Renewables: variation and storage

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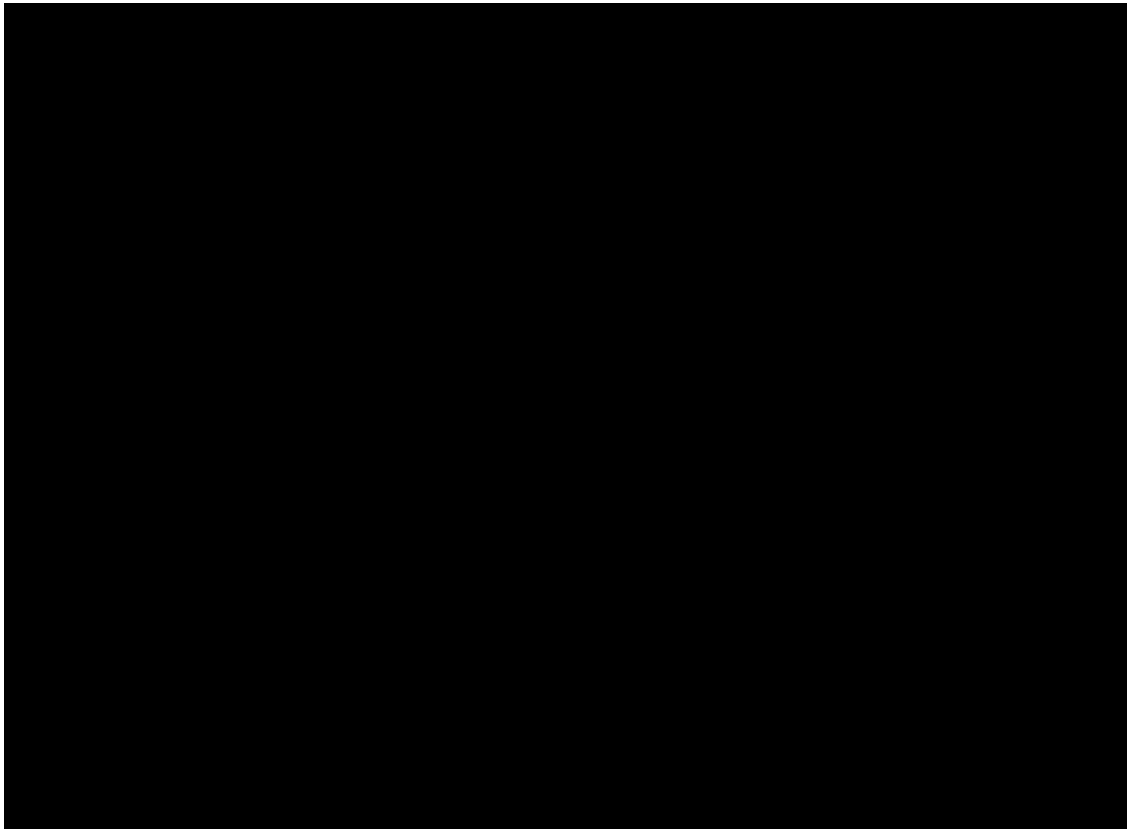
TFIAM, Brescia
8 May 2018

(run presentation to see animations)

Realising Energy Storage Technologies in Low-carbon Energy Systems (RESTLESS)

EPSRC Pioneering research and skills

UKERC UK Energy Research Centre

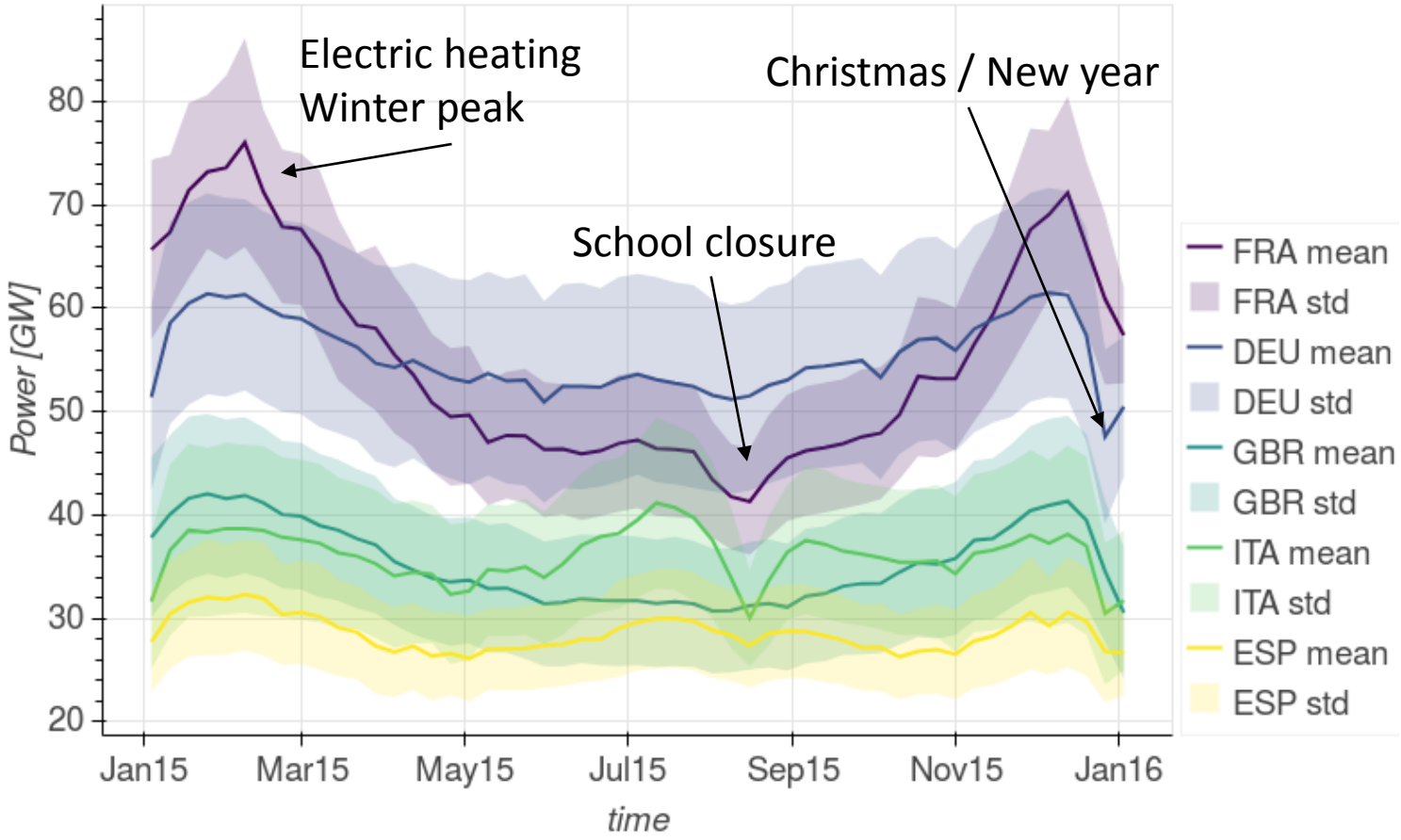


Renewables: the power, the glory, the caprice

- Wind and solar: indefinitely large, low emission resource but outputs vary.
- Social patterns and meteorology drive variations in demands.
- How will demands and renewables vary at the same time?
- What is the optimal mix of storage and transmission for balancing demand and renewables?
- Demands and renewables will change with climate.

Historic demand/supply analysis

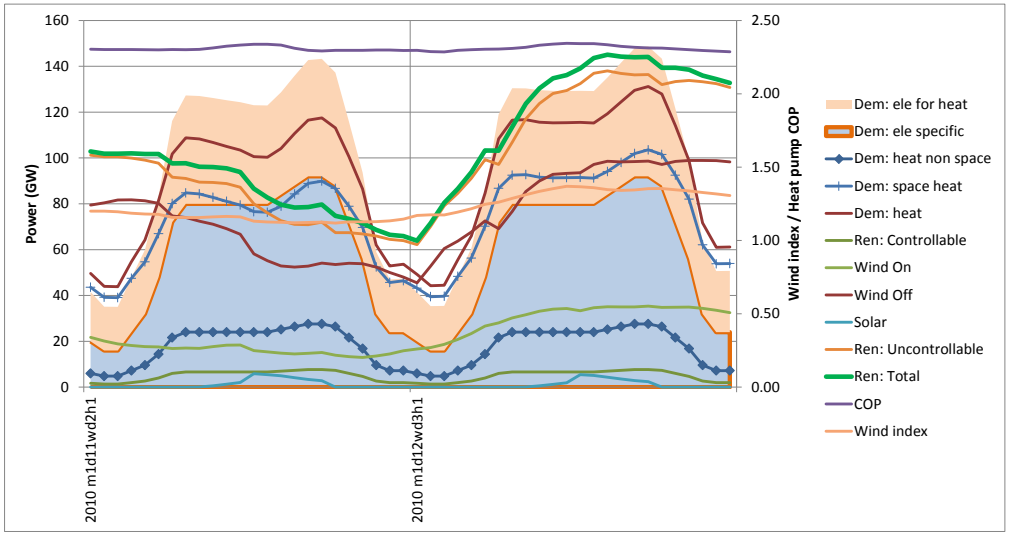
Weekly electricity demand in Germany, France, United Kingdom, Italy and Spain
Note air conditioning in Italy and Spain.



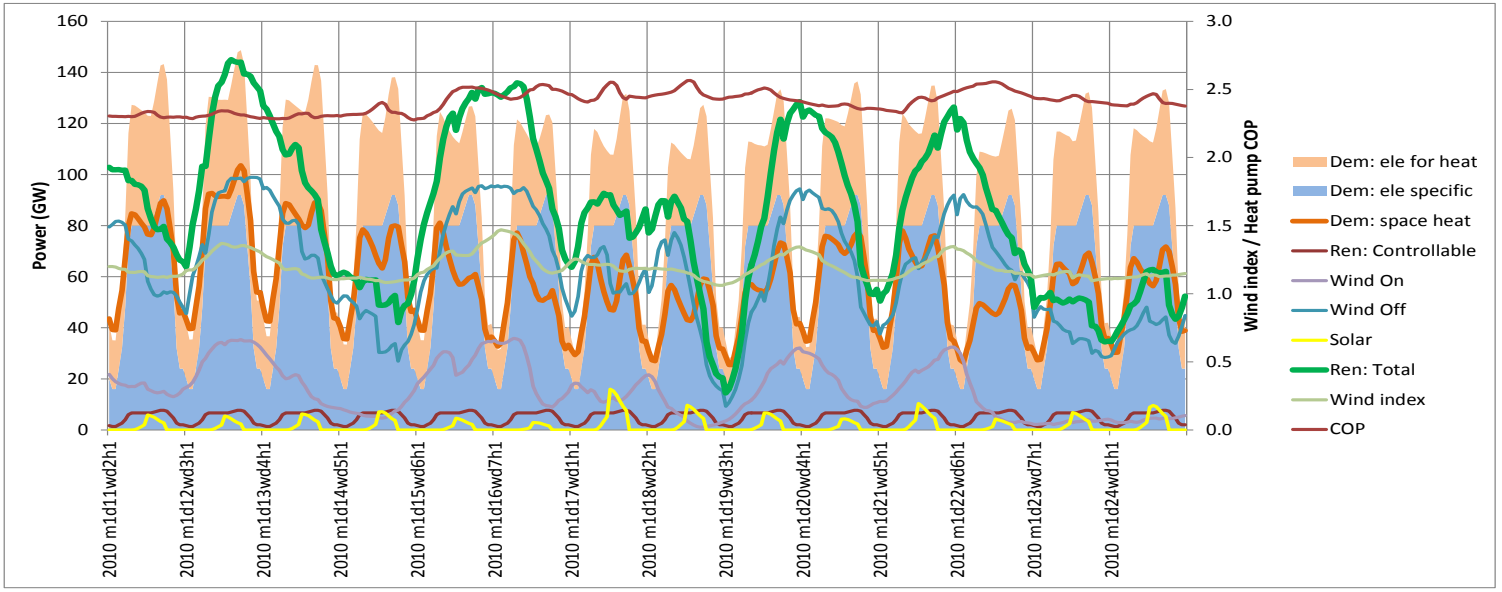
Energy system dynamics: simple hourly model

Sample 2 days and 2 weeks

2 days



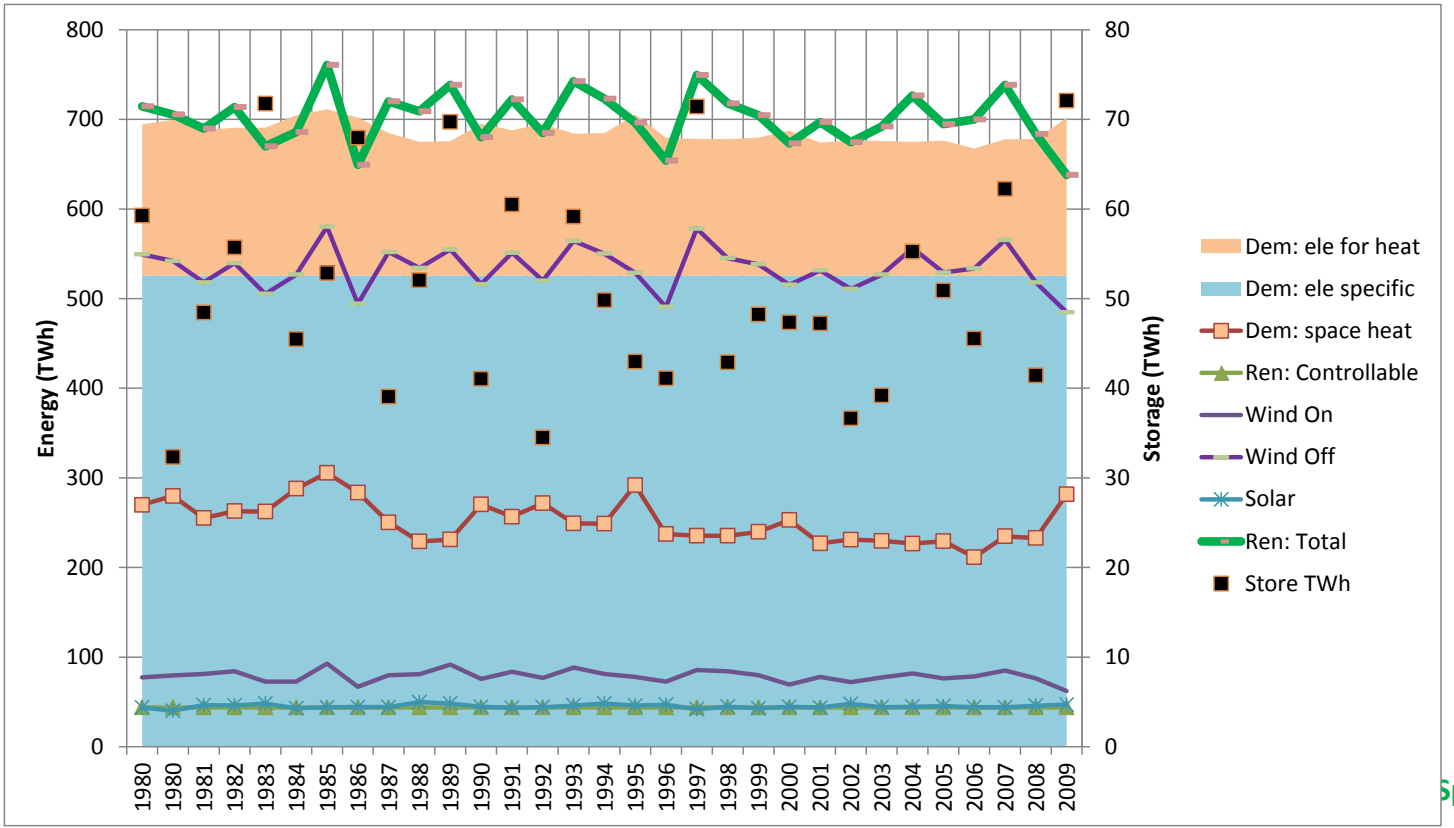
2 weeks



Energy system dynamics: simple hourly model

Annual demand and renewable supply variation over 31 years

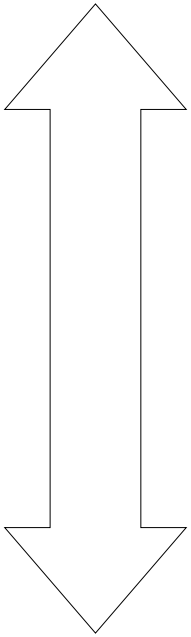
- Considerable inter-annual variation in wind generation (about +/-20% on shore; +/- 10% off-shore)
- Less variation in total demand (about 5%) because the weather driven component of electricity demand is small (in scenario)
- Large variation in storage required



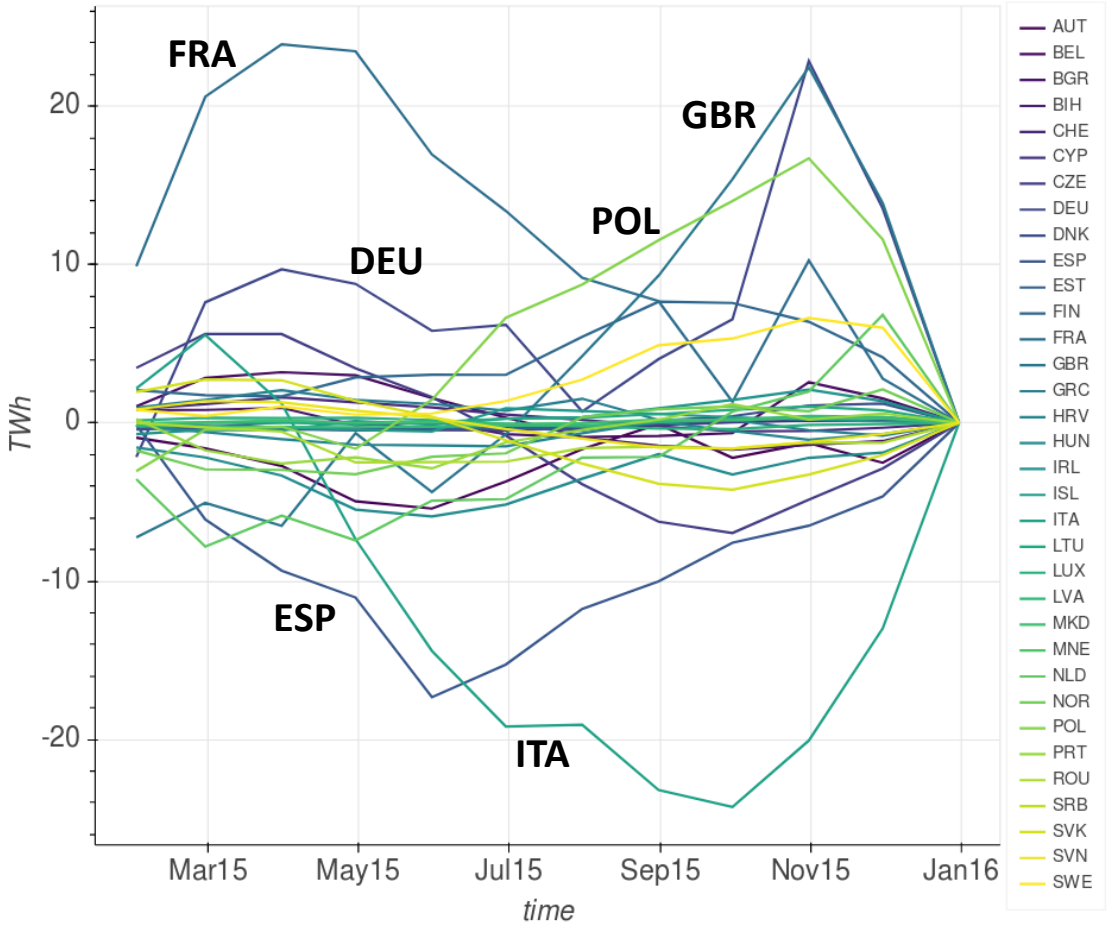
Historic demand/supply analysis

Monthly electricity cumulative residual demand assuming wind and solar generation (EU35, 2015)

Unmet demand



Generation surplus



Primary

coal

oil

gas

biomass

nuclear

Heat

Storage in energy systems

Service

Chemical

Electricity

Hydropower

Resource

Precipitation (rain, snow) onto heights stores potential energy.

Reservoir schemes

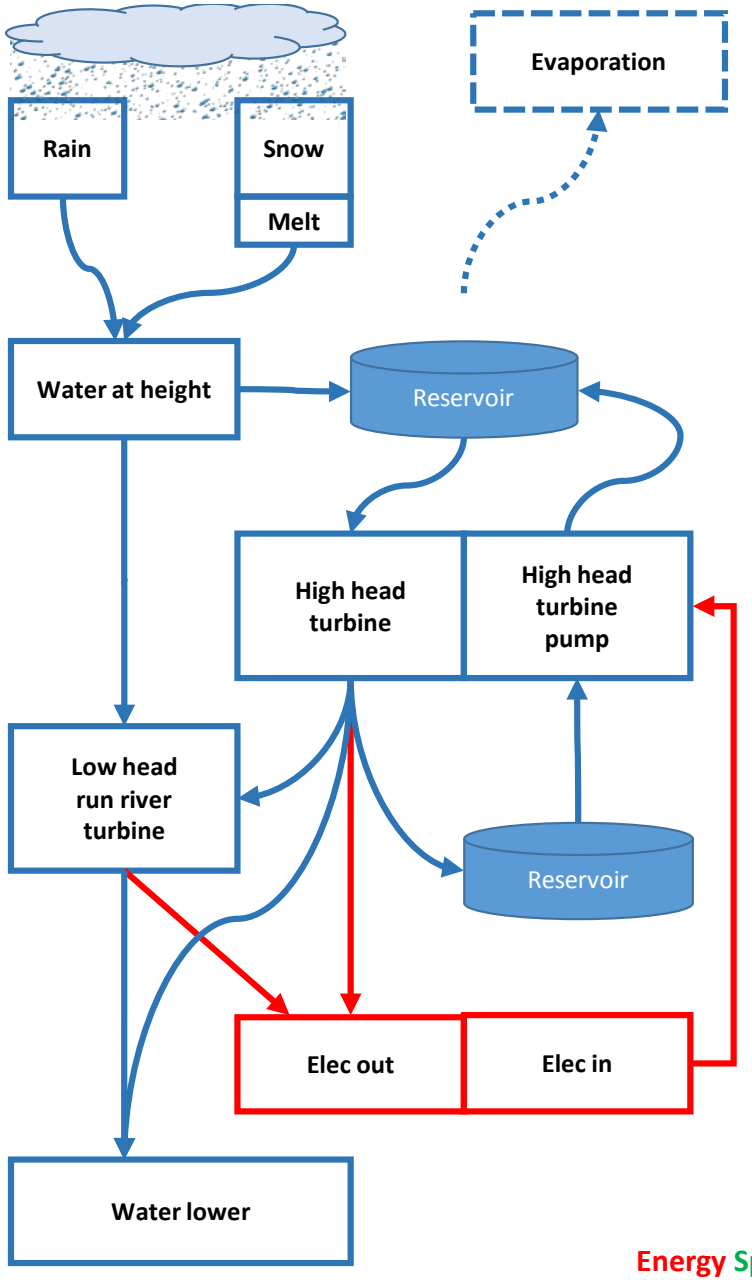
- Water may be stored in reservoirs and let out through turbines to generate – usually **high head** hydro.
- If water turbines are also used to pump water upwards for energy storage it is called **pumped storage**.

Run-of-river

- There is less storage and so generation follows upstream riverflow

There may be minimum required water flow and reservoir levels for many reasons:

- Environmental and ecological protection
- To meet water demands



Hydro

What are the correlations between hydro inflow/potential generation and:

- Precipitation?
- Ambient temperature (a demand driver)?
- Wind generation?
- Solar generation?

How much is hydro generation driven by demand, how much by inflow?

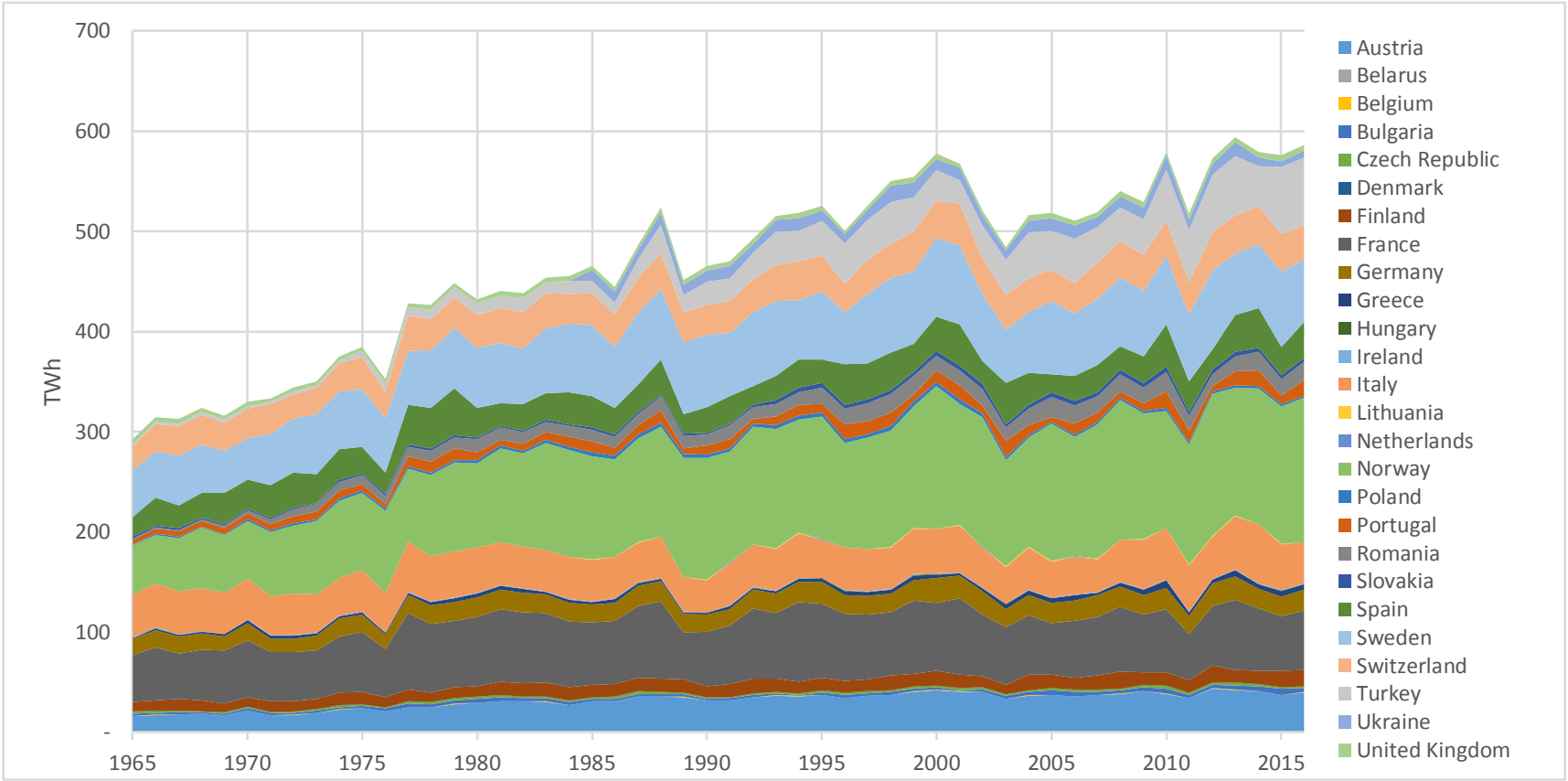
How does environment protection constrain hydro generation?

What extended/new hydro power plant might be built – once through or pumped storage ?

Hydropower annual variability - Europe

Large variation possible: a 16% fall 2000 => 2003

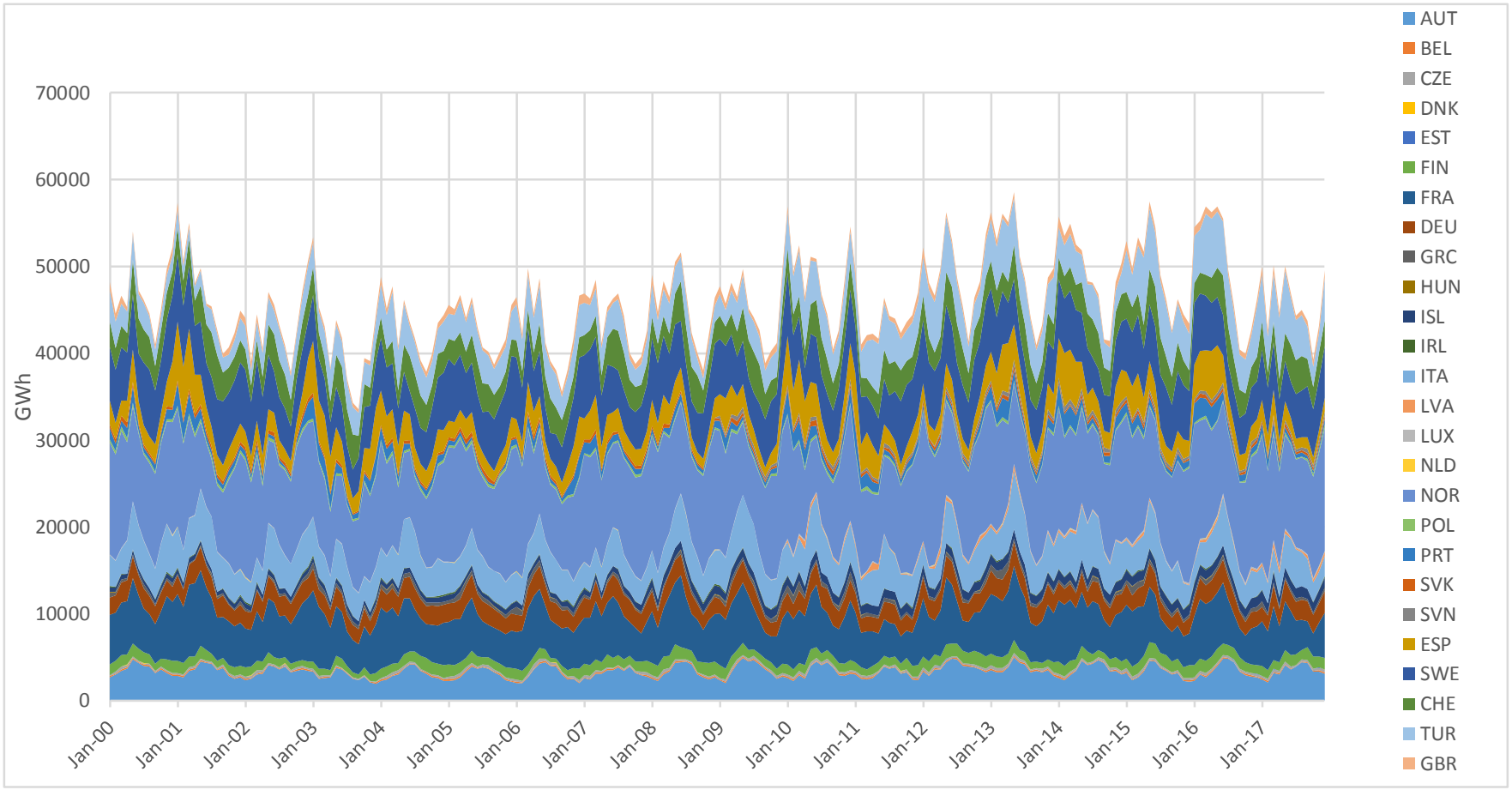
How much variation is driven by inflow – how much by demand?



https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

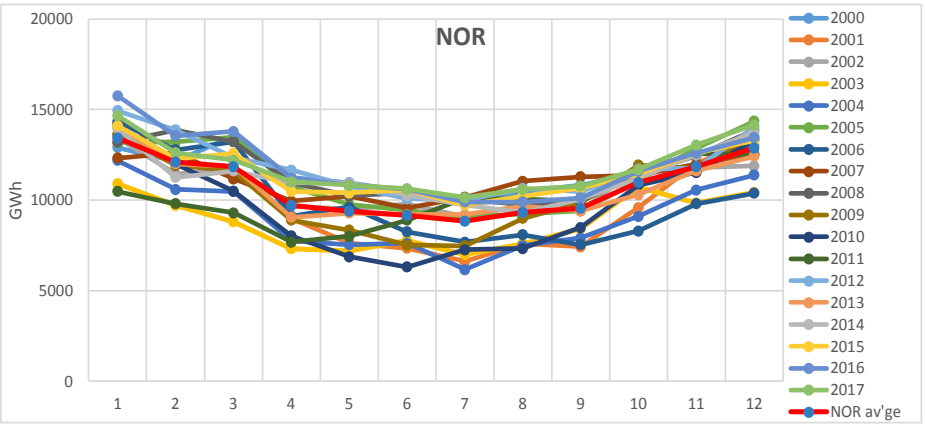
Hydropower - Europe monthly history

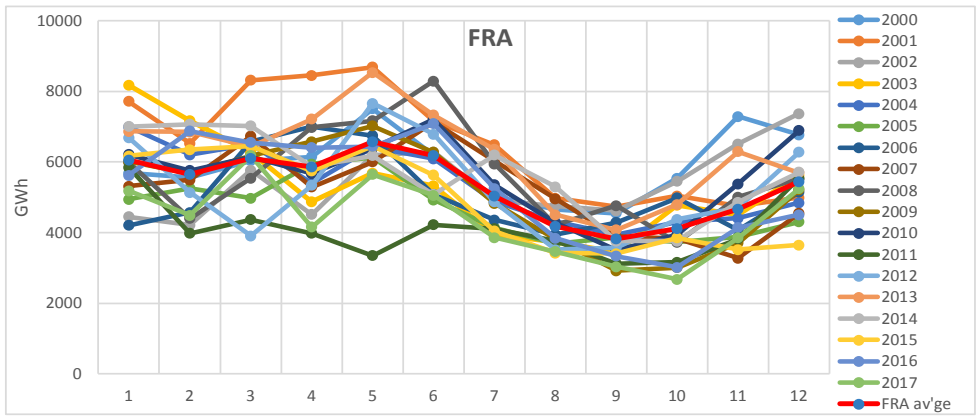
How much variation is driven by inflow – how much by demand?

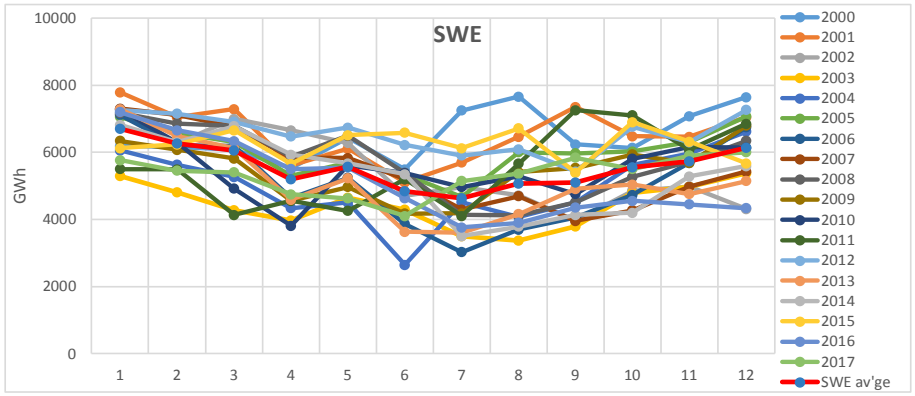


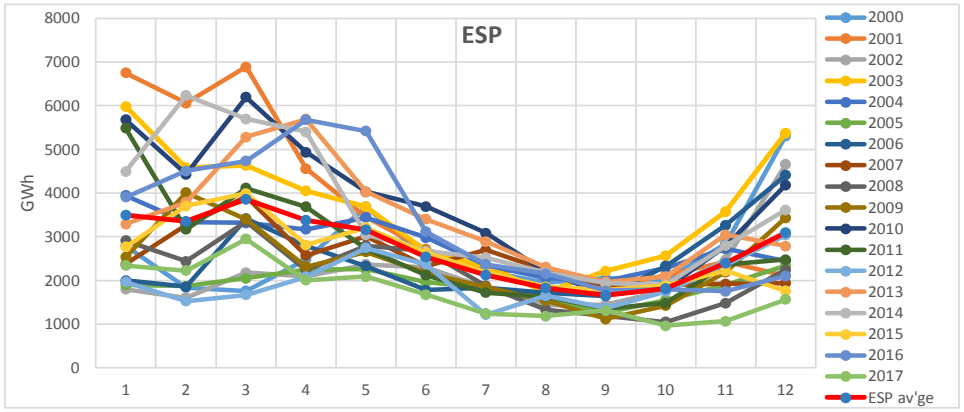
http://www.iea.org/statistics/monthlystatistics/monthlyelectricitystatistics/

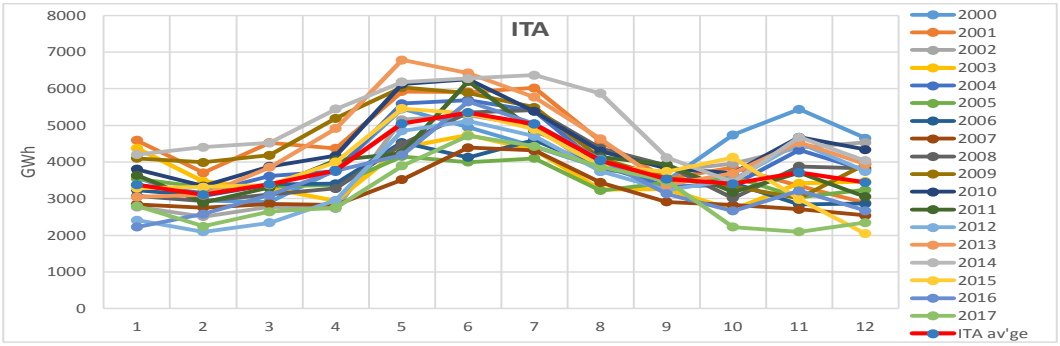
Hydropower - Europe monthly history











http://www.iea.org/statis
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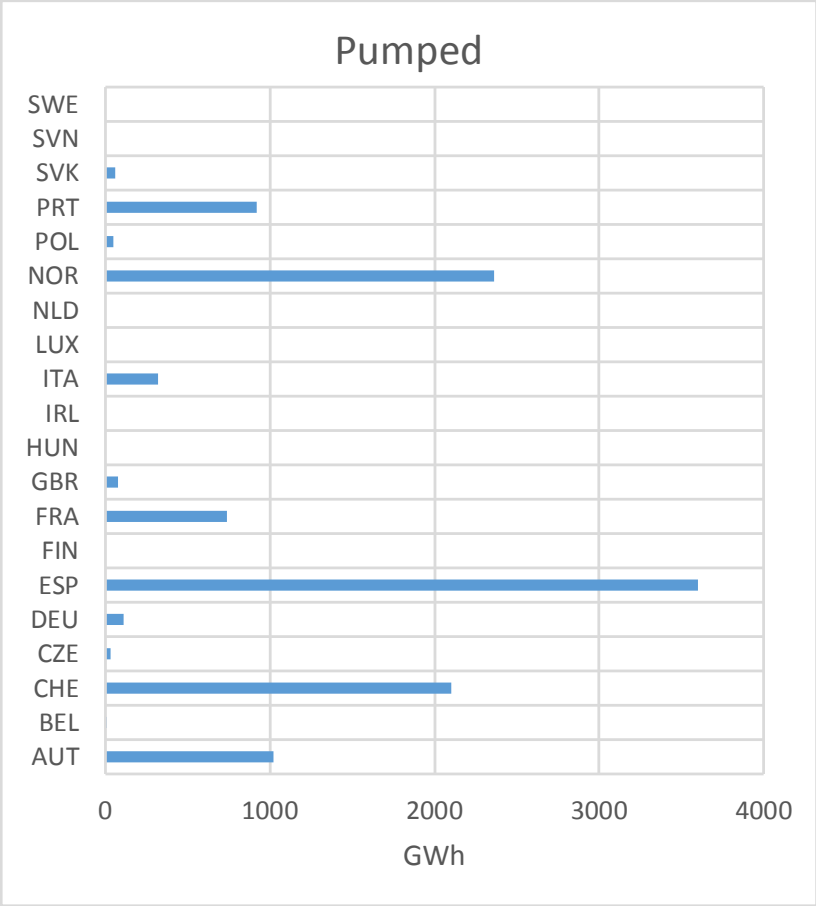
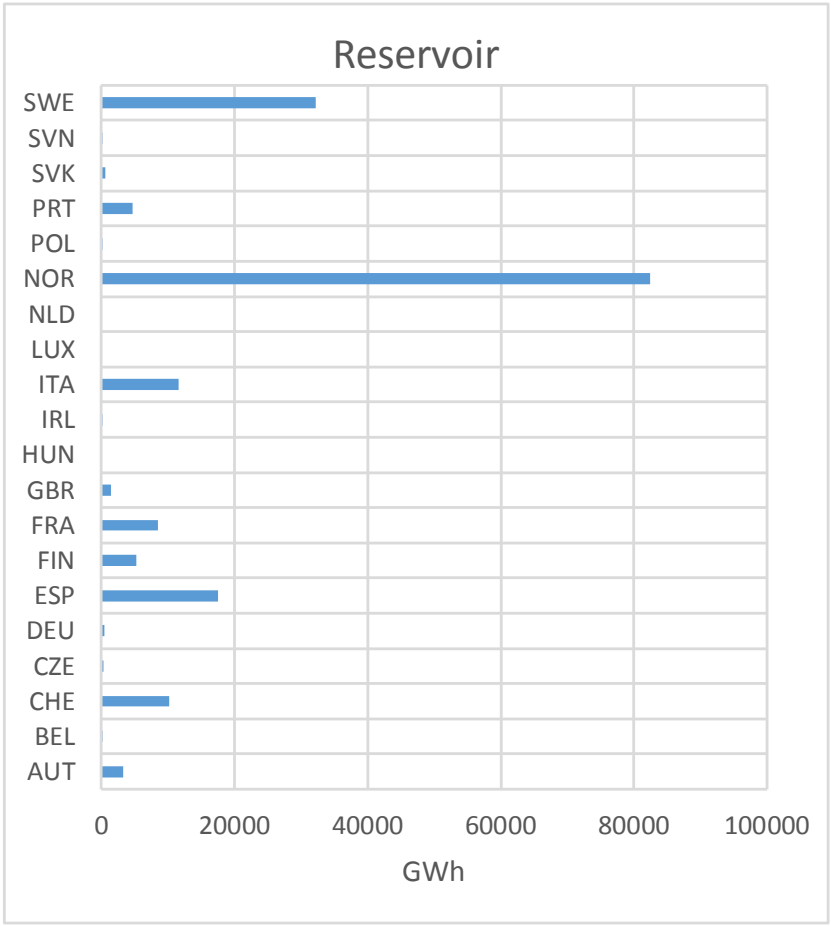
Hydropower - Europe storage

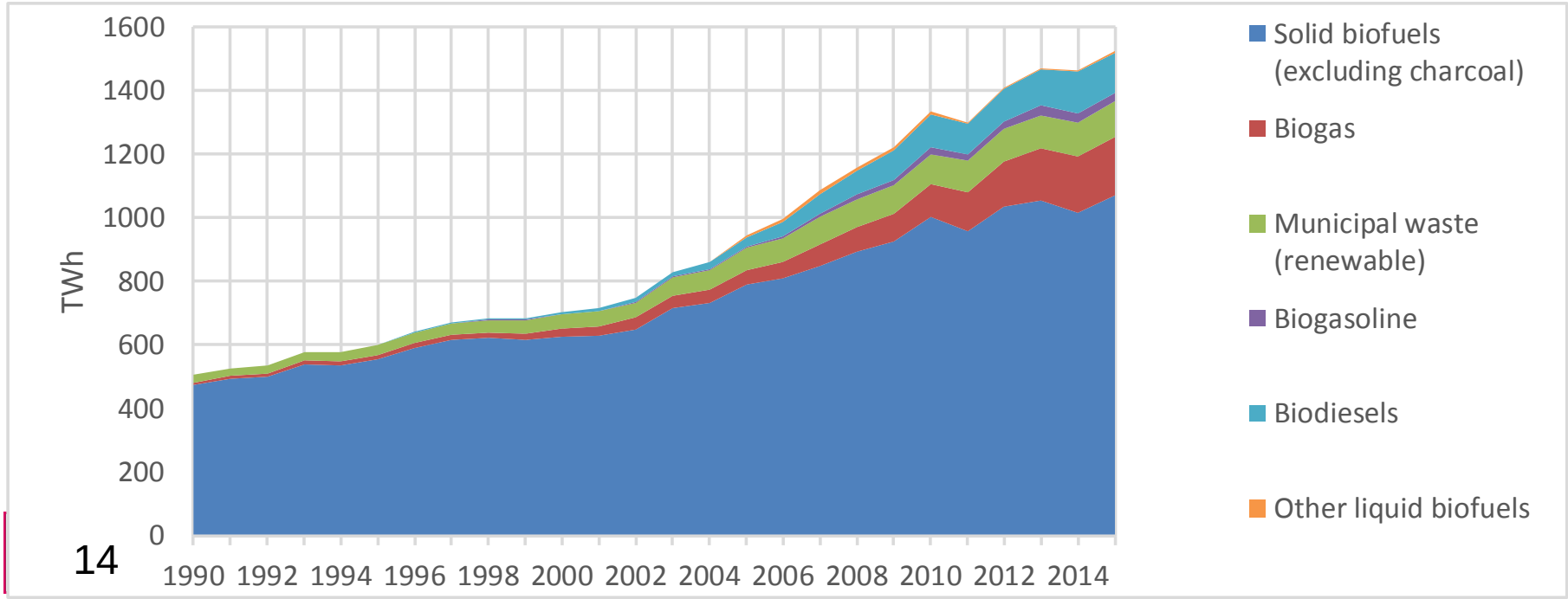
Once through reservoir storage ~30 X larger than pumped storage





Biomass production

What are the sustainable European resources of different kinds?
How will this change with waste management, biocrops etc.?
How can they be stored?
Does meteorology cause significant variations in annual biomass supply ?
How can the resources be best used for electricity, heat, biofuels?
What low emission bio-technologies are there?



Biomass – wood chip trade

Europe 2015
6.5 Mt imports

Is this sustainable?

Is it secure for the future?

	Production		Imports (1)		Exports (1)	
	2010	2015	2010	2015	2010	2015
	(1 000 tonnes)					
EU-28 (1)	7 898	16 050	2 576	6 476	70	206
Belgium	0	0	315	1 123	38	120
Bulgaria	7	112	1	48	8	158
Czech Republic	85	1 503	15	297	99	1 204
Denmark	0	:	1 443	2 176	35	79
Germany	1 744	1 998	270	674	740	699
Estonia	423	1 120	50	20	421	885
Ireland	28	40	12	0	0	0
Greece	0	0	0	:	0	:
Spain	184	350	13	28	5	40
France	449	1 050	144	310	231	299
Croatia	:	246	:	8	:	232
Italy	539	510	816	1 670	2	30
Cyprus	0	0	0	6	0	0
Latvia	615	1 643	9	131	589	1 630
Lithuania	205	275	44	91	213	339
Luxembourg	8	:	4	:	11	:
Hungary	0	:	43	:	12	:
Malta	0	:	0	0	0	0
Netherlands	120	289	1 024	160	135	187
Austria	686	1 055	231	490	397	595
Poland	429	1 462	34	79	69	366
Portugal	486	1 038	64	66	550	695
Romania	175	730	3	9	165	395
Slovenia	65	115	45	181	42	148
Slovakia	87	100	4	45	38	100
Finland	177	302	11	65	109	69
Sweden	1 386	1 660	697	381	117	460
United Kingdom	0	343	551	6 548	60	88
Norway	45	95	14	481	1	1 298
Switzerland	0	160	:	90	:	2

Note: for Member States, both extra-EU trade and intra-EU trade are included
(1) Extra-EU trade for the EU-28 aggregate.
Source: Eurostat (online data code: for_basic)

Hydro and biomass

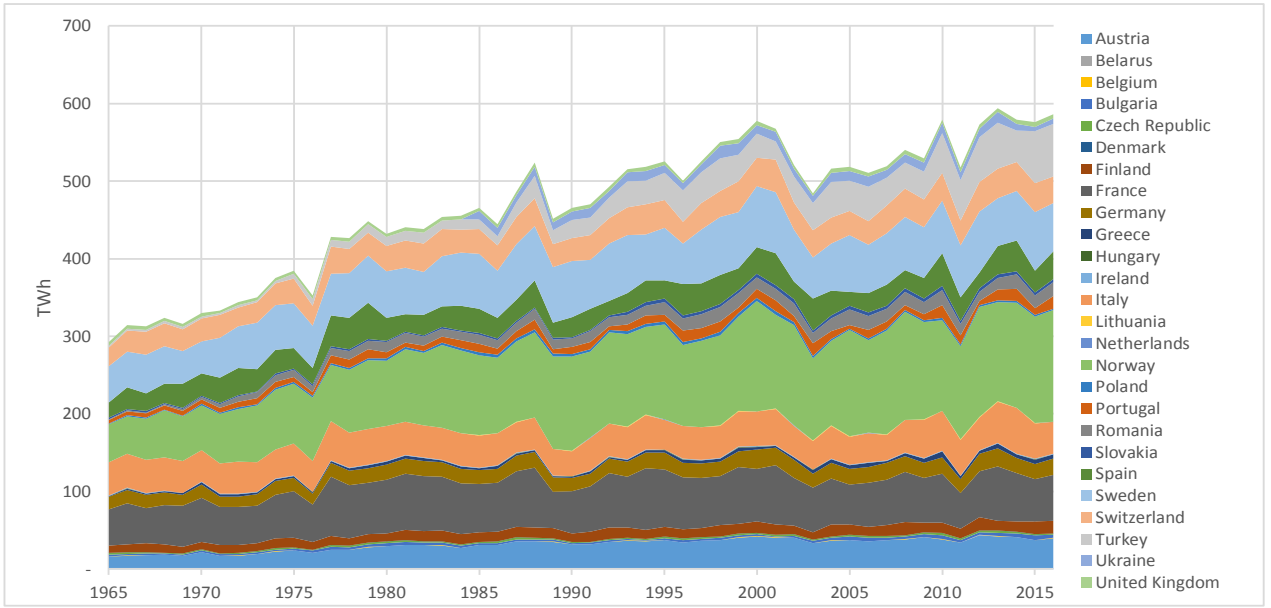
What are operational constraints on hydro and biomass?

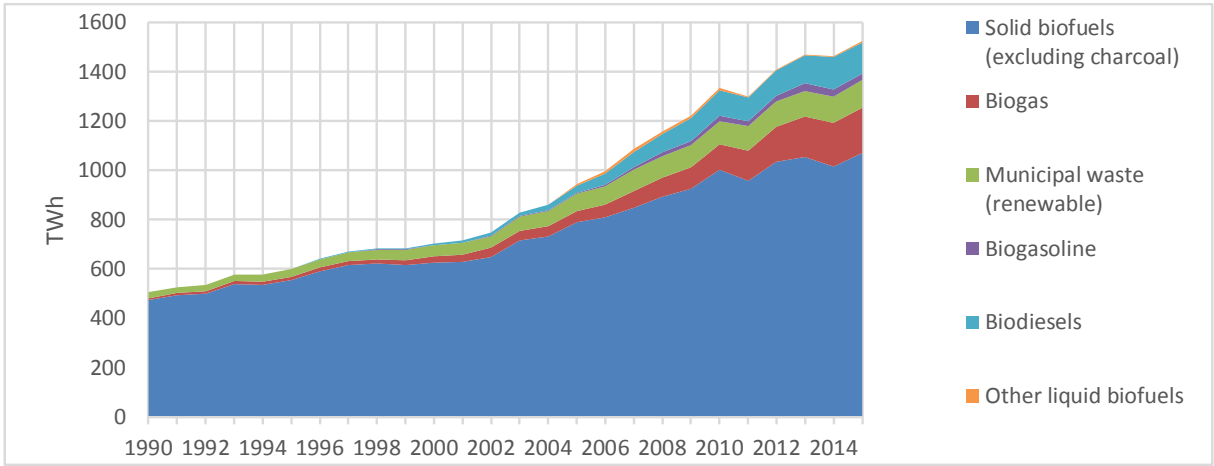
What are correlations with wind and solar?

Possible to design 100% renewable systems with storage and transmission.

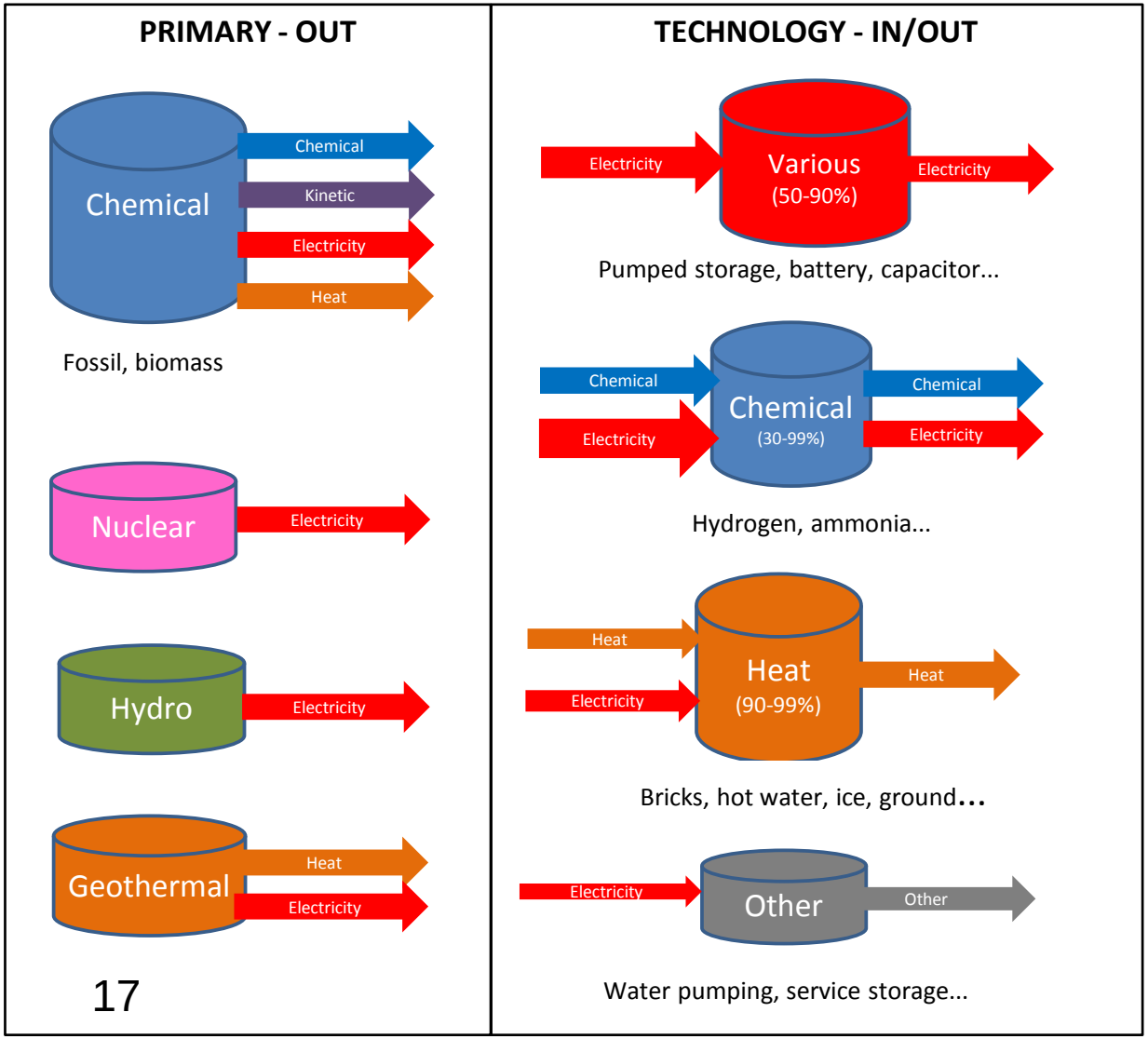
Renewable power and fuels for buildings, industry, road and rail transport, ships.

But what about aviation and cement?





Some storage types



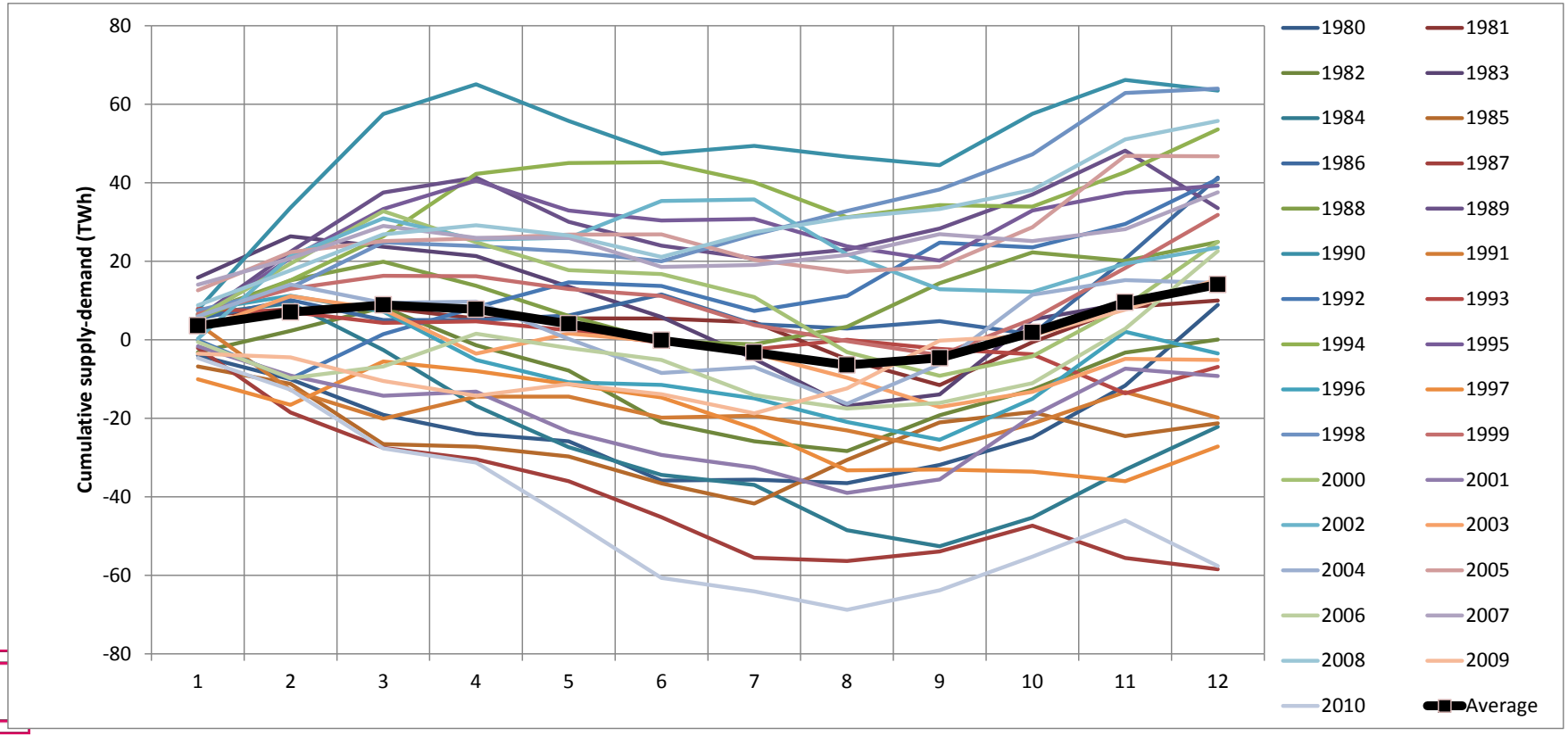
Technical
Efficiency/losses
kWh/kg or m3
kW/kg
Cycle life
Charge/discharge rate
Ramp rate

Costs
£/kWh
£/kWin
£/kWout

Energy system dynamics: simple hourly model

Monthly cumulative supply-demand variation for each of 31 years

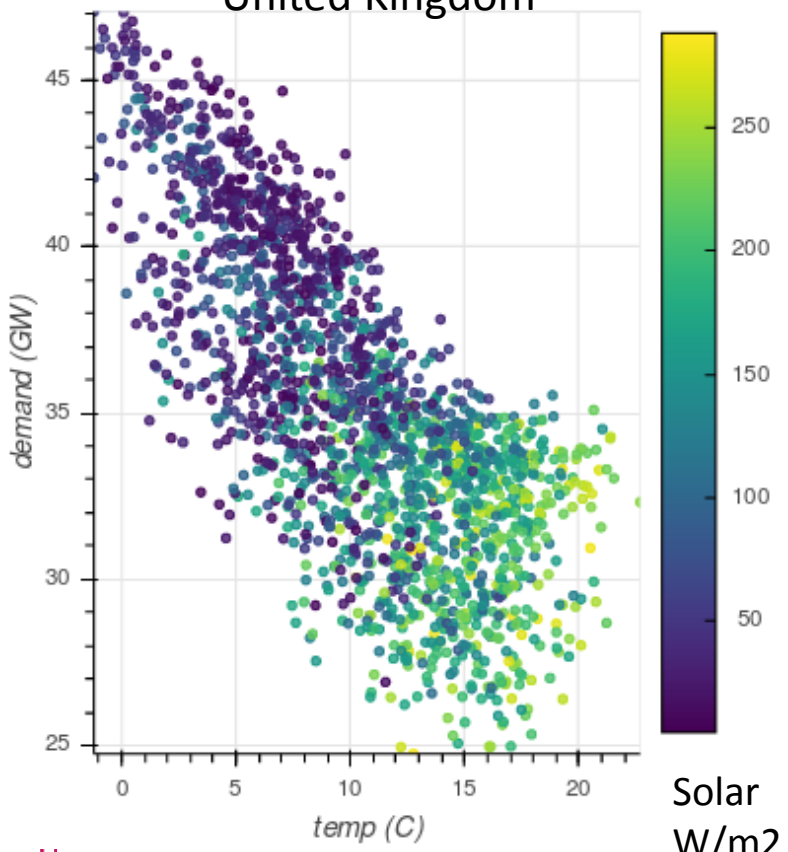
Considerable monthly variation in cumulative supply-demand resulting in minimum and maximum of about +/- 70 TWh, or +/- 10% of annual demand.



Historic demand/supply analysis

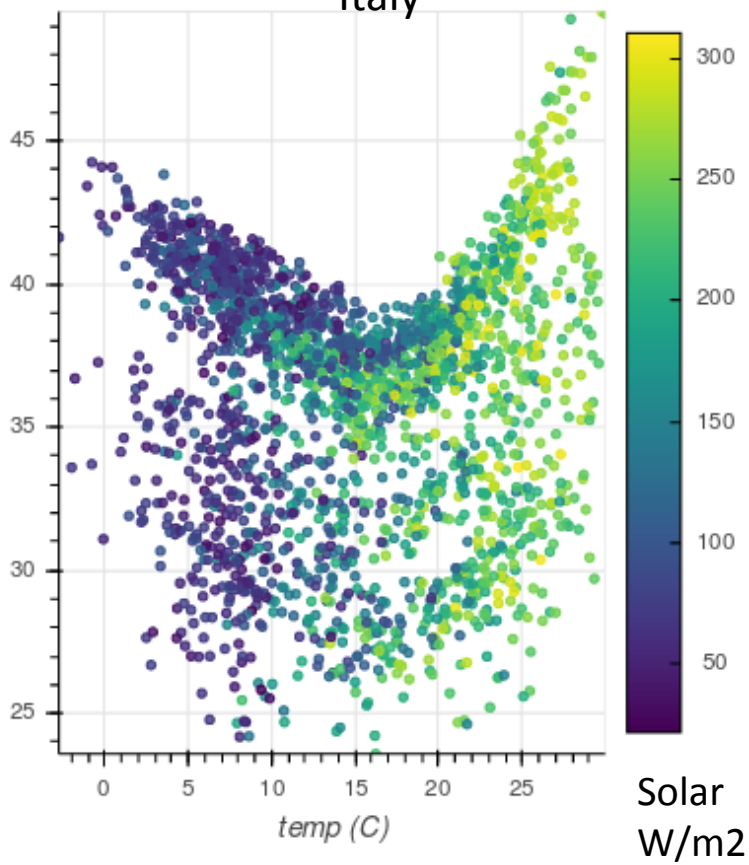
Sensitivity of daily electricity demand to population weighted temperature coloured by solar radiation (2010-2015)

United Kingdom



Solar W/m2

Italy



Solar W/m2

Some (electrically connected) storage options for system management

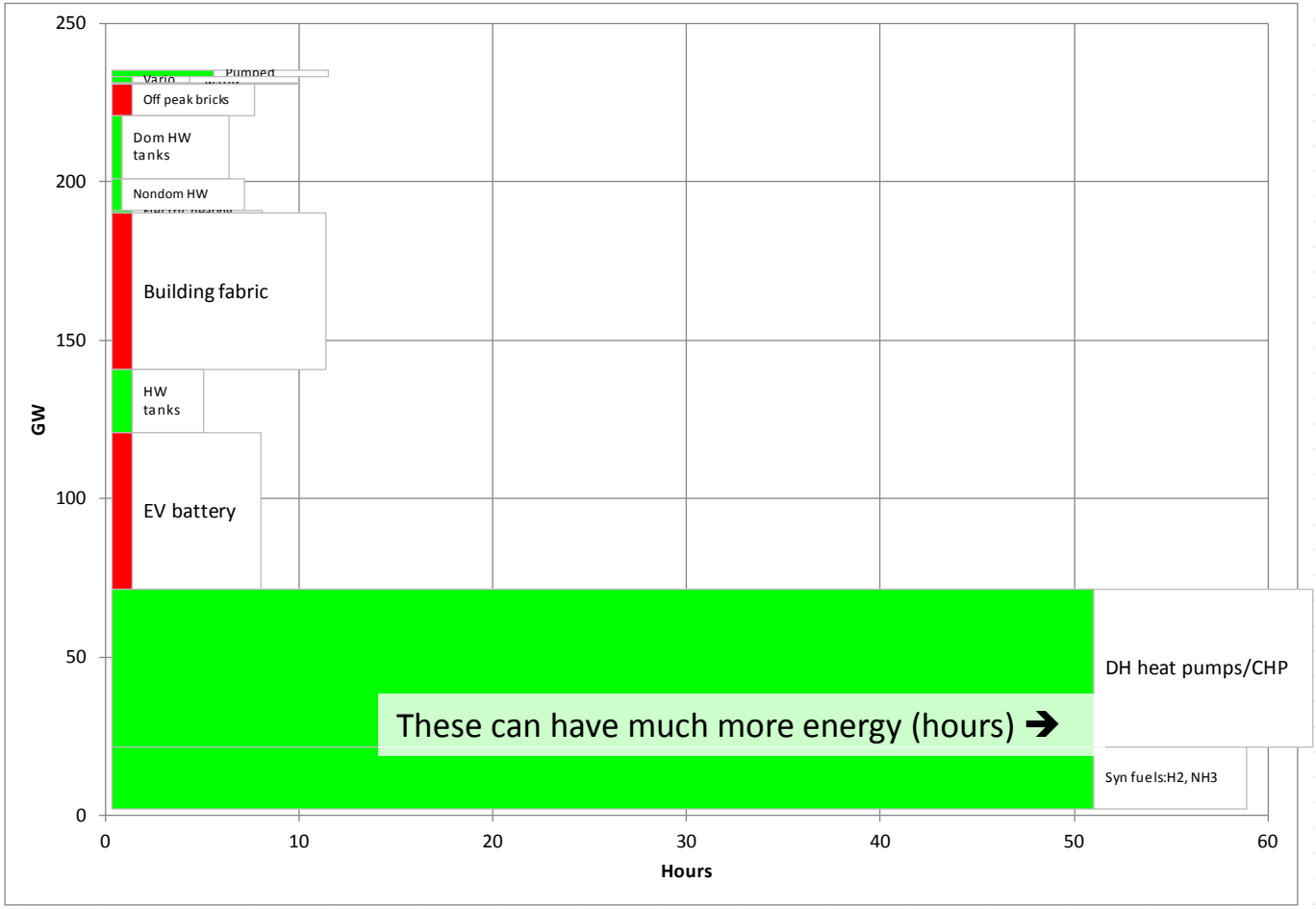
Power (GW) and time (hours)/ energy potential

(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.

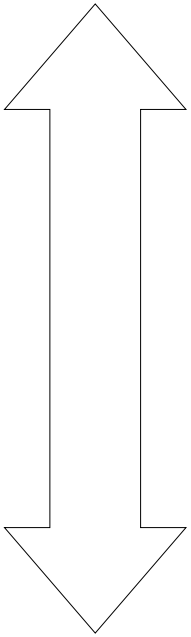


Energy Space Time

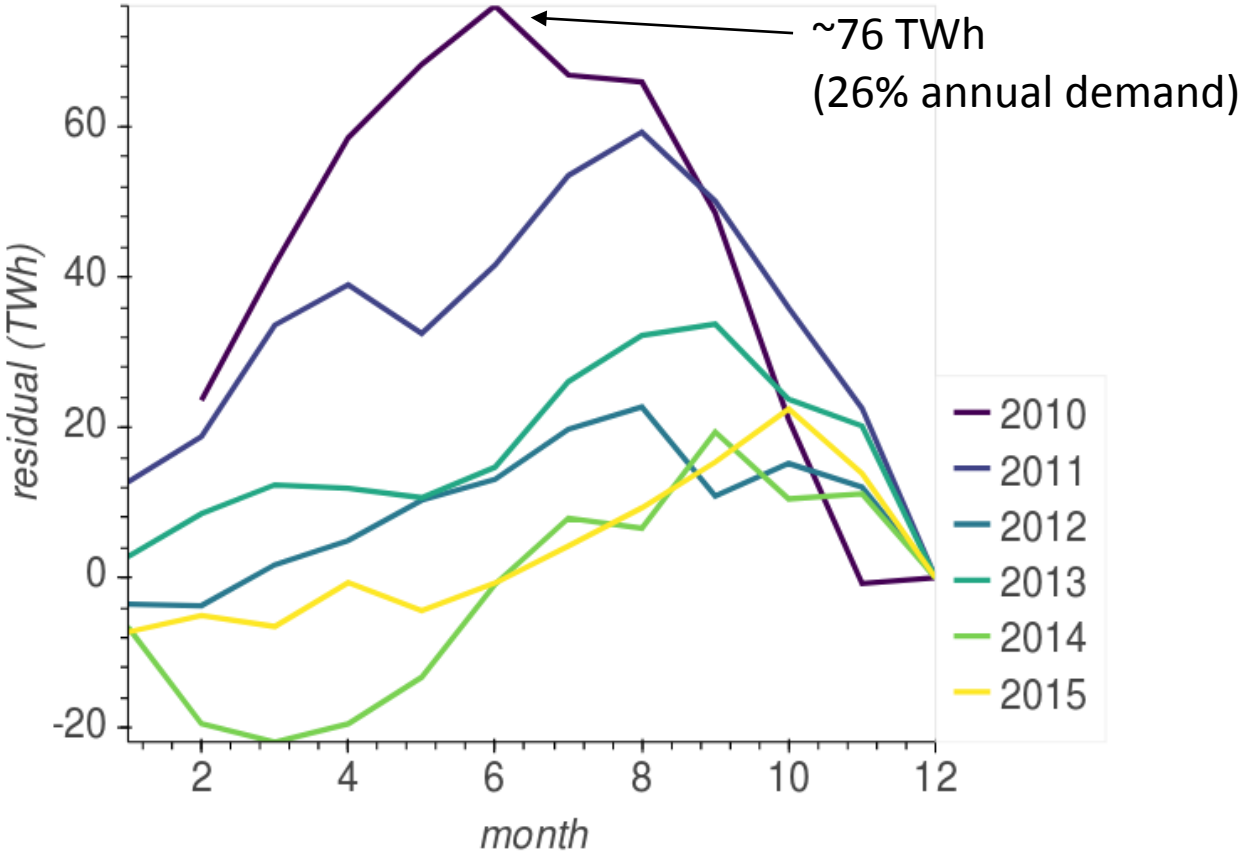
Historic demand/supply analysis

Monthly electricity cumulative residual demand (= demand – generation) for UK from 2010 to 2015 assuming wind and solar generation

Unmet demand

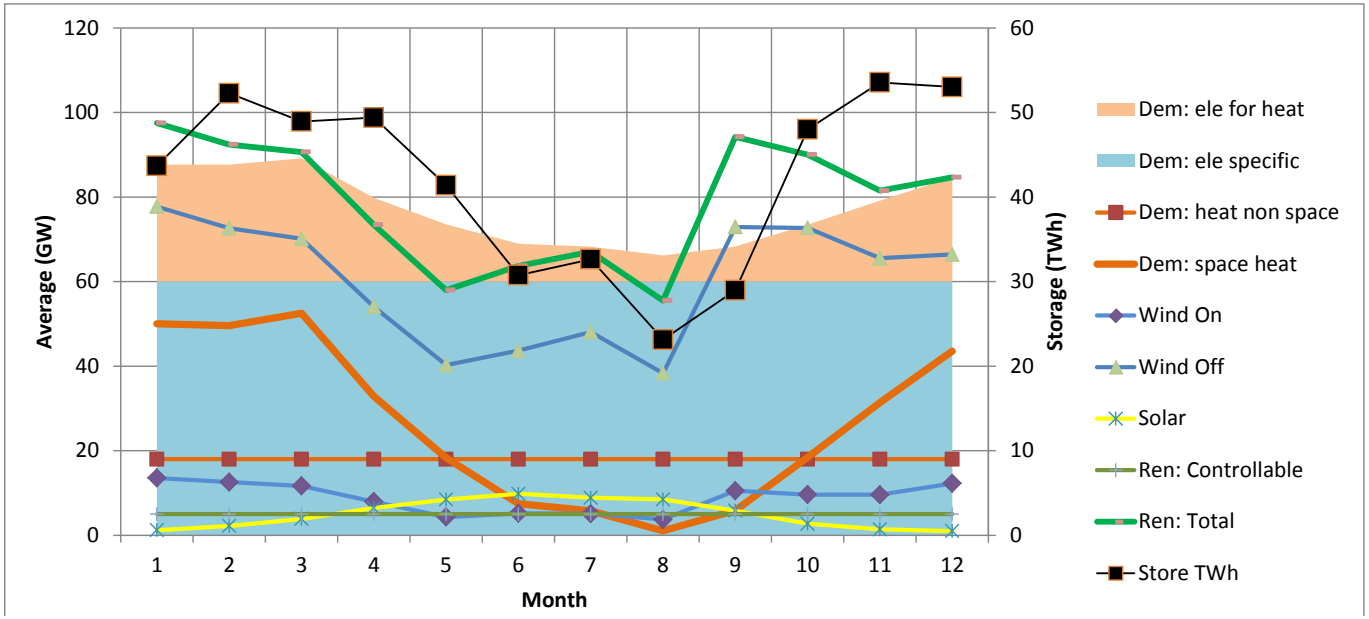


Generation surplus



How much storage is needed?

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



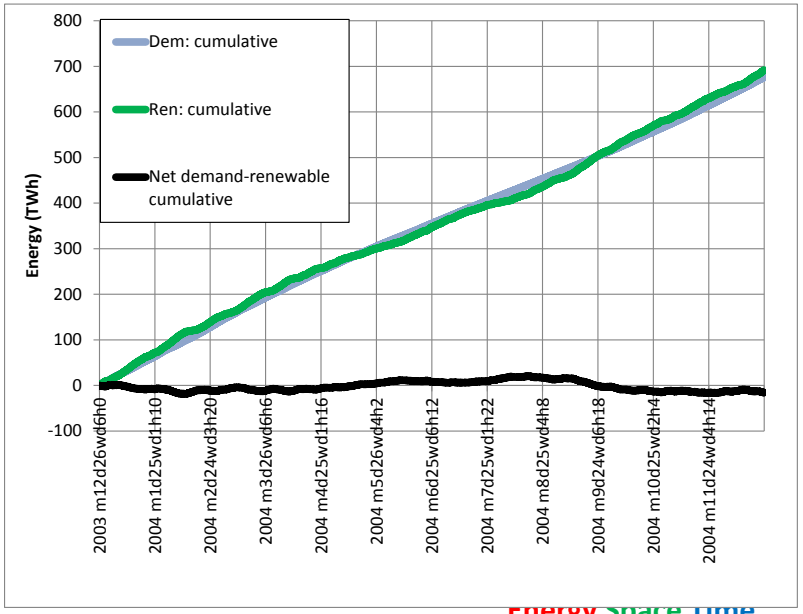
For year 2000, from 31 years of hourly meteorology and wind power generation from Dr Ed Sharp

1. Model hourly demands and renewables across the year

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

For a 700 TWh/a demand/supply system around 70 TWh of **electricity equivalent** storage is required, but will vary depending on demand and renewable patterns.

Storage can be a mix of heat, EV batteries, chemical, biomass, fossil etc.



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