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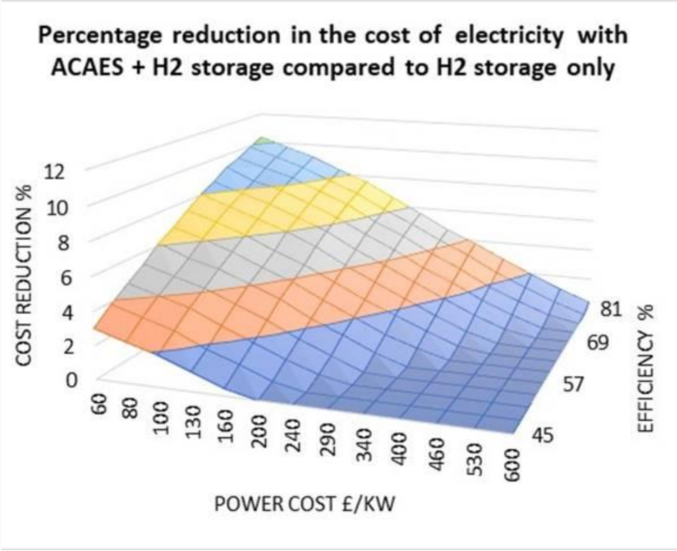
Modelling Energy Systems Including Multiple Stores

A contribution to MDES2024

Seamus Garvey

The Summary Message First!

- The least expensive net-zero energy system comprises renewable energy gen^{n}. (mainly wind + PV) and a blend of storage solutions.
- Policy makers should not *believe* any one party. They should *do the math* themselves. It is not hard!
- A toolset called [*NStore_sim*] provides the computational wherewithal to find what combination of energy stores is most cost effective
- Documentation and code for [*NStore_sim*] can be found at a Google Drive URL accessible via … www.TinyURL.com/NStore-Sim



Why a combination of stores is best.

[NStore_sim] requires that we know the following main metrics about all energy storage systems:

• Cost per unit¤ of rated input power	$(£/kW(e_{input}))$
• Cost per unit¤ of rated output power	$(£/kW(e_{output}))$
• Cost per unit¤ of storage capacity (*volume*)	$(£/kWh(e_{output}))$
• Round-trip efficiency	(%)
• Cost per unit of energy-fill reduction¥ (*end – start*)	(£/MWh)

Different systems are good in different ways. No one system is ideal for all purposes. At large scales, these metrics are effectively constants. We must know these constants ¥ for each storage type.

¤ These costs comprise both CapEx and OpEx components

¥ This matters only for very long-duration store types (including fossil-fuelled genⁿ)

[*NStore_sim*]: The problem statement

For some single-node energy system of interest, given the following information: …

- Cost information about *N* different energy storage options
- A long trajectory of total electrical demand
- A corresponding profile of RE generation (that we will scale)
- Knowledge of the turnaround efficiencies of each storage option
- A clear criterion for what it means for the system to be acceptable

… what set of storage parameters will lead to lowest overall cost?

[*NStore_sim*] enables the user to answer this question effectively.

Note: [*NStore_sim*] does not find the exact lowest cost configuration but it does invariably find a good configuration with cost close to minimum.

What are the *storage parameters* ?

With *N* different stores, there are normally[¥] 3*N* *storage parameters*

Store Type	Rated Input Power (GW)	Rated Output Power (GW)	Capacity (GW(e)) (out)
1	?	?	?
2	?	?	?
3	?	?	?
4	?	?	?
:	:	:	:

¥ For some "store types", we need fewer than 3 parameters … e.g.

Wind Integrated Storage … Input Power and Output Power are not independent.
Dispatchable Generation … Input Power=0, Capacity=∞. We need Output Power and "*R.T.E*"

System problem definition:

- Demand Data … Hourly data for 37 yrs - as per Royal Society report
- Supply Profile … From *Ninja Renewables* (37 years)
  (80% Wind & 20% Solar to balance seasons)
- Costs of R.E. … £35/MWh or £40/MWh or £45/MWh
- Discount Rate … 5% (*real* discount rate!)
- “Financial life” = the length of the supply & demand data sets.
  (i.e. O&M costs maintain systems in full pristine condition)
- Currency: … GBP (2021)

No allowance for transmission costs here.

The only contingency here is 2GW slack at every hour.

Hydrogen Storage Only … “(1)”

Using the same figures used in the Royal Society report:

Cost Component	Value
Input Power, CapEx	£333.0 / kW(e)
Output Power, CapEx	£315.0 / kW(e)
Storage Capacity, CapEx	£0.728 / kWh(e) (o/p)
Input Power, Annual OpEx	1.5% of CapEx
Output Power, Annual OpEx	1.5% of CapEx
Storage Capacity, Annual OpEx	1.5% of CapEx
Energy Deficit Cost (end – start)	£60/MWh

$$\eta = 40.7\%$$

Hydrogen Storage Only … "(1)"

The optimal system costs emerge as …

Storage	R.E. £35/MWh	R.E. £40/MWh	R.E. £45/MWh
(1)	£57.83 /MWh	£64.48 /MWh	£71.10 /MWh

Mix in some MDES (ACAES) … “(2)”

Using the same figures used in the Royal Society report:

Cost Component	Value
Input Power, CapEx	£220.0 / kW(e)
Output Power, CapEx	£280.0 / kW(e)
Storage Capacity, CapEx	£3.626 / kWh(e) (o/p)
Input Power, Annual OpEx	4.0% of CapEx
Output Power, Annual OpEx	4.0% of CapEx
Storage Capacity, Annual OpEx	1.0% of CapEx
Energy Deficit Cost (end – start)	£60/MWh

$$\eta = 68\%$$

Mix in some MDES (ACAES) … "(2)"

The optimal system costs emerge as …

Storage	R.E. £35/MWh	R.E. £40/MWh	R.E. £45/MWh
(1)	£57.83 /MWh	£64.48 /MWh	£71.10 /MWh
(1)&(2)	£56.24 /MWh	£62.00 /MWh	£68.77 /MWh
(2)	£65.40 /MWh	£72.24 /MWh	£78.57 /MWh

Mix in ***Wind Integrated Storage*** … "(3)"

For background see this presentation to BEIS of 04/02/2021

https://docs.google.com/presentation/d/1jhBAuYzkNj7UzMXq0MWcSCECW0-mQxoW/edit?usp=sharing&ouid=104407450146476914335&rtpof=true&sd=true

Cost Component	Value
Input Power, CapEx	£100.0 / kW(e)
Output Power, CapEx	£100.0 / kW(e)
Storage Capacity, CapEx	£10.0 / kWh(e) (o/p)
Input Power, Annual OpEx	4.0% of CapEx
Output Power, Annual OpEx	4.0% of CapEx
Storage Capacity, Annual OpEx	1.5% of CapEx
Energy Deficit Cost (end – start)	£60 / MWh

$$\eta = 85\%$$

Mix in *Wind Integrated Storage* … "(3)"

The optimal system costs emerge as …

Storage	R.E. £35/MWh	R.E. £40/MWh	R.E. £45/MWh
(1)	£57.83 /MWh	£64.48 /MWh	£71.10 /MWh
(1)&(2)	£56.24 /MWh	£62.00 /MWh	£68.77 /MWh
(1)&(2)&(3)	£55.49 /MWh	£61.72 /MWh	£67.83 /MWh
(2)	£65.40 /MWh	£72.24 /MWh	£78.57 /MWh

Mix in some Batteries … "(4)"

Using representative values

Cost Component	Value
Input Power, CapEx	£15.0 / kW(e)
Output Power, CapEx	£15.0 / kW(e)
Storage Capacity, CapEx	£100.0 / kWh(e) (o/p)
Input Power, Annual OpEx	2.0% of CapEx
Output Power, Annual OpEx	2.0% of CapEx
Storage Capacity, Annual OpEx	6.0% of CapEx
Energy Deficit Cost (end – start)	£60 / MWh

$$\eta = 92\%$$

Mix in some Batteries … “(4)”

The optimal system costs are not lowered! (NB 1hr data intervals)

Storage	R.E. £35/MWh	R.E. £40/MWh	R.E. £45/MWh
(1)	£57.83 /MWh	£64.48 /MWh	£71.10 /MWh
(1)&(2)	£56.24 /MWh	£62.00 /MWh	£68.77 /MWh
(1)&(2)&(3)	£55.49 /MWh	£61.72 /MWh	£67.83 /MWh
(1)&(2)&(3)&(4)	£56.88 /MWh (!)	£61.89 /MWh (!)	£68.03 /MWh (!)
(2)	£65.40 /MWh	£72.24 /MWh	£78.57 /MWh

Blending in batteries does not give readily-visible advantages!

Storage times (for the batteries) ~5hrs

Mix in some *Dispatchable Gen$^{\underline{n.}}$* … "(5)"

Dispatchable Generation (a.k.a. gas-fired genn. with CCS) can be treated as a storage asset. It has 0 input power, near-infinite storage capacity (at 0 cost) and the store starts quite full.

Cost Component	Value
Input Power, CapEx	N/A (£0.0)
Output Power, CapEx	**£500.0 / kW(e)**
Storage Capacity, CapEx	N/A (£0.0)
Input Power, Annual OpEx	N/A (£0.0)
Output Power, Annual OpEx	**2.5% of CapEx**
Storage Capacity, Annual OpEx	N/A (£0.0)
Energy Deficit Cost (end – start)	**£200 / MWh**

η irrelevant

Mix in some *Dispatchable Gen*$^{\underline{n.}}$ … "(5)"

The optimal system costs are not lowered!

Storage	R.E. £35/MWh	R.E. £40/MWh	R.E. £45/MWh
(1)	£57.83 /MWh	£64.48 /MWh	£71.10 /MWh
(1)&(2)	£56.24 /MWh	£62.00 /MWh	£68.77 /MWh
(1)&(2)&(3)	£55.49 /MWh	£61.72 /MWh	£67.83 /MWh
(1)&(2)&(3)&(4)	£56.88 /MWh (!)	£61.89 /MWh (!)	£68.03 /MWh (!)
(2)	£65.40 /MWh	£72.24 /MWh	£78.57 /MWh
(1)&(5)	£57.46 /MWh	£64.080 /MWh	£70.36 /MWh

With the assumed "representative values", *Dispatchable Generation* is only very slightly helpful compared with the use of only hydrogen

Closing remarks.

- Hydrogen store in caverns will certainly be the kingpin of future cost-effective *Net-Zero* energy systems.

- Further savings of ~5% easily possible by using a blend of storage solutions

- A powerful toolset called [*NStore_sim*] is available openly. (accessible through www.TinyURL.com/NStore-sim)

- [*NStore_sim*] enables robust conclusions to be drawn about the values of *baseload* and *Dispatchable Generation*.

University of Nottingham
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Thanks for listening.

Seamus.Garvey@nottingham.ac.uk