neModSpaceTime.xls:4

SENCO **Energy, space, time model** Dummy data Year: 2025 August Hour: 24

Designing a 100% renewable energy system

a low regret energy strategy to meet security, climate and air pollution objectives

A preliminary development for illustration only

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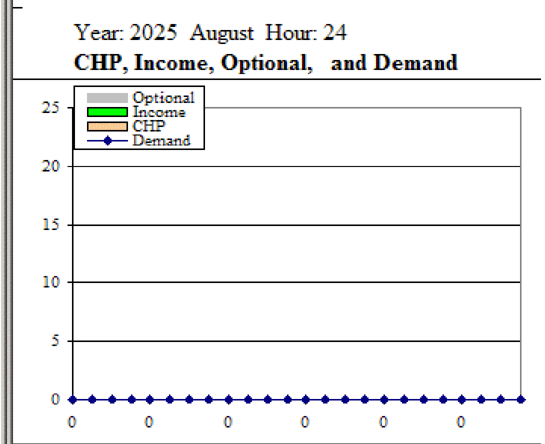
Energy Space Time group

(run presentation to see animations)



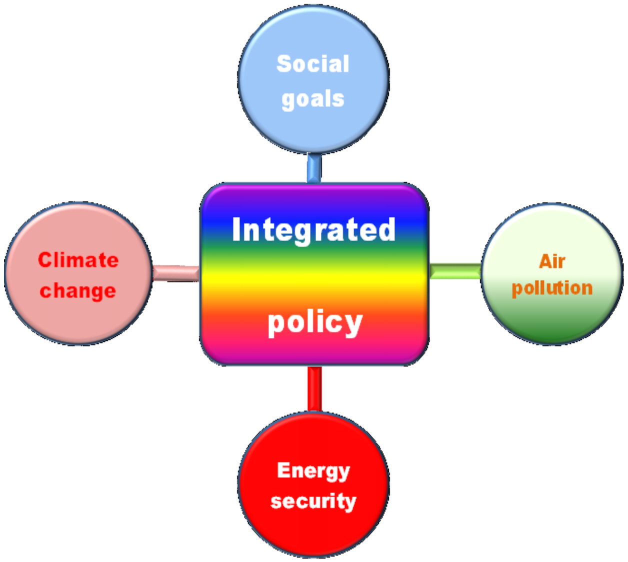
Energy Space Time

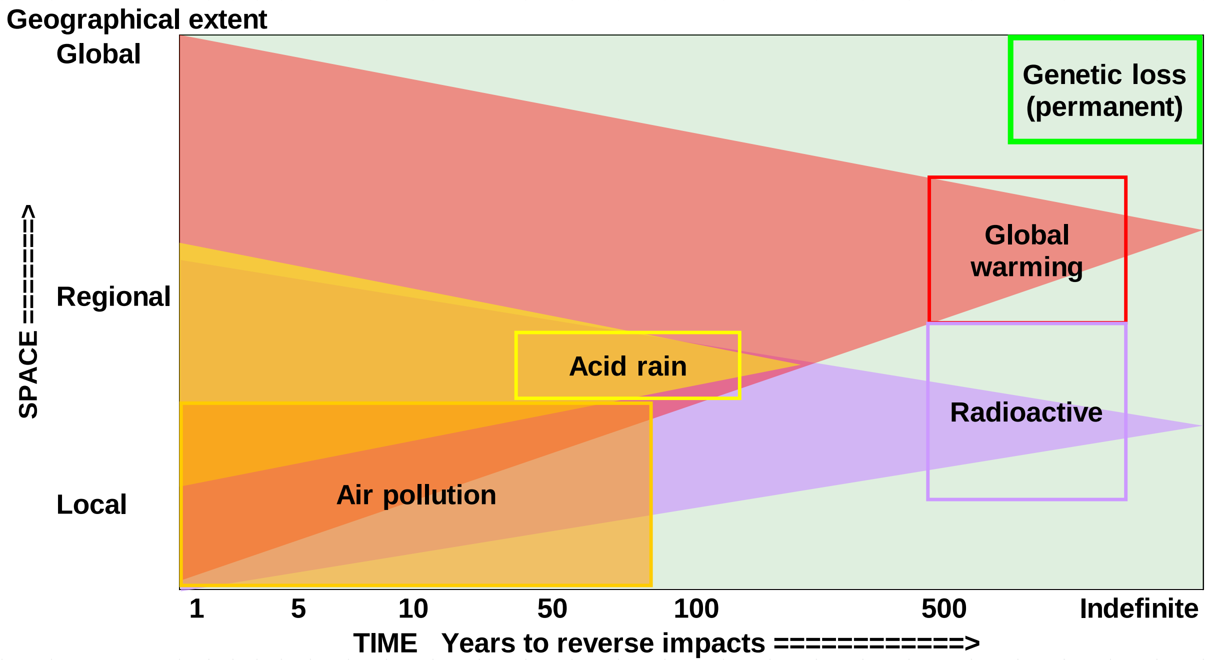
Policy objectives

Renewable energy can be the foundation for an integrated, low risk, reversible and long term energy policy for:

- Social well being
- Energy security
- Climate stabilisation
- Air pollution

Many renewables do not incur long term, spatially expansive environmental impacts.





Qualitative aspects of low carbon supply options

- Qualitative aspects are major drivers of social and political technology choice, as exemplified by concerns about nuclear power, shale gas and carbon sequestration.
- Mass produced renewables are the reversible, low risk, low cost option.

Relative subjective marks: 10 – good

	Renewables Hydro river Biowaste Solar Wind	Wave Tidal flow	Tidal barrage Hydro reservoir	Biocrop	**Nuclear**	**Fossil Carbon Sequestration**
Reversibility	10	10	5	7	0	0
Risk	10	10	5	5	0	2
Climate change mitigation	10	10	10	5	10	7
Other environment	10	10	8	6	0	8
Potential impact outside UK	10	10	10	10	0	0
Consumption global resources	10	10	10	5	5	7
International political impact	10	10	10	10	0	8
Political security	10	10	10	8	0	9
Transparency	10	10	8	7	0	5
Certainty costs and performance	10	5	6	7	0	2

UK renewable electrical energy technical and economic potential

Estimates based on current costs.

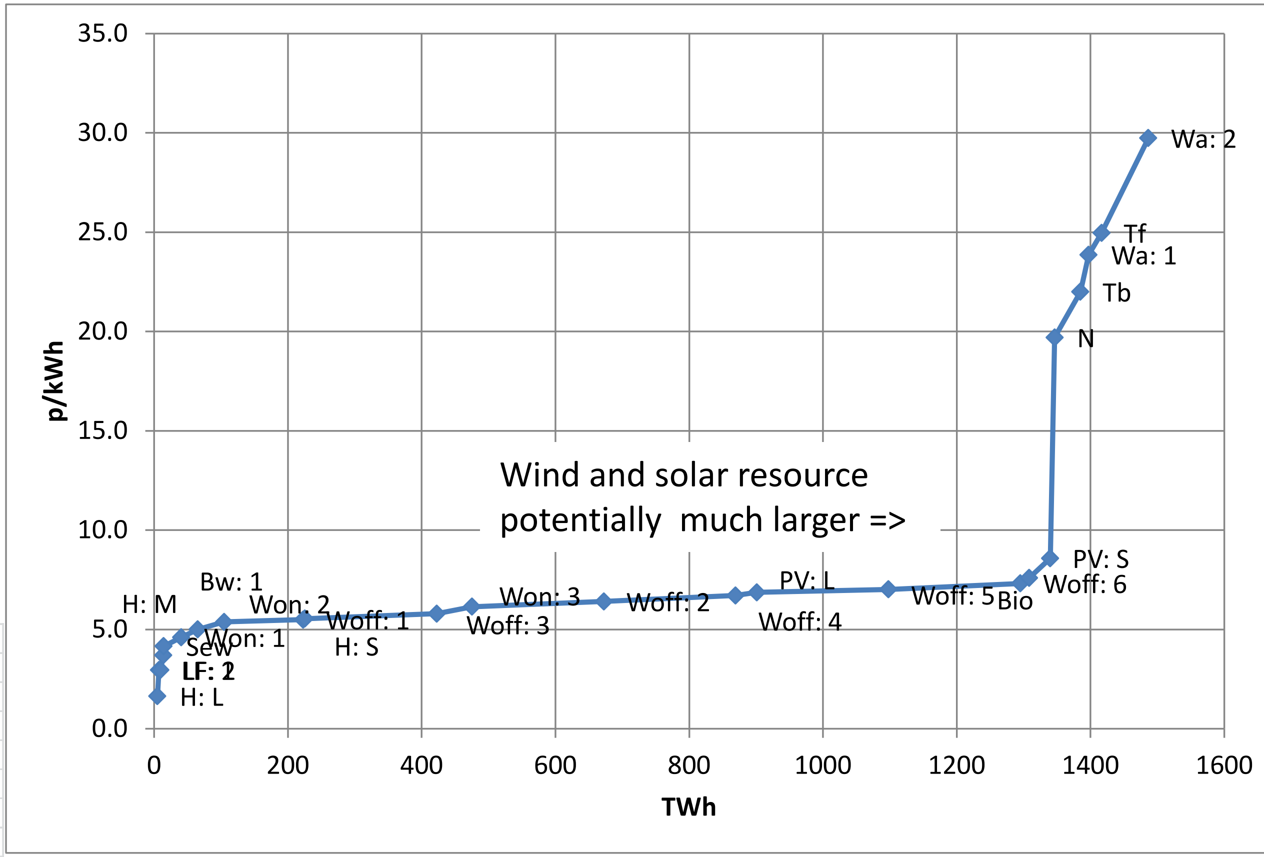
Wind and solar:

- mass produced technologies
- resource vast

Uncertain commercial cost

- Tidal, wave, (nuclear)

An advantage of tidal is that it is predictable, and output can be partially controlled from barrage schemes with storage.



Hydro	H
Biomass	Bio
Biowaste	Bw
Land Fill Gas	LF
Sewage	Sew
Wind-on	Won
Wind-off	Woff
Tidal barrage	Tb
Tidal flow	Tf
Wave	Wa
Solar PV	PV
Nuclear	N

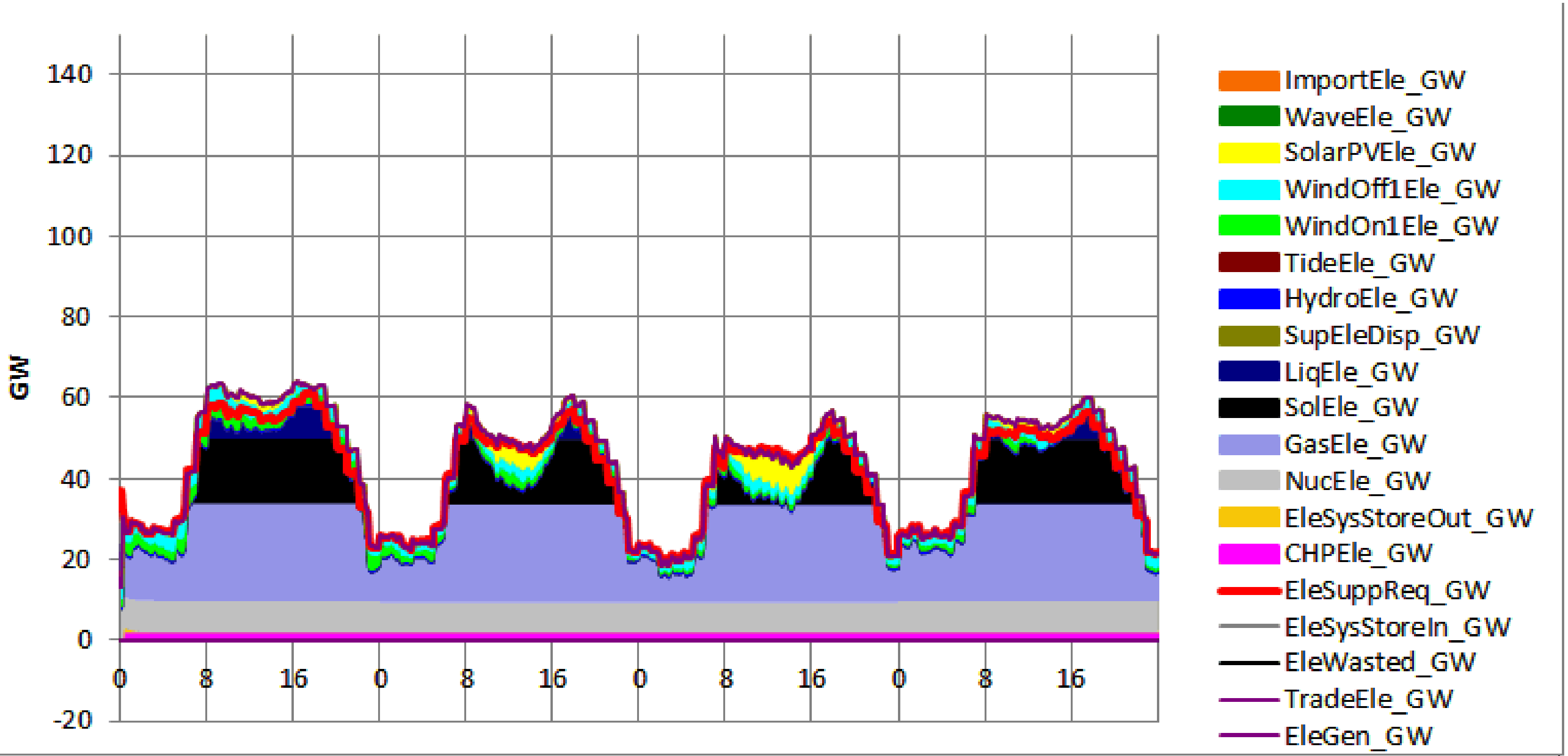
Generation only: excludes system balancing
Discount rate: 5 %/a

DynEMo

Evolution of electricity system dynamics

(wait for animation)

2015 to 2055, increasing demand and uncontrollable renewables absorbed with storage, dispatchable renewables and trade. CHP increases and declines.



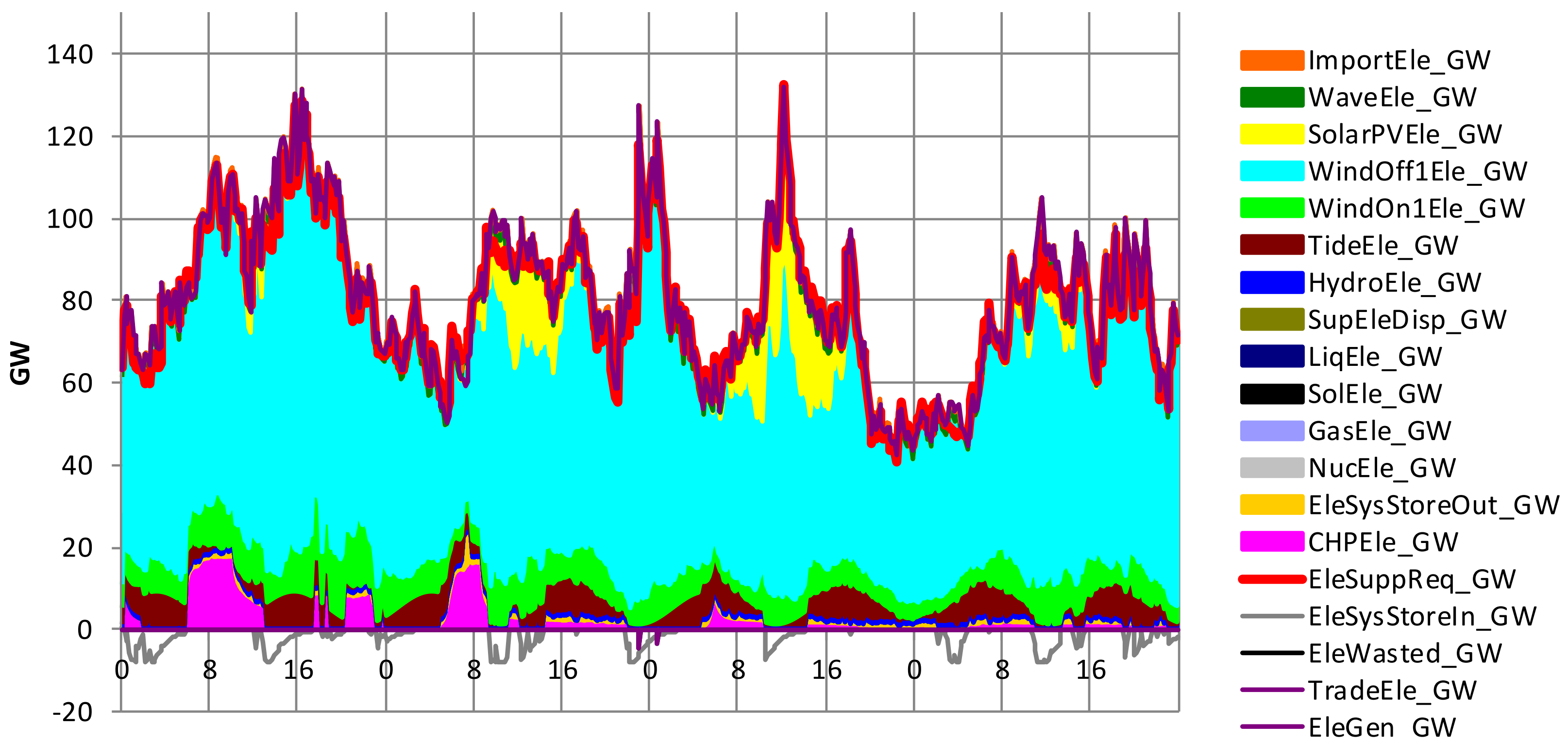
GBR: 2015: 4 days, 1 d/mth, mths 1,4,7,10; Δt=10m

winter spring summer autumn days

DynEMo

Evolution of electricity system dynamics

2055: all electricity provided with renewable generation
- biomass district heating CHP the main dispatchable plant



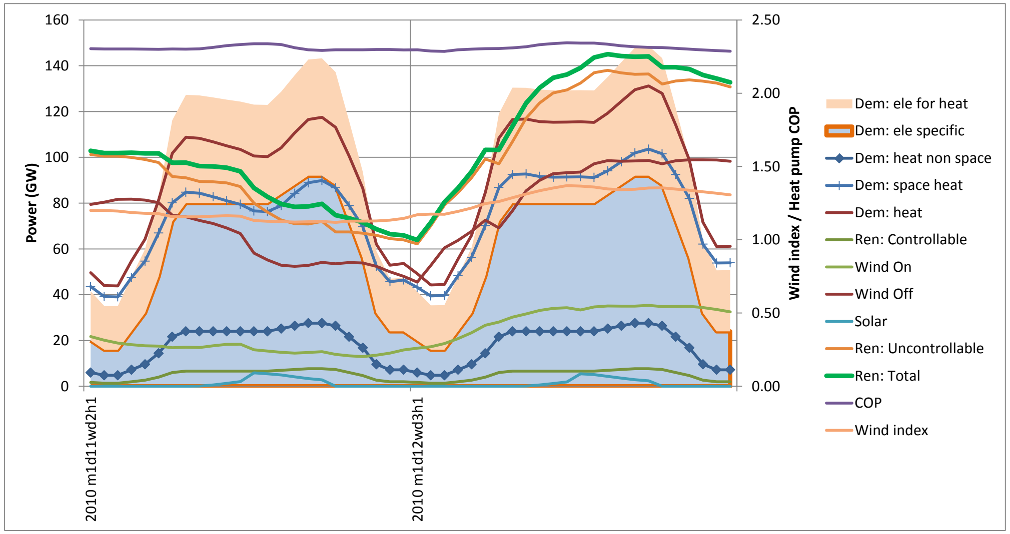
GBR: 2055: 4 days, 1 d/mth, mths 1,4,7,10; Δt=10m

winter spring summer autumn days

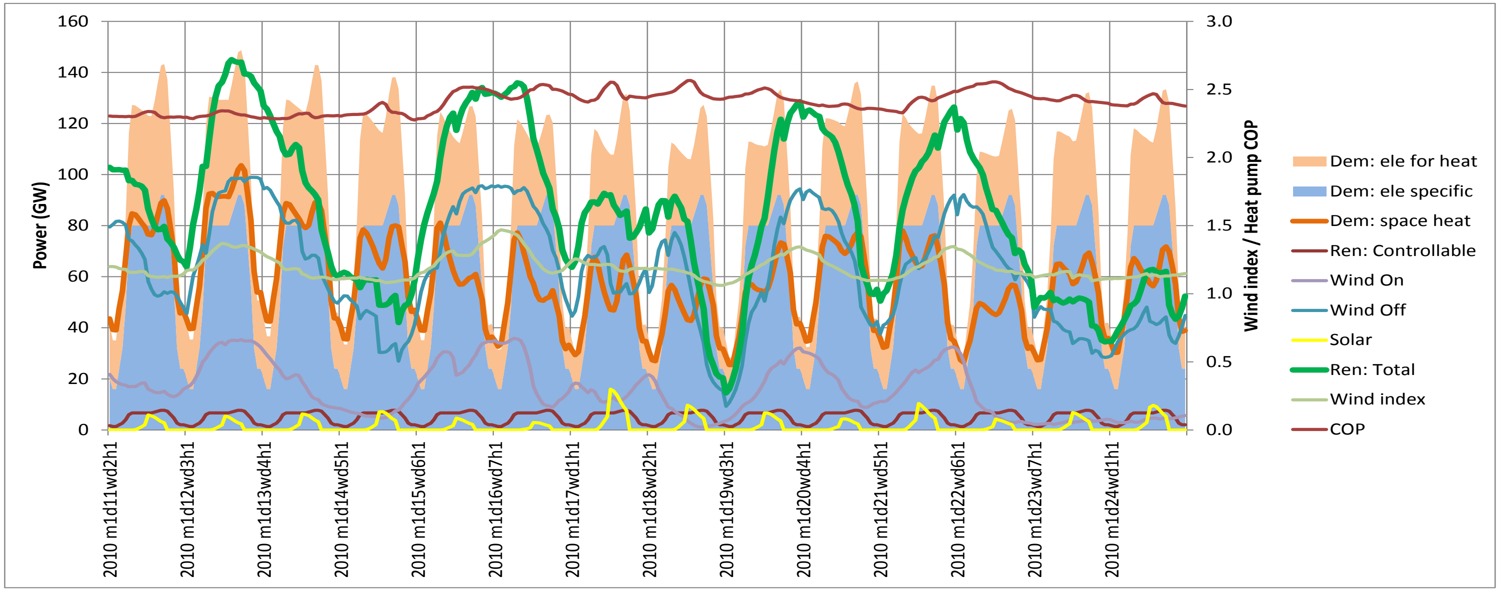
Energy system dynamics: simple hourly model

Sample 2 days and 2 weeks

2 days

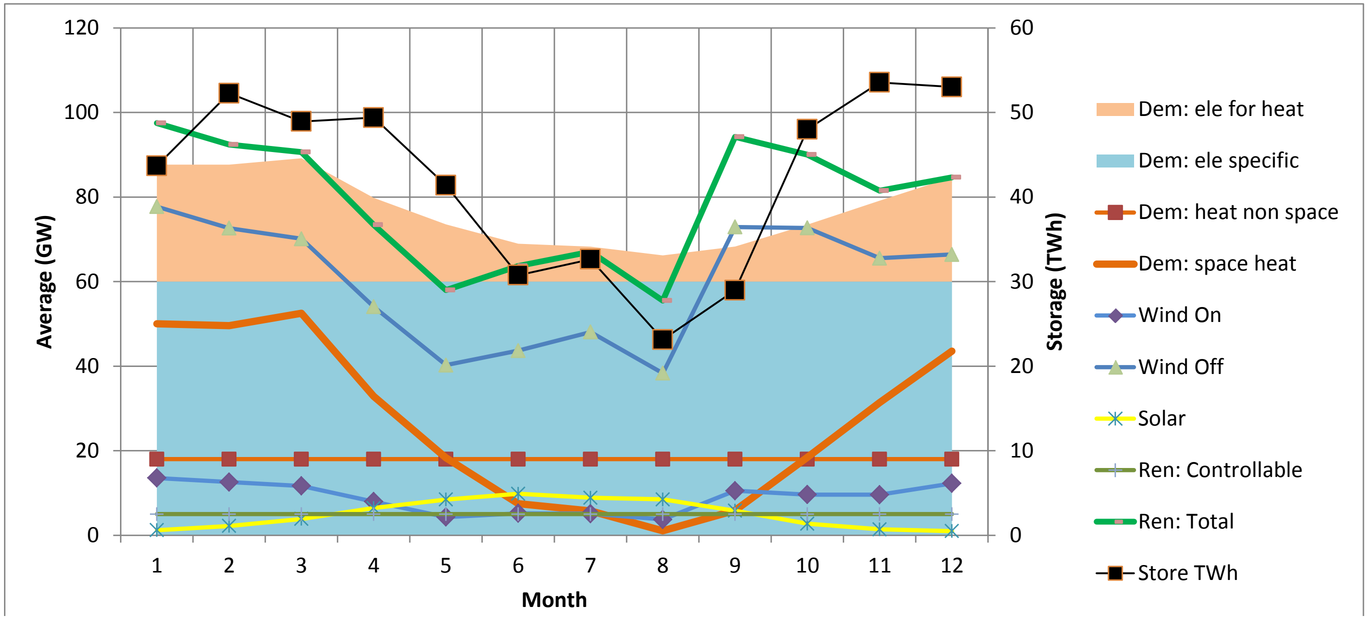


2 weeks

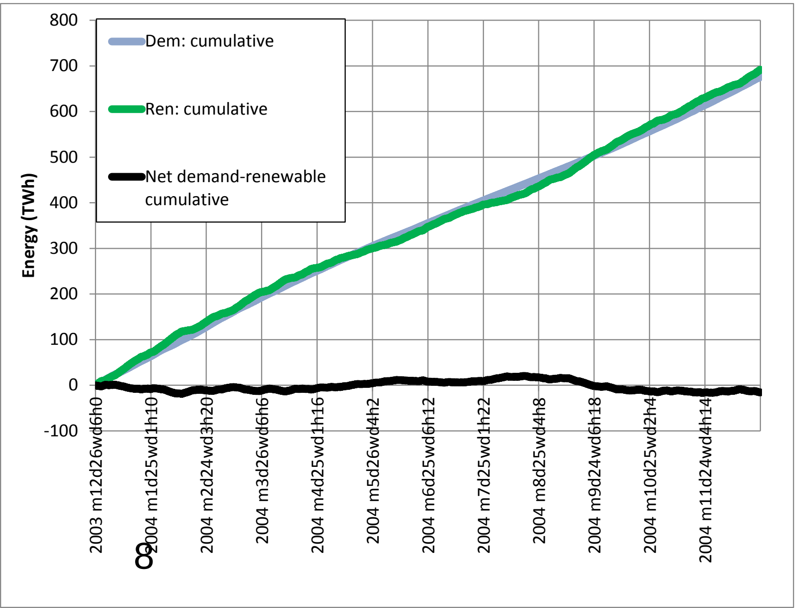


How much storage is needed?

(Simple model: assuming 100% renewables and no trade)



For year 2000, from 31 years of hourly meteorology and wind power generation from Dr Ed Sharp

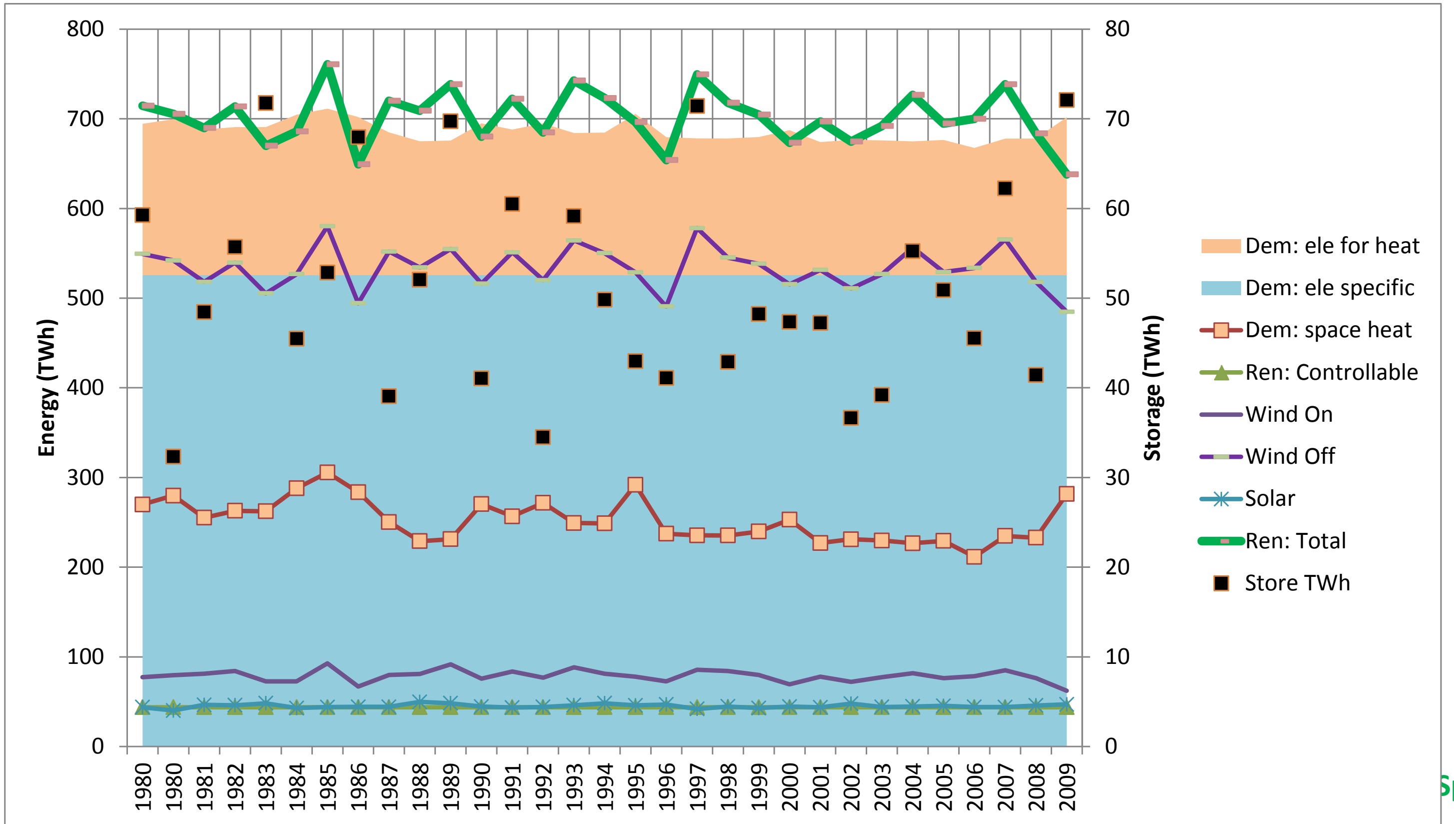


1. Model hourly demands and renewables across the year

2. The minimum storage is the maximum difference between cumulative demand and supply

Annual demand and renewable supply variation over 31 years

- Considerable inter-annual variation in wind generation (about +/-20% on shore; +/- 10% off-shore)
- Less variation in total demand (about 5%) because the weather driven component of electricity demand is small (in scenario)
- Large variation in storage required. **For a 700 TWh/a demand/supply system around 70 TWh of storage** is required, i.e. 10% of annual demand. Storage can be a mix of heat, EV batteries, chemical, biomass, fossil etc.



Some (electrically connected) storage options for system management

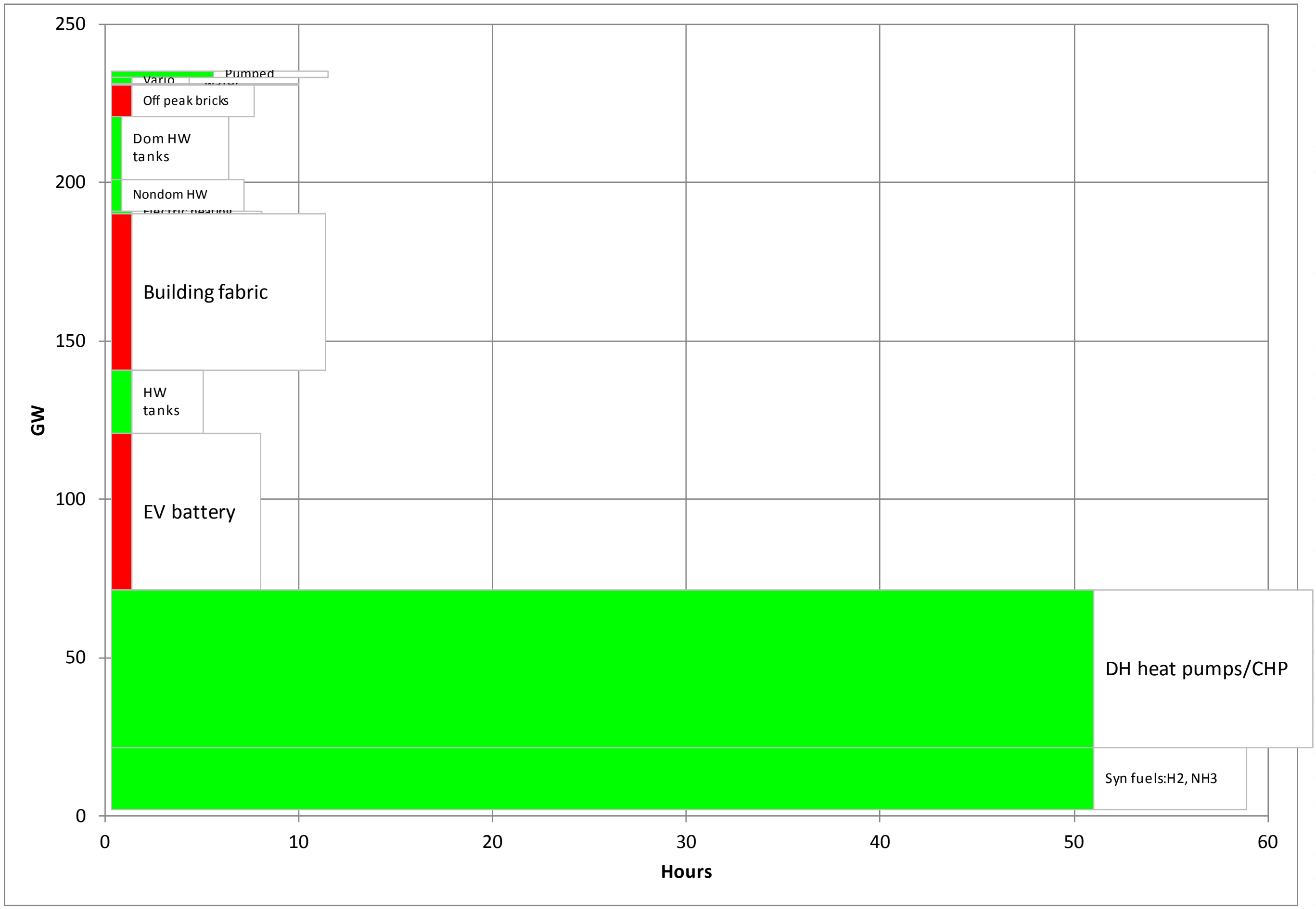
- for UK, excluding bioenergy and fossil energy stores

Potential storage with upwards of 200 GWe power and 5 TWh energy.

Ammonia/hydrogen and district heat stores can be very large.

System electricity storage (batteries etc.) relatively costly and inefficient.

Power (GW) and time (hours) energy storage potential



International trade

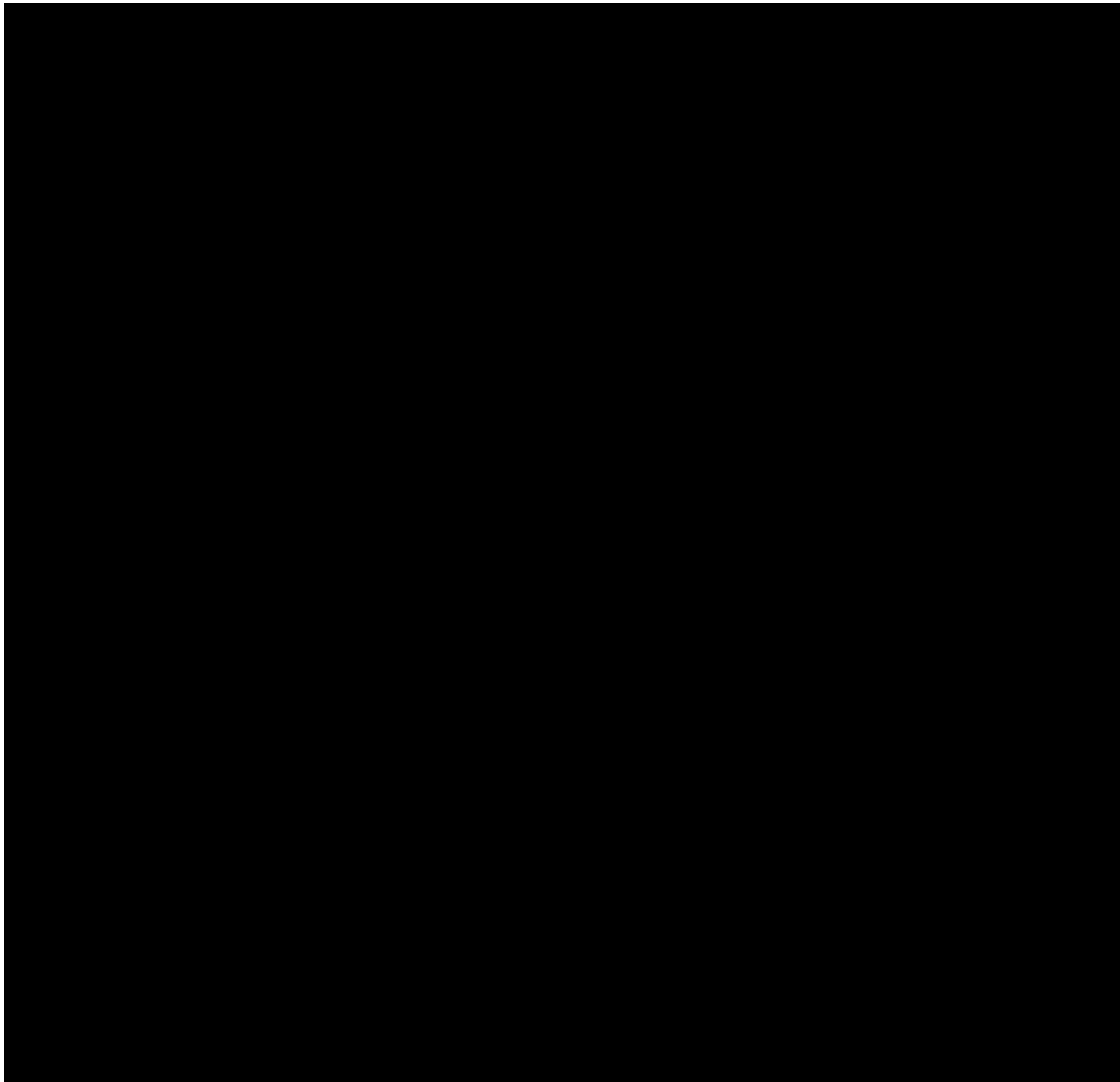
Transmission evens out the variations in demands and renewable supplies so that the demand-supply matching problem is reduced and less storage is needed.

The UK now has 4 GW interconnection, and another 8 GW is planned, so perhaps 12 GW by 2025.

How will international trade flows vary hour by hour? Need to model all the countries/regions.

What can we rely on importing in time of need? And exporting in time of surplus?

What is the best balance between storage, transmission and trade?



What is the best balance between storage, transmission and trade?

System consists of :

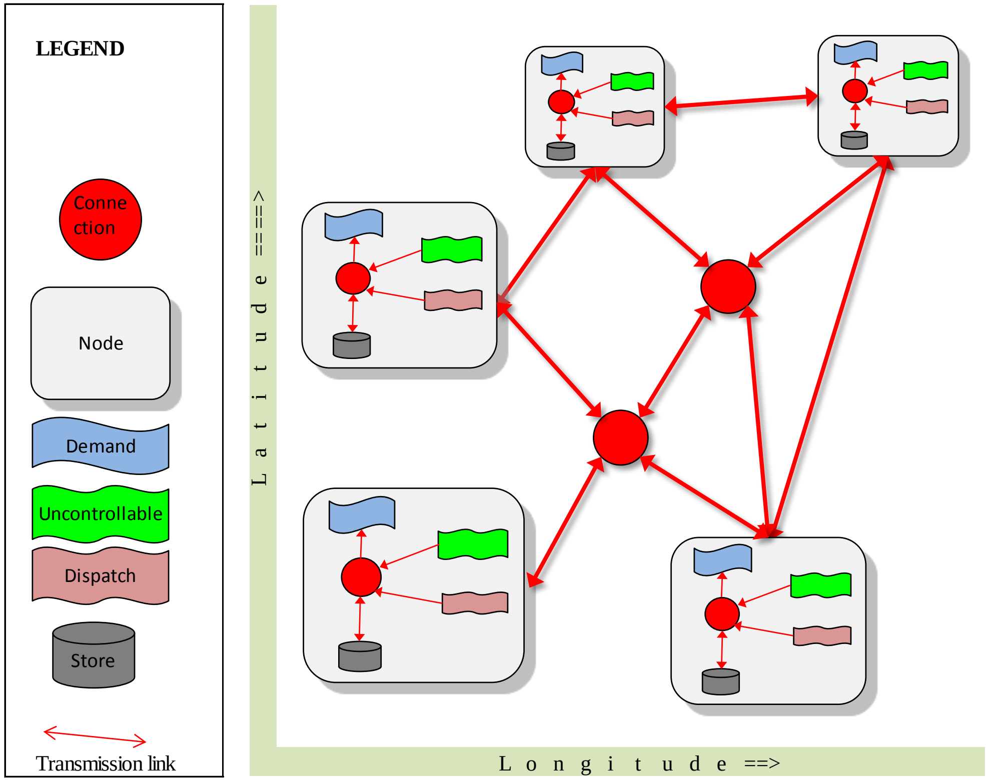
Nodes with

- Demands – heat and electricity
- Intermediate conversion – district heating, heat pumps…
- Renewables variable uncontrollable
- Renewables dispatchable (hydro, biomass)
- Stores – heat and electricity

Transmission links with certain capacity (GW)

Nodes can be individual countries or groups of countries.

The further apart nodes are, the more meteorology, demands and renewables are 'smoothed' so less storage is needed.



What is the best balance between storage, transmission and trade?

First scope – Europe, but databases global

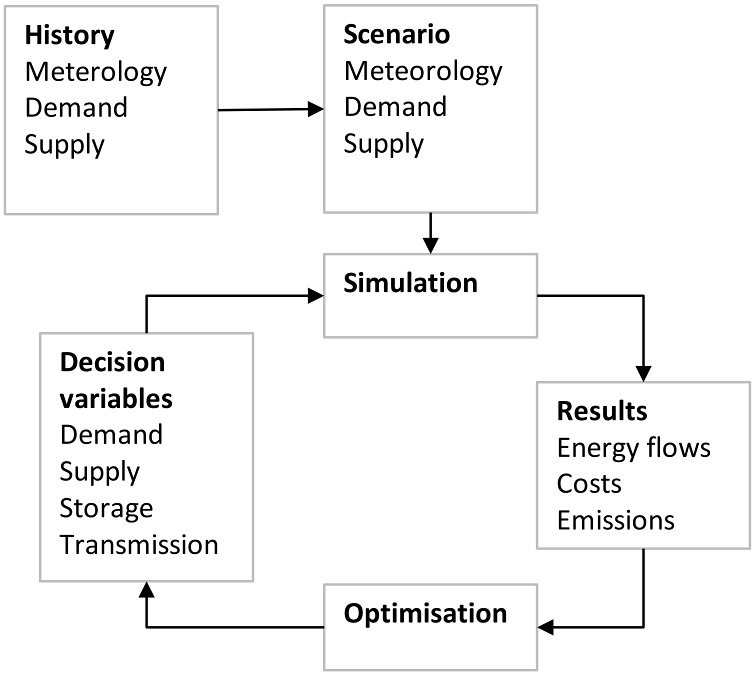
A. For each country

1. Collect hourly meteorology and renewable resource
2. Collect base year data for demand and supply
3. Project scenario demands
4. Project initial generation, storage and transmission capacities

B. Optimise – iterate simulation changing decision variables (generation, storage and transmission capacities) to find least total capital and running cost of system

For each country, for each hour across year, simulate:

1. demands using social activity patterns and meteorology
2. uncontrollable renewable energy – solar, wind
3. flows to country demands
4. flows to country stores of heat and electricity
5. flows from countries with surplus to countries with deficits
6. generation by dispatchable sources (hydro, bioenergy) to meet remaining deficit

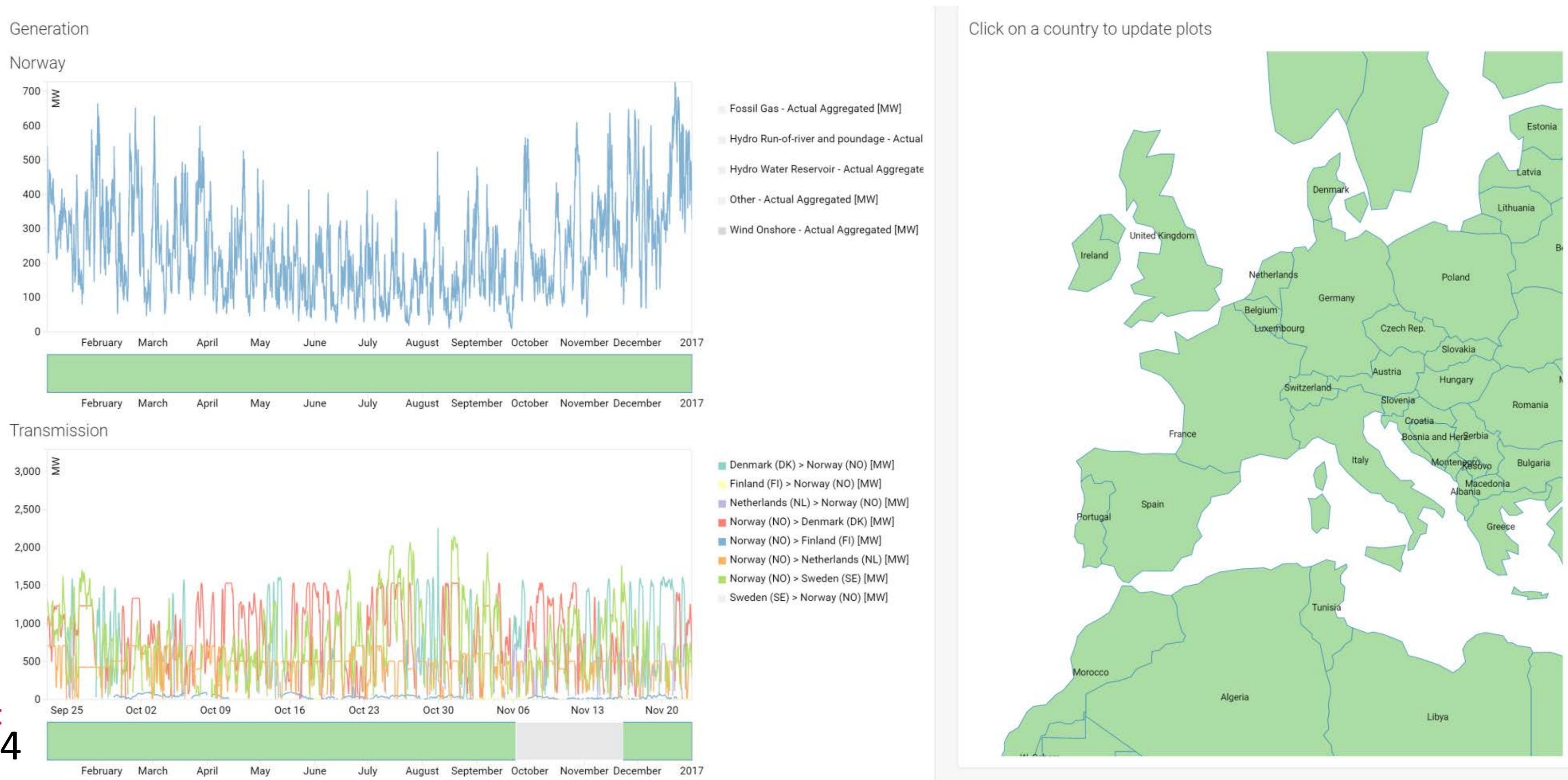


Simulate and optimise for different weather years to find extreme weather that stresses the system

Country by country data

Historical hourly generation and trade

Example: Norway



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Bioenergy

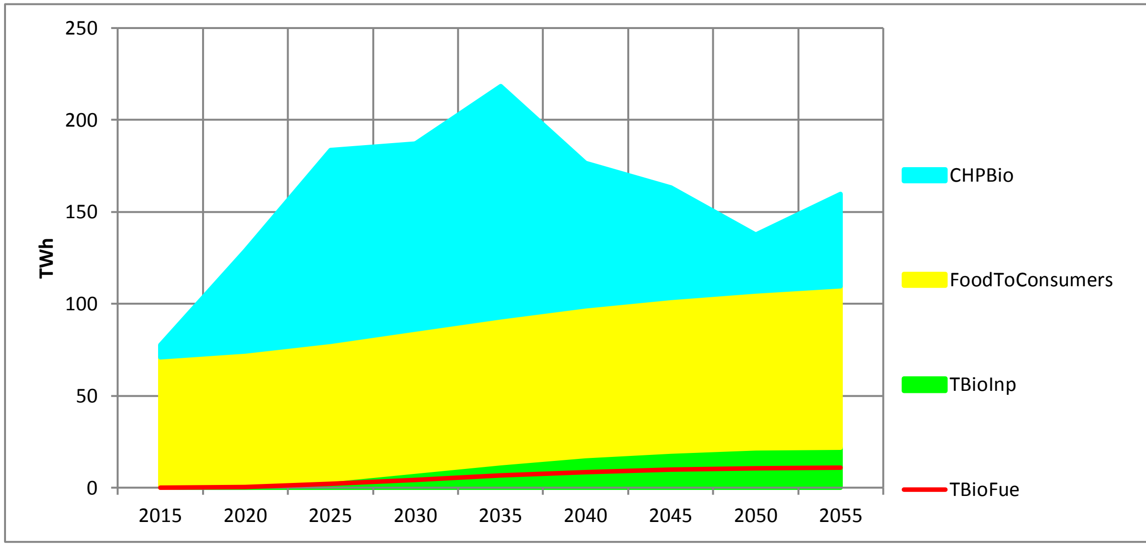
Bioenergy is a premium renewable:

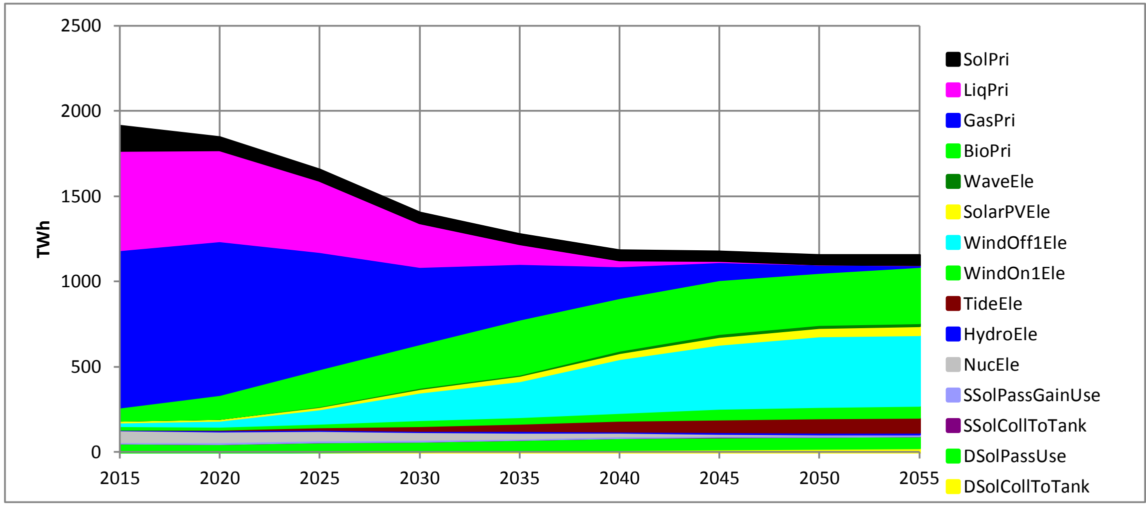
- Has carbon (!) and can be used to make liquid transport fuels
- Has integral energy storage and may be a critical component of high renewable systems

But:

- Can compete with food production
- Has complex environmental impacts
- Is scarce, e.g. UK waste bioenergy perhaps enough to make <50% aviation fuel
- Causes combustion and othr emissions

UK bio and primary energy scenarios





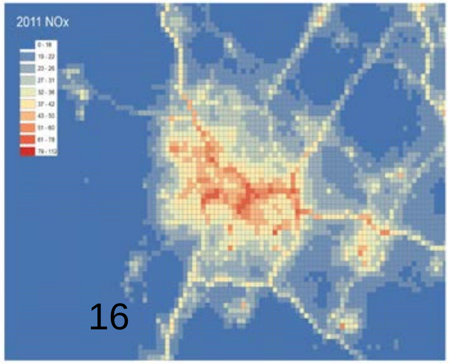
Non CO2 global warming: aviation, methane and biomass

Global warming (NB different time horizons) from:

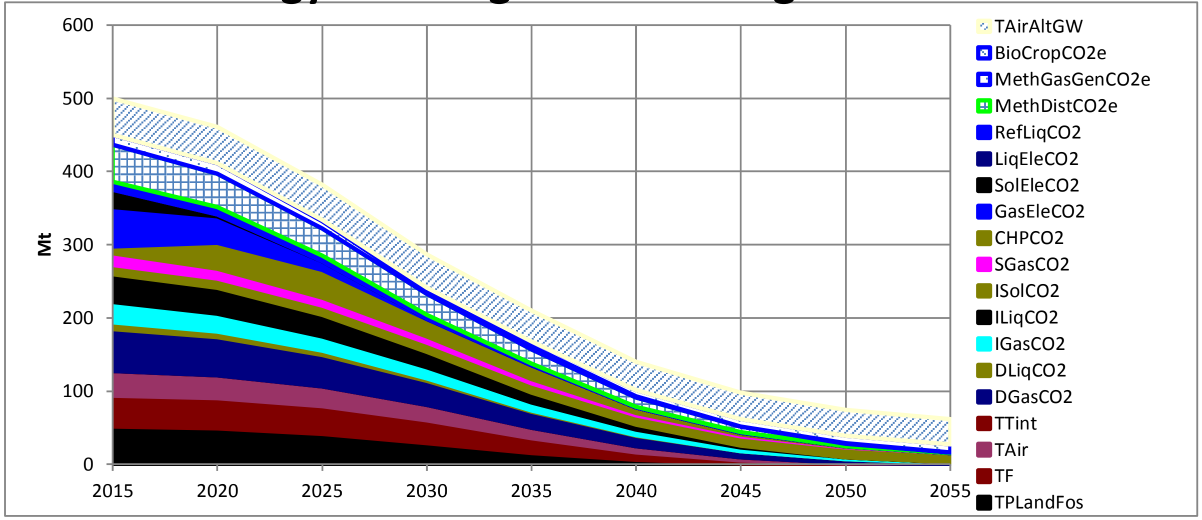
- high altitude aviation
- Natural/bio gas leakage (pipe, LNG, flare, etc.)
- bioenergy (sequestered carbon loss, CH4, N2O, etc.)

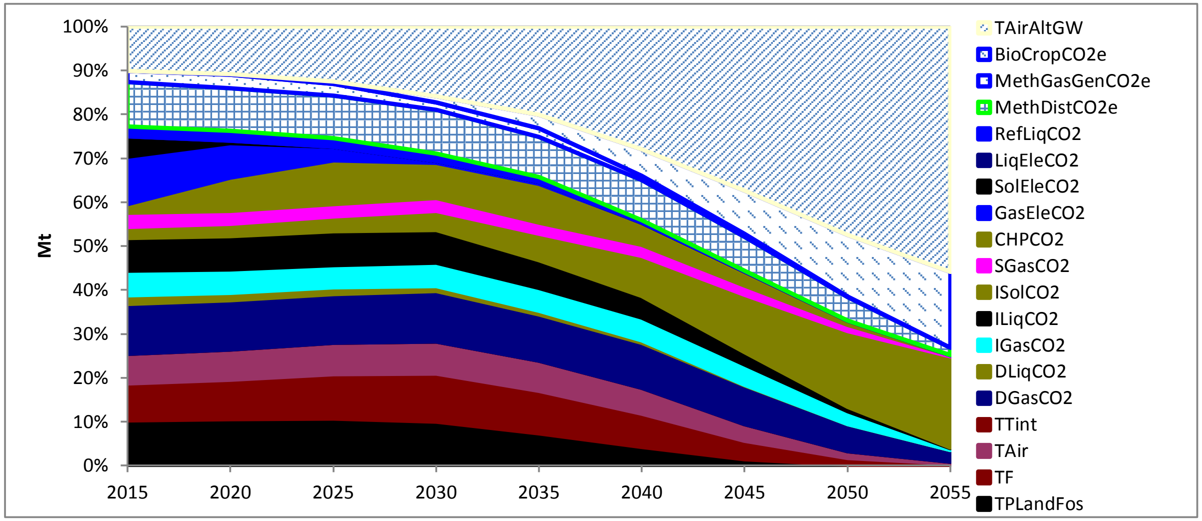
Very uncertain but a significant fraction of total GW, perhaps 50-70% in low carbon scenarios.

(And aviation growth will make it difficult to control air pollution around airports.)



UK energy related global warming scenarios





Development

Implications for air pollution from fossil combustion

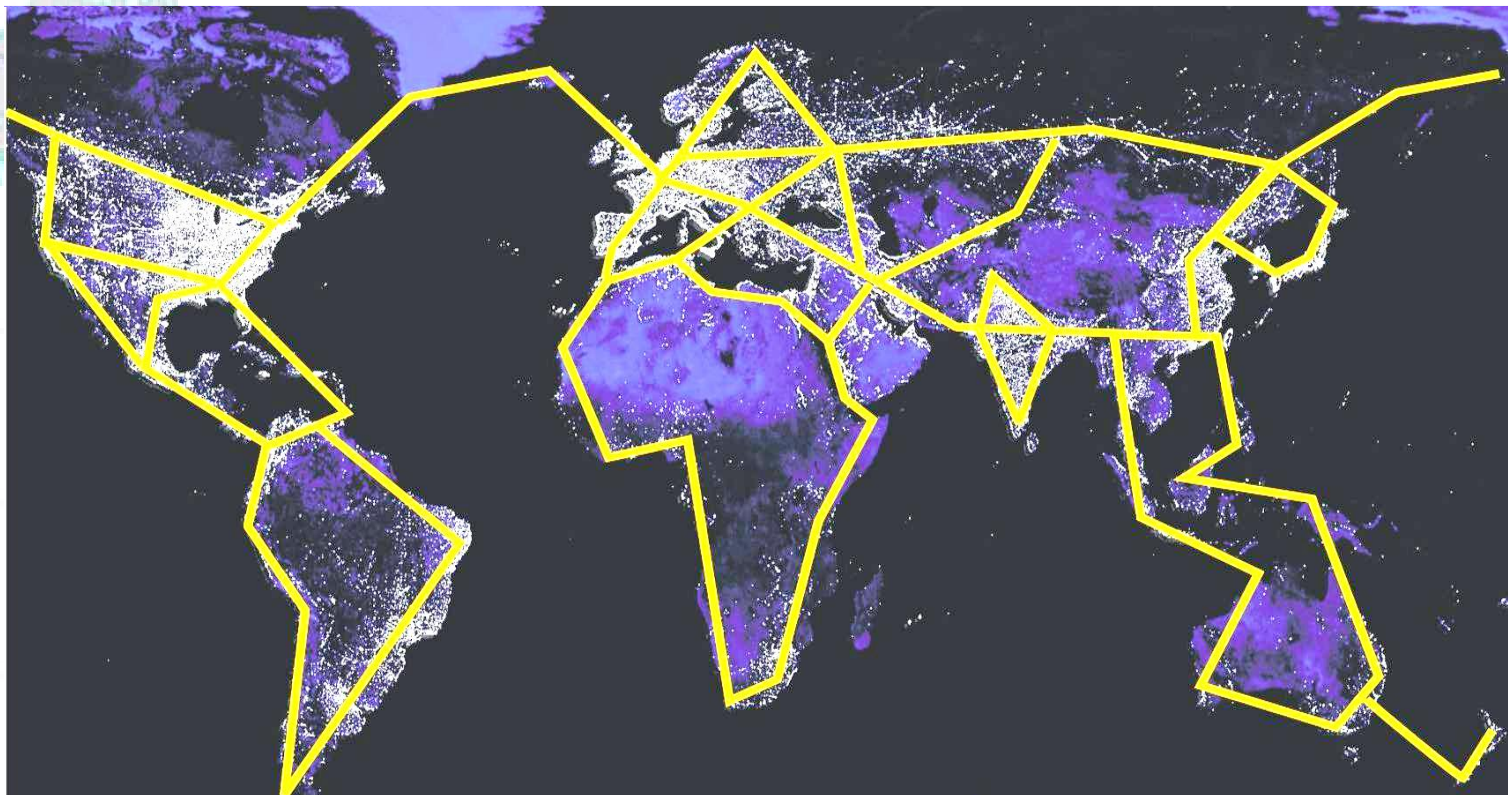
1. General reduction in annual emission

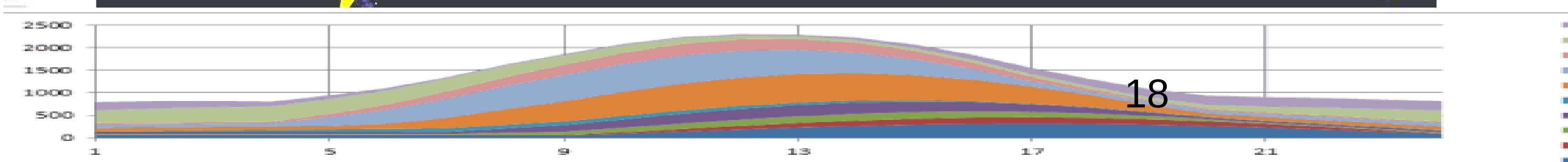
2. Emissions will be more variable in space and time (hours to seasons) as dispatchable bioenergy is used to when other renewables low, so relatively high energy related emission episodes might remain

3. There will be correlations between meteorology, and demand, renewables and atmospheric pollutant processes

How long might the cables be?

- Regular east-west diurnal, and seasonal, variations in demands and renewables
- Match varying demand and supply with transmission as well as storage
- Energy exchange enhances political security





DynEMo

Designing a national renewable energy system

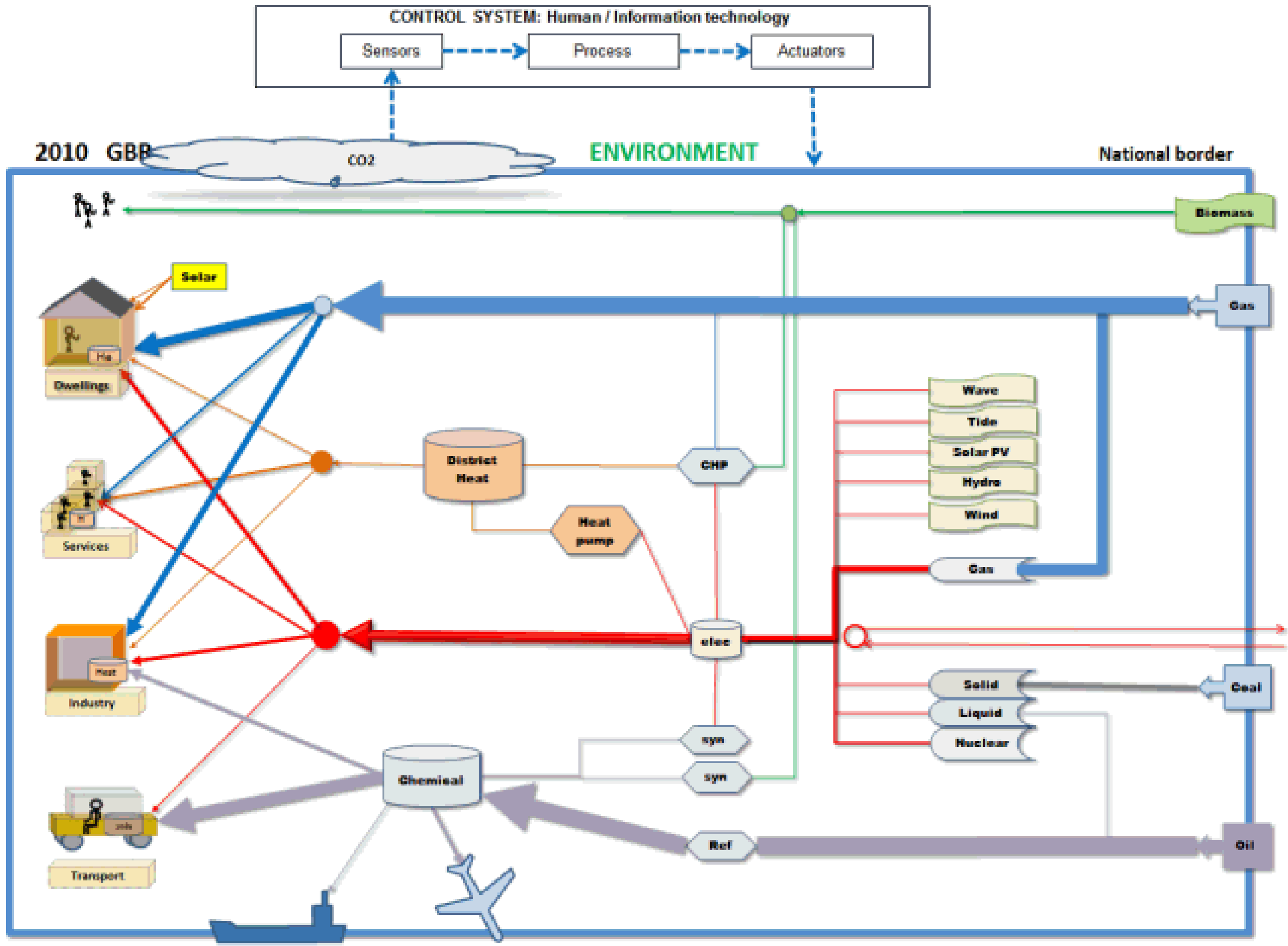
A system which will operate hour by hour across the days, months and years.

1. Demand

2. Supply

3. Integration

4. Operation

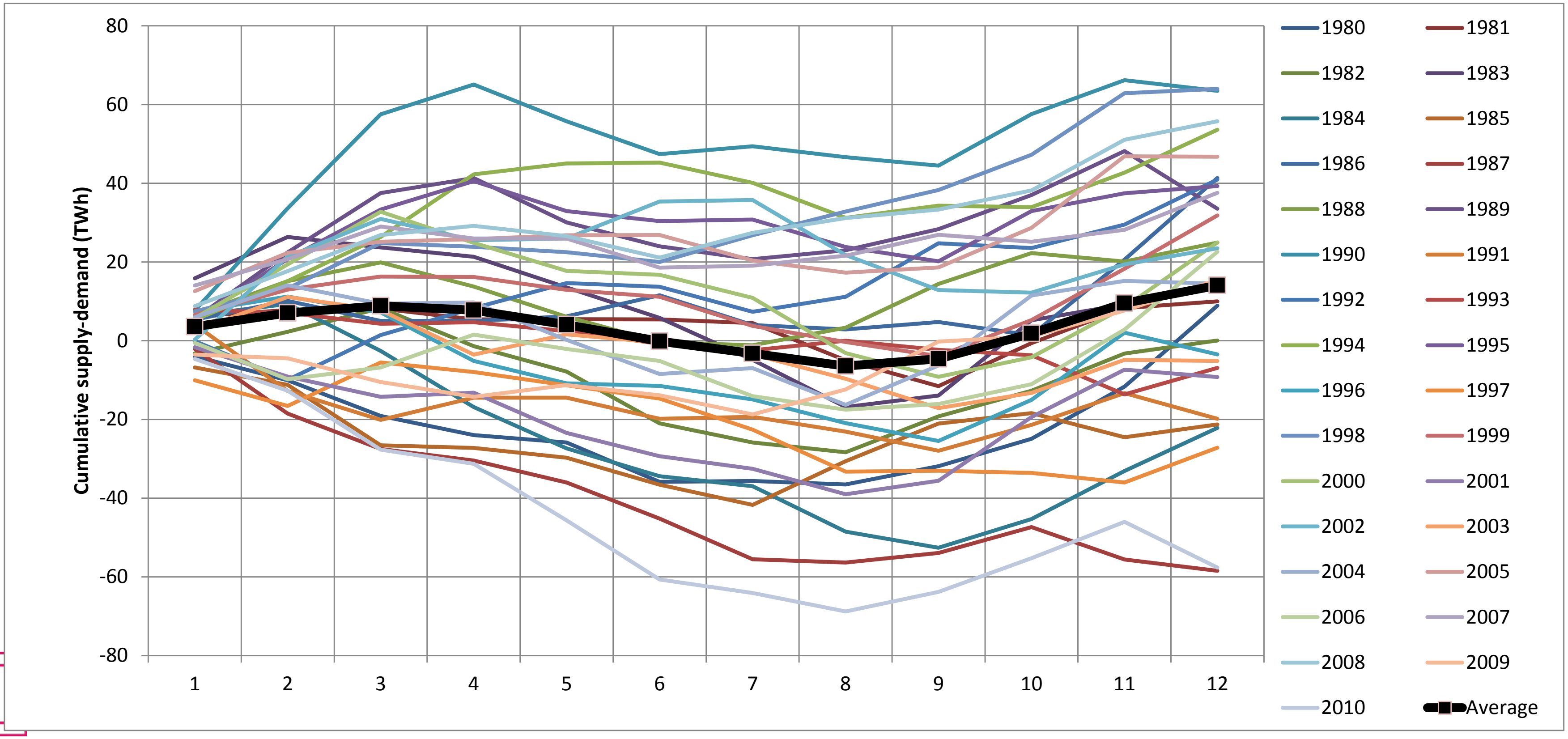


Energy system dynamics: simple hourly model

Monthly cumulative supply-demand variation for each of 31 years

(Modelling based on 31 years of hourly meteorology and wind power generation from Dr Ed Sharp)

Considerable monthly variation in cumulative supply-demand resulting in minimum and maximum of about -/+ 70 TWh, or 10% of annual demand.

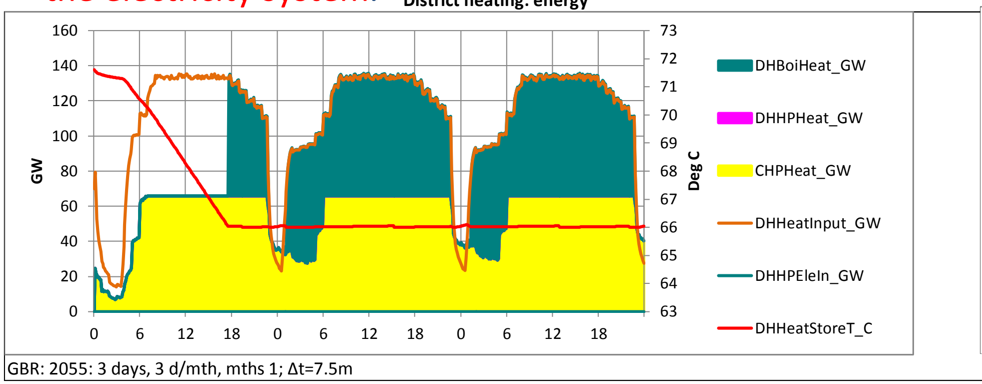


DynEMo

Electricity system stress examples over 3 days

WINTER-5 oC. No wind, no trade.

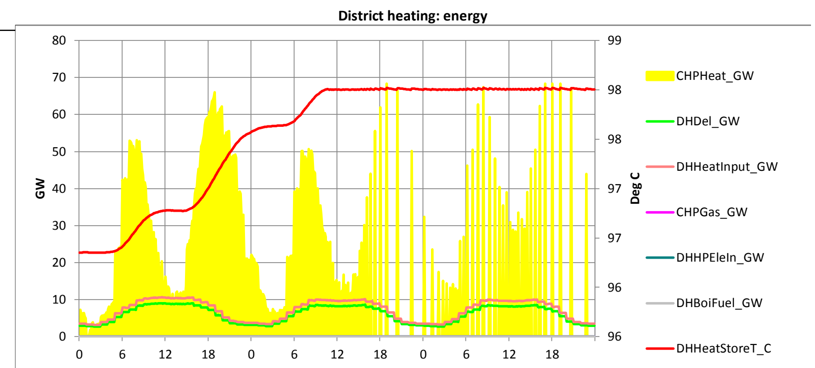
DH: CHP at maximum. Boiler used when DH store empty and more heat required – gas heating used to manage the electricity system.



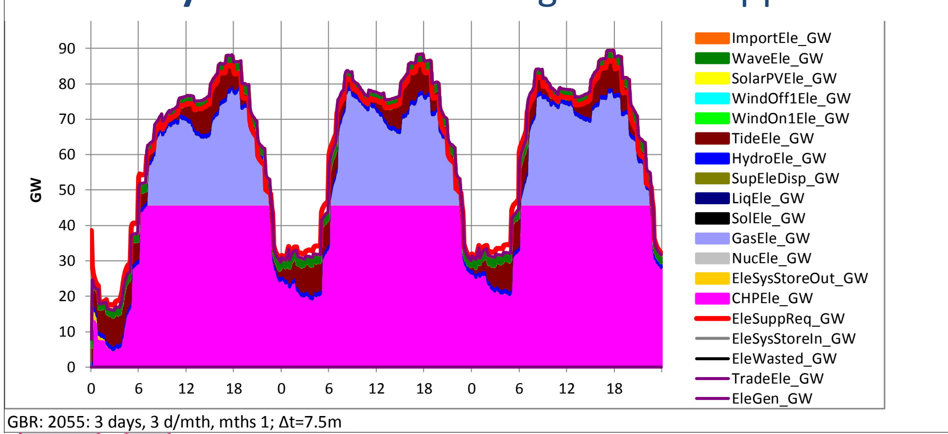
SUMMER. 35 oC. No wind, no trade.

DH: CHP fills store to maximum then just tops up.

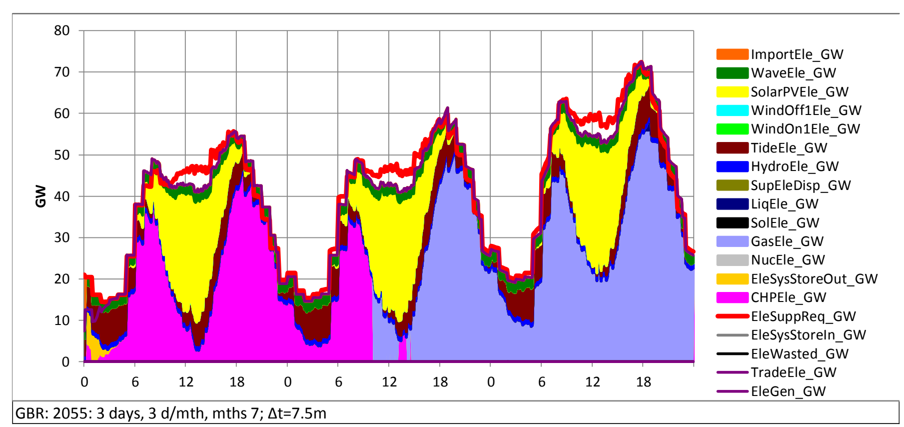
What if DH were used for cooling?



Electricity: bio CHP and fossil gas main supplies.



Electricity: Solar, CHP then fossil gas when DH store full



Conclusions

- It is possible to design 100% renewable systems that will function hour by hour in different meteorological conditions.
- Detailed spatiotemporal modelling is needed to explore functioning systems.
- There is abundant renewable electrical energy potential. If demand is higher then renewables, storage etc. can be scaled up.
- Biomass energy resources are uncertain and may be insufficient for aviation.
- Risky, irreversible nuclear is unnecessary and fossil CCS is insufficient for near zero carbon.
- District heating and synthetic fuels have important management roles through storage and multi-fuelling.
- Aviation growth is probably incompatible with UK climate change mitigation targets.

Thank you for listening.

Questions?