ENERGY STORAGE, ENERGY SPILLAGE & LAKE ONSLOW

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THEME: USE ENERGY WISELY!

- Renewable energy is finite, as are the materials used to harness, transmit and utilise it.
- Energy has quality (2nd law of thermodynamics)
- Social equity
SYSTEM CONCEPTS

• Energy storage can be minimised by specifying generation over-capacity
• Optimal combinations of installed capacity plus storage exist
• Energy spill results; this may be used to produce other energy carriers, directed to secondary loads or dump loads, or curtailed
STORAGE TECHNOLOGY vs TIMEFRAME

We need to mobilize technologies from the Energy Storage Landscape...

- Central gas storage, Electrolysis, Interconnectors, pumped hydro, Energy Island
- Central heat storage, CAES, Biomass, Interconnectors
- Electric vehicles, Heat pumps, Battery's 2nd life, Smart Grid
- Supercaps, Flywheels, Batteries

Securing power quality | Shifting night and day | Storing for the weather | Leveling the seasons

Timescale (hour-day-week-month-year)

Energy vs Power
400 MWh; 100 MW
OPTIMISATION

- A) EROEI basis (few studies)
- B) Financial cost basis (most studies)
- LCOE = net present value/lifetime energy

\[ LCOE_{BEIS} = \frac{NPV_{Costs}}{NPE} = \sum_{t=1}^{n} \frac{C_t + O_t + V_t}{(1 + d)^t} / \sum_{t=1}^{n} \frac{E_t}{(1 + d)^t} \]

Where: t= time period (y); n=lifetime (y); C = capital cost (including decommissioning) ; O= fixed operation cost; V = variable operation cost (e.g. taxes, fuel cost, carbon cost); E= energy generated; d=discount rate (Aldersey-Williams & Rubert, 2019)
GRID-SCALE STORAGE MINIMISATION
Budischak et. al., 2013

- Modelled wind plus solar, 4 y, hourly resolution, PJM network, North Eastern USA
- Installed capacity => 30, 90, 99.9% hrs met by RE
- Rapid peaking; no inflexible base-load
- Hydrogen, chemical batteries, grid integrated vehicles
- Energy spillage, or curtailment
- Financial cost optimisation
Load was met with renewable generation and storage 99.9% of hours over 4 years; fossil backup needed on five occasions

Penetration: 290%
Fig. 4. Response of the optimized energy system (99.9% coverage, 2030 costs) to a challenging week for three storage technologies: hydrogen (left column), centralized battery (center column), and GIV (right column). Top row distinguishes three types of renewable generation compared to load. Bottom row distinguishes generation, storage, and spilled generation. Abscissa scale is hour of simulation.
HOUSEHOLD-SCALE STORAGE MINIMISATION

• Residential PV-battery systems
• Demand data: 30-min, I y, Christchurch
• Solar data: hourly, Christchurch
• Penetration range: 1-10
• Energetic & financial optimisation
METHODOLOGY

• Penetration = annual gross generation/annual demand
• Solve for storage with no-spill; pen approx. 1.10
• Solve for storage at increased pen values
• Calculate EROEI & NPC for each pen
• Determine optimal pen values
STORAGE PATTERN - profile N
STORAGE PATTERN - profile B, pen 3.5
STORAGE CAPACITIES – all profiles
SPILL PATTERNS – profile N

- Graphs showing normalized spillage over time (Julian Day):
  - a)
  - b)
  - c)
  - d)
  - e)
  - f)
ENERGY INVESTED & EROEI (profile N)
## Table 11
Penetrations for energetic and economic optima.

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Note: <sup>a</sup>Battery cost; <sup>b</sup>Reduced panel costs and 30 year battery lifetime incorporated.
TO CURTAIL OR STORE?

Barnhart & Benson, 2013; Barnhart et. al, 2013

ESOI

\( H_2 \), 120 d, steel, = 4.0

Hydro (NZ)

Wind (NZ)

ESOI_e

Fig. 2 A bar plot showing ESOI, the ratio of total electrical energy stored over the life of a storage technology to its embodied primary energy. Higher values are less energy intensive.

Fig. 4 At a curtailment rate or storage fractions of \( \phi \), as indicated by the lines bisecting the plot, various combinations of resource EROI (y-axis) and storage ESOI_e (x-axis) result in energy systems in which it is energetically favorable to store the resource (green region) or curtail the resource (blue region).
UTILISING SPILL

- Secondary (discretionary) loads
- Dump loads
- Curtailment
- Electro-fuels; ‘Power to X’ (low efficiency)

- The story so far: Storing wind & PV surpluses using PHES is energetically an excellent choice.
- Spill utilisation increases CF & EROEI (gen); maybe EROEI (system)
PROPOSED LAKE ONSLOW SCHEME, 4-12 TWh, 1300 MW (Source Majeed, 2019)

Figure 3.12 Cross section of the simulated Onslow PHES.
PHES – CAPITAL COST

PHES 2016 Capital Costs (Source: Majeed, 2019; except Cultuna (Transmission & Distribution, Oct/Nov, 2017))

0.33
DEBATE

Pros

• Facilitates more variable renewable electricity; e.g. wind, solar PV
• Less volatile market; lowers peaks, raises floor (Taylor, 2021)
• Improves CF, EROEI (gen)
• Environmentally friendly
• Societal benefits; major infrastructure project; jobs, long lifetime; low Capex/GWh

Cons

• High Capex in absolute terms
• Very long tunnel; H:L 0.026
• Requires wind/PV/hydro surpluses or low cost energy to be supplied
• Alternatives? (Pellow et. al, 2015 for H₂ vs Li-ion storage)
• “RHFC storage is generally unfavorable for wind overgeneration; it is energetically preferable to simply curtail the wind overgeneration than to spend additional energy to build RHFC storage capacity.”
SOME RESEARCH QUESTIONS

• What are the energetically and financially optimal storage capacities for a future NZ electricity system?
• Is the present electricity market system fit for purpose? If not, what modifications are needed? Can spill be priced at zero?
• How would a modern macroeconomic conceptual framework incorporating the laws of thermodynamics, environmental limits and social equity, e.g. society’s cost of energy (SCOE), impact our energy storage/system decisions?
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REFERENCES

THANKS FOR LISTENING

Any questions ☟

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