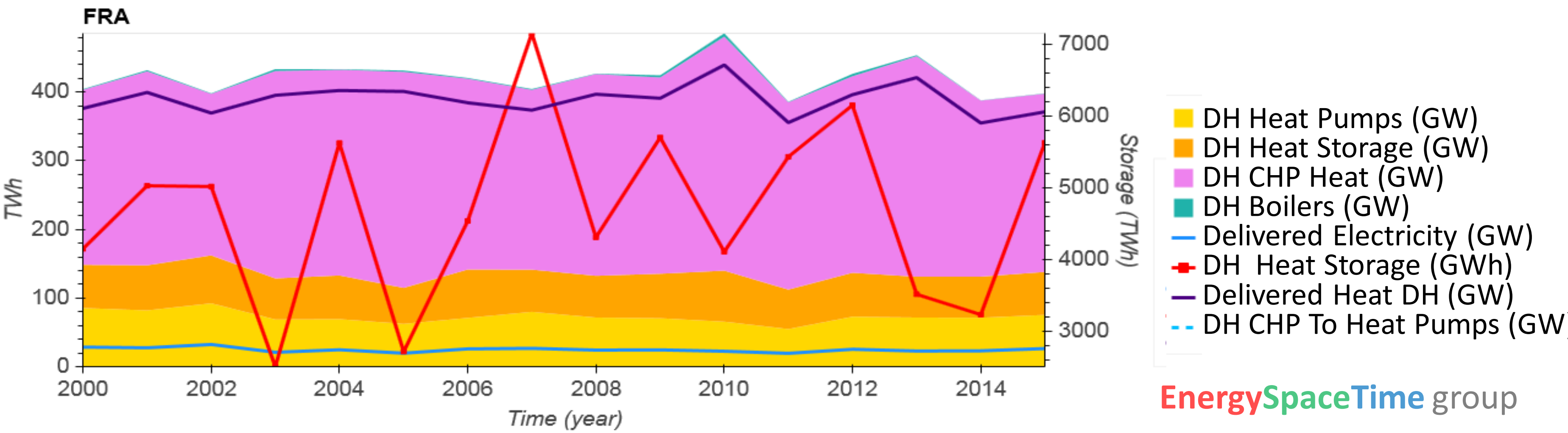




ESTIMO – district heating (annual sum)

Contiguous multiple years of weather are needed to investigate long term system requirements to adapt to climate change and rare weather events (high usage of storage in 2010 in the UK)





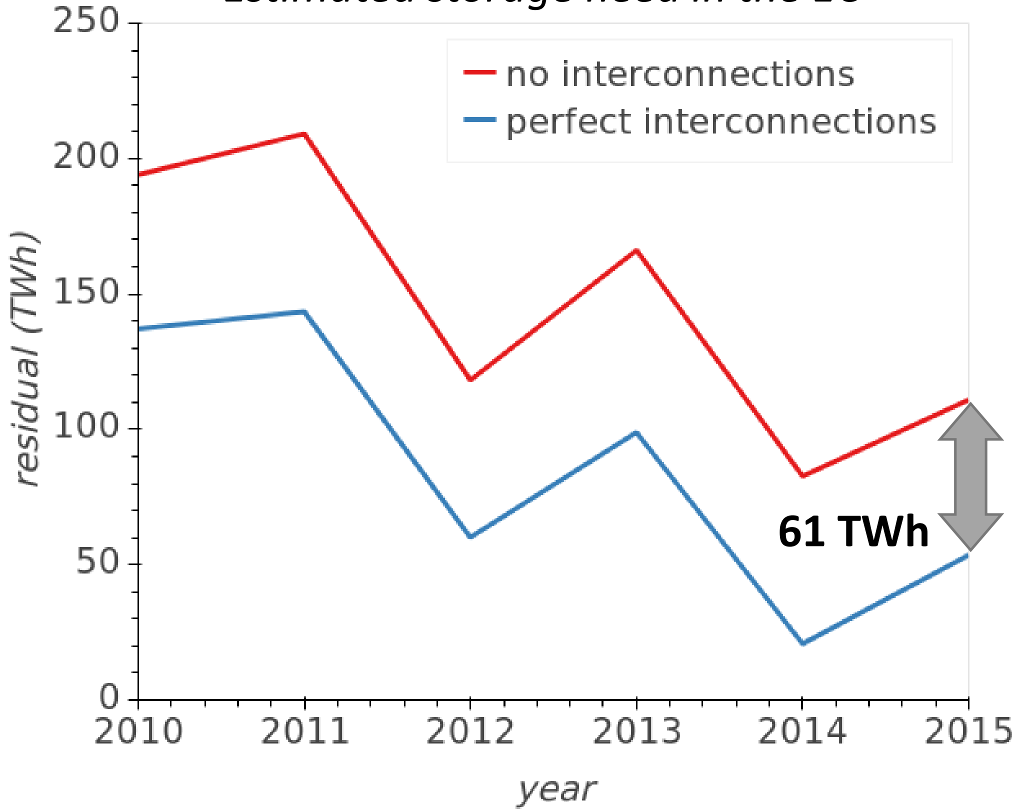
Interconnections can substantially help reducing storage

Residual demand (i.e. storage need) = cumulative demand – variable renewables

The UK would need 10-15% annual demand (equivalent to ~50 TWh storage) in a high-renewable system.

We estimated that EU would need **30%-75%** (depending on the year) **less storage**, assuming **perfect interconnections among countries**.

Estimated storage need in the EU



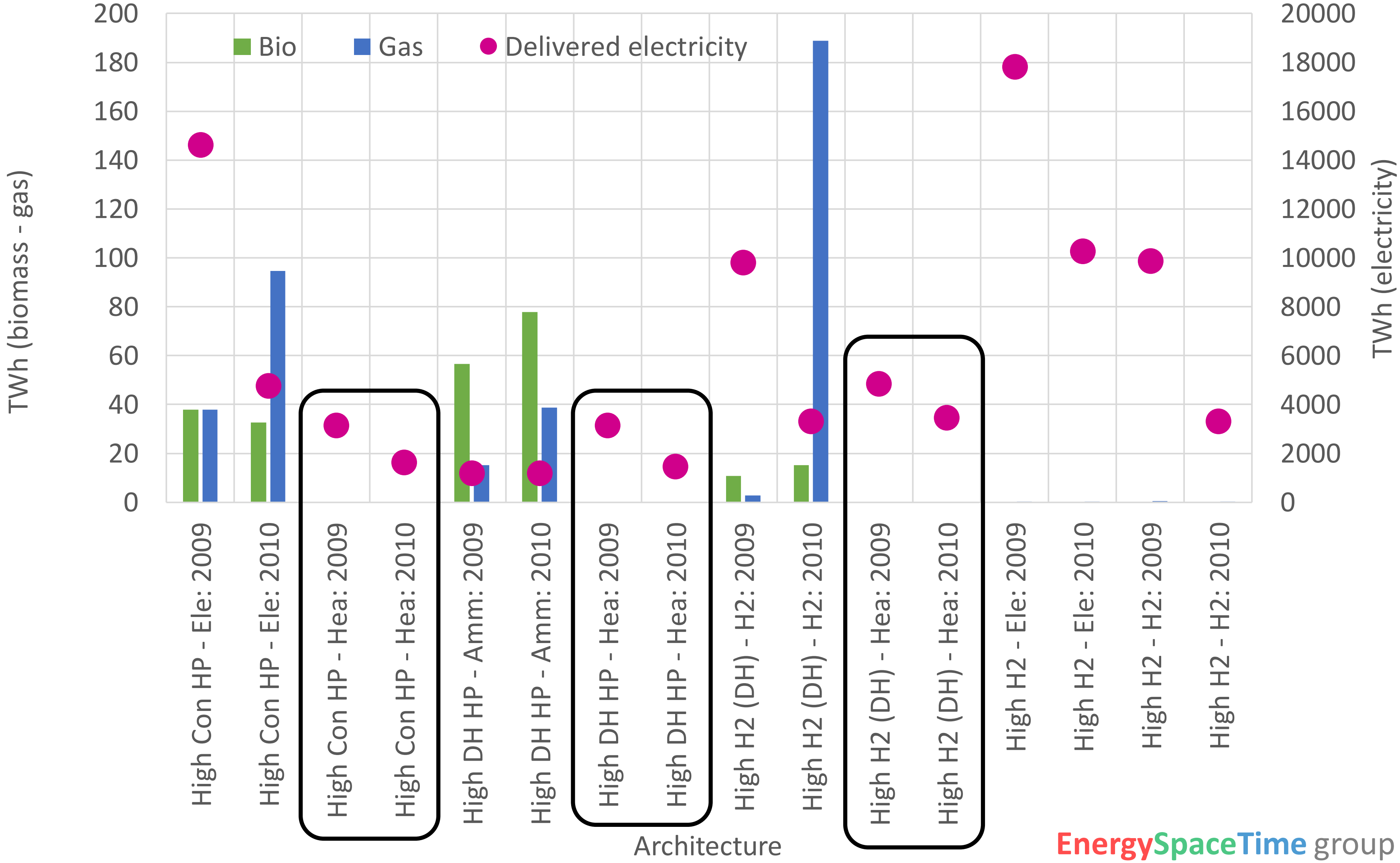
ESTIMO – weather resilience of architectures in Europe (2009-2010)

Measures of system flexibility for weather resilience:
- Biomass and natural gas to estimate emissions
- Electricity required to meet system demand

First scenarios for the European system:
- 5 nodes: UK, EU Nord, EU East, EU South, EU West
- 2 years of contiguous weather: 2009-2010 (low wind and temperatures)
- 100% renewable supply: Hydro 5%, Geothermal 5%, PV 15%, Wind 75%
- Interconnectors: 250% of current capacities
- Aviation fuel supply excluded (currently not in the model)
- Heat architectures (shown in the next slide)
  - 70% consumer heat pumps, 30% district heating, grid storage
  - 70% consumer heat pumps, 30% district heating, heat storage
  - 70% district heating, 30% consumer heat pumps, ammonia storage
  - 70% district heating, 30% consumer heat pumps, heat storage
  - 70% hydrogen boilers, 30% district heating (80% heat pump), hydrogen storage
  - 70% hydrogen boilers, 30% district heating (80% heat pump), heat storage
  - 70% hydrogen boilers, 30% consumer heat pumps, grid storage
  - 70% hydrogen boilers, 30% consumer heat pumps, hydrogen storage

ESTIMO – Heat storage and heat pumps critical for emissions and resilience

No emissions with DH heat storage and high electricity demand with hydrogen boilers



ESTIMO – weather resilience of architectures in Europe (2009-2010)

Key results:

- Architectures with District Heating heat storage do not need biomass and gas, so no emissions
- Heat storage is efficient, cheap, and can meet seasonal demand, so it is a critical component for net-zero energy systems
- Benefits of heat storage are present also when the share of district heating is small
- Architectures with a high share of hydrogen require more electricity than the others, due to the lower efficiency of the hydrogen systems compared to heat pumps

Conclusions

1) To design low emission systems it is essential to detail:

- the impact of meteorology and climate change on demands and renewables
- behaviour demand drivers
- all the technologies for system flexibility: storage, interconnections, etc.

2) ESTIMO has been developed for the design of renewable, near zero emission system for providing services to stationary, land and sea transport sectors. A prototype of **dynamic spatiotemporal control system** has been developed.

3) High efficient **heat pumps and heat storage are critical** to minimise emissions and to provide weather resilience

4) Next 'easy' steps: integrated heating and cooling, optimisation

5) Known unknowns (future developments):

- aviation
- cement, etc.

EnergySpaceTime group

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Thank you for your attention!