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Financial and Environmental Multi-Objective Optimisation of a Revenue-Stacking Solar+Battery Farm

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1. Introduction

Backup power for renewable generators is mostly provided by natural gas. Energy storage can be less environmentally damaging, but more expensive (McKenna et al. 2017).

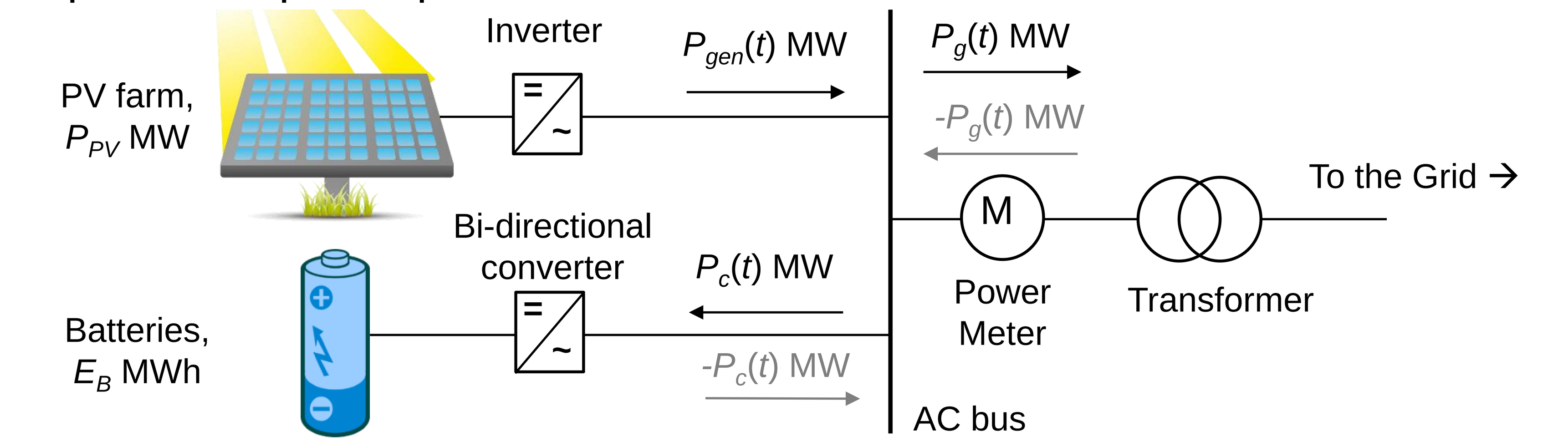
Grid-scale batteries today can generate returns by providing frequency response. This saves some emissions compared to keeping gas plants in spinning reserve, but not much (Fripp 2011).

The two functions can be combined by revenue-stacking (Moreno et al. 2015). This is usually done to increase revenue – little work exists examining the environmental impacts of revenue-stacking renewable+storage systems.

- What trade-offs between profits and environmental benefits?
- Are batteries better than no batteries?
- Are second-life batteries better than new ones?
- Is some market intervention still necessary?

2. The System

Behind-the-meter solar PV farm with batteries, grid-connected. Essentially a dispatchable power plant, with some constraints.



Day mode: trade electricity on the N2EX day-ahead market.

Night mode: provide Enhanced Frequency Response.

3. Scheduling the Solar+Battery Plant

Linear Programming is carried out based on daily forecasts of solar generation and N2EX price.

Objective: day-ahead revenue

Variables: grid export/import; battery charging/discharging power

Constraints:
- Battery stored energy (low and high); charge/discharge power
- Grid export limit (in a constrained network)
- Power balance (PV > export + charging)
- Time continuity of stored energy
- 'Foot-room' upon entering night mode

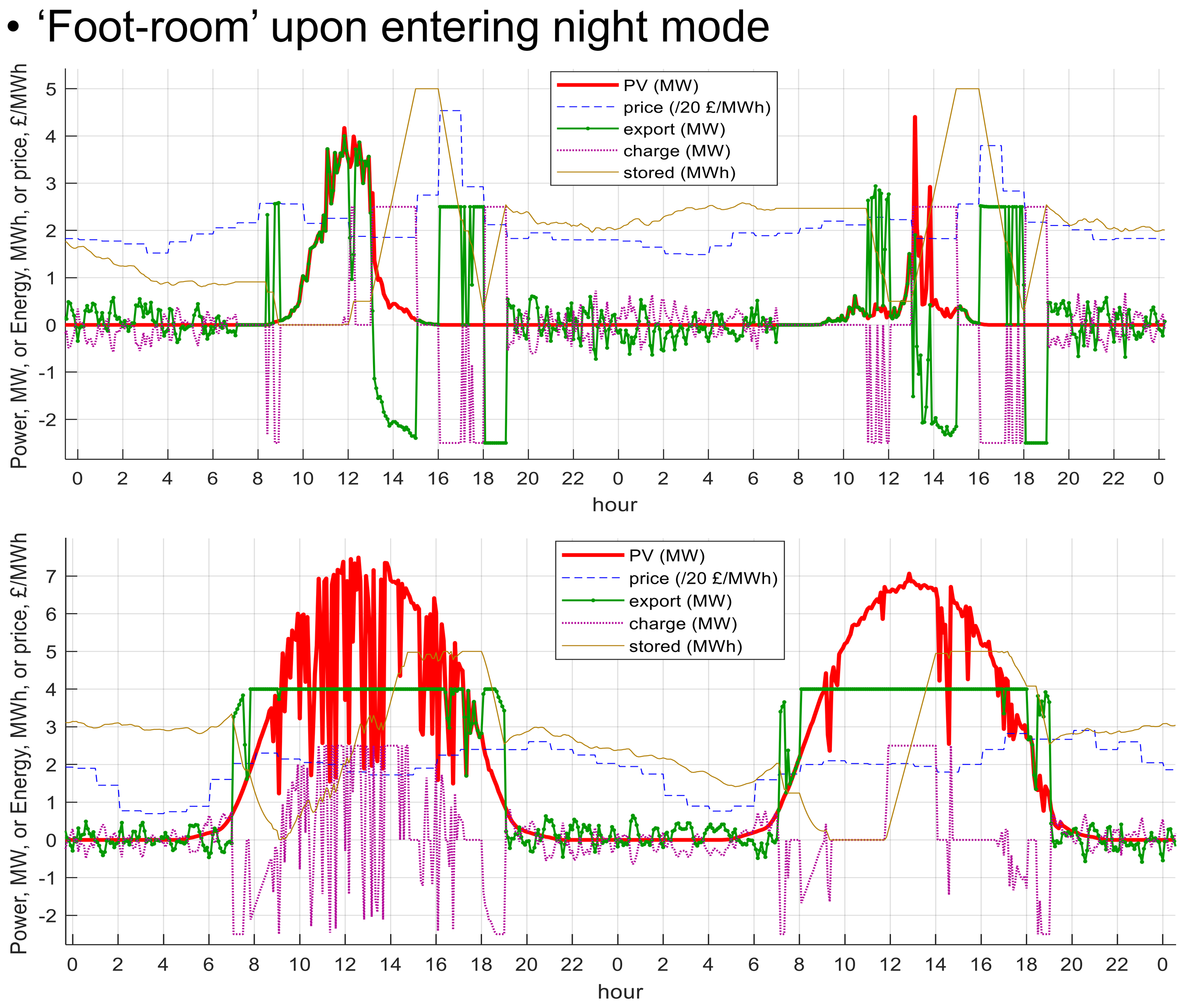


Fig. 1: Examples of system scheduling to maximise N2EX day-ahead revenue.

Left: 5-6th January;

Bottom left: 5-6th June

PV: 7.5 MW

Battery: 5.0 MWh

Day mode: 07:00-19:00

Grid export limit: 4.0 MW

4. Environmental Impacts

Using the ReCiPe framework (Huijbregts et al. 2016):

Midpoint impact data (climate change, ozone depletion, terrestrial acidification, etc.) are found for manufacture of PV panels, batteries (various), laying distribution networks, and electricity generation (various).

These are synthesised into endpoint impacts for each:
- Human Health (DALY, Disability-Adjusted Life Years)
- Ecosystems (species.years, i.e. biodiversity lost)
- Resources (USD, cost of finite reserves becoming harder to extract)

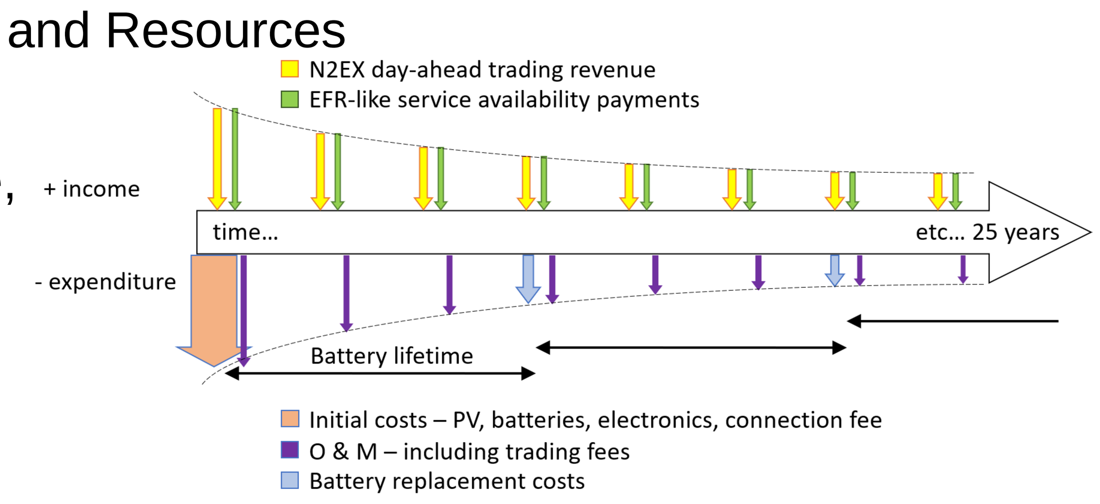
5. Calculating Long-Term Objectives

Variables: PV capacity (MW), battery capacity (MWh), day-mode hours

Objectives: Internal Rate of Return (IRR, %) and analogous expressions for Human Health, Ecosystems and Resources

Net Present Value (NPV) = income minus expenditure, future cash flows being discounted by interest rate.

IRR is the interest rate which makes NPV = 0.



6. Results

Multi-objective Genetic Algorithm – population 50, for 50 generations.

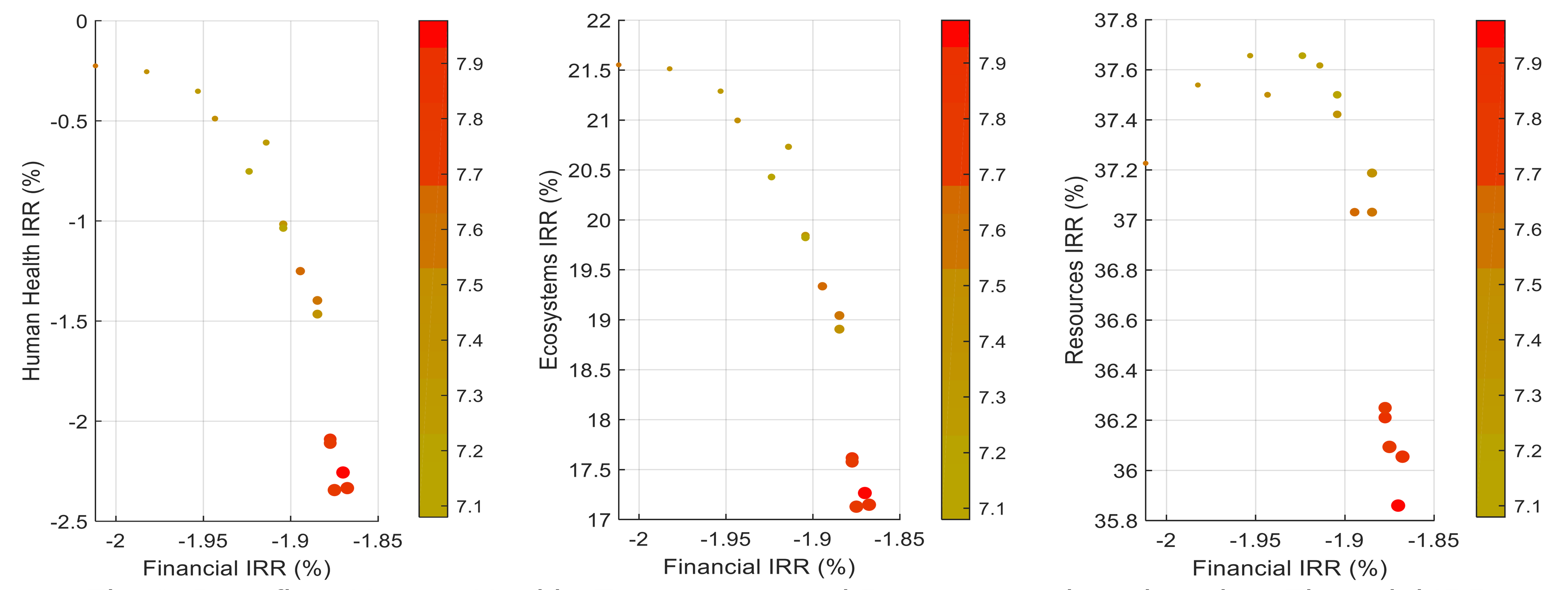


Fig. 2: Benefit to Human Health, Ecosystems and Resources, plotted against Financial IRR.

PV: 7.1 - 8.0 MW; Battery: 2.2 – 5.6 MWh; day-mode: 07:00-19:00 for all.

7. Further Work

- Grid emissions scenarios – need high-resolution long-term series of what environmental damage will be displaced by this system.
- Battery modelling – I-V characteristics, degradation with time/cycles/etc.
- Imperfect forecasting – of PV and price – what effects; trip events?
- Sensitivity analyses – component prices, environmental impact, etc.
- Run batteries vs. no batteries; new batteries vs. second-life.

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