Techno-economic Analysis of Second Life Electric Vehicle Batteries for Stationary Energy Storage Applications

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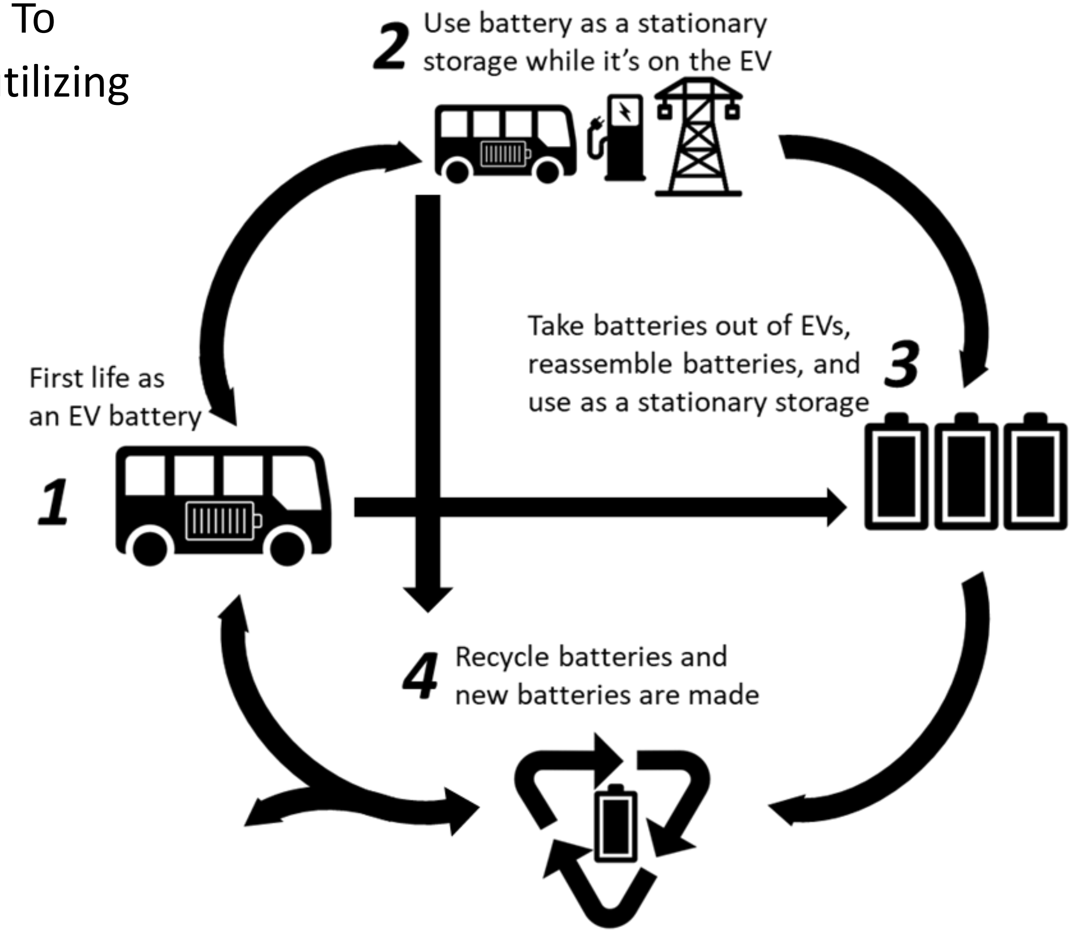
Context

The growing number of electric vehicles (EVs) on our streets has brought a significant concern regarding the large quantity of retired EV batteries. To decrease the environment pollution and increase economic benefits, utilizing second life applications for these batteries is essential.

Research gaps

- There is no technical and economic analysis of using second-life EV batteries for community microgrids with renewable energy sources.
- There is no technical and economic analysis of using second-life EV batteries for load frequency control.
- The control algorithms for second-life EV batteries for both applications need to be developed.
- The factors that affect the economic benefits and technical performance of second-life batteries for both applications need to be analysed.



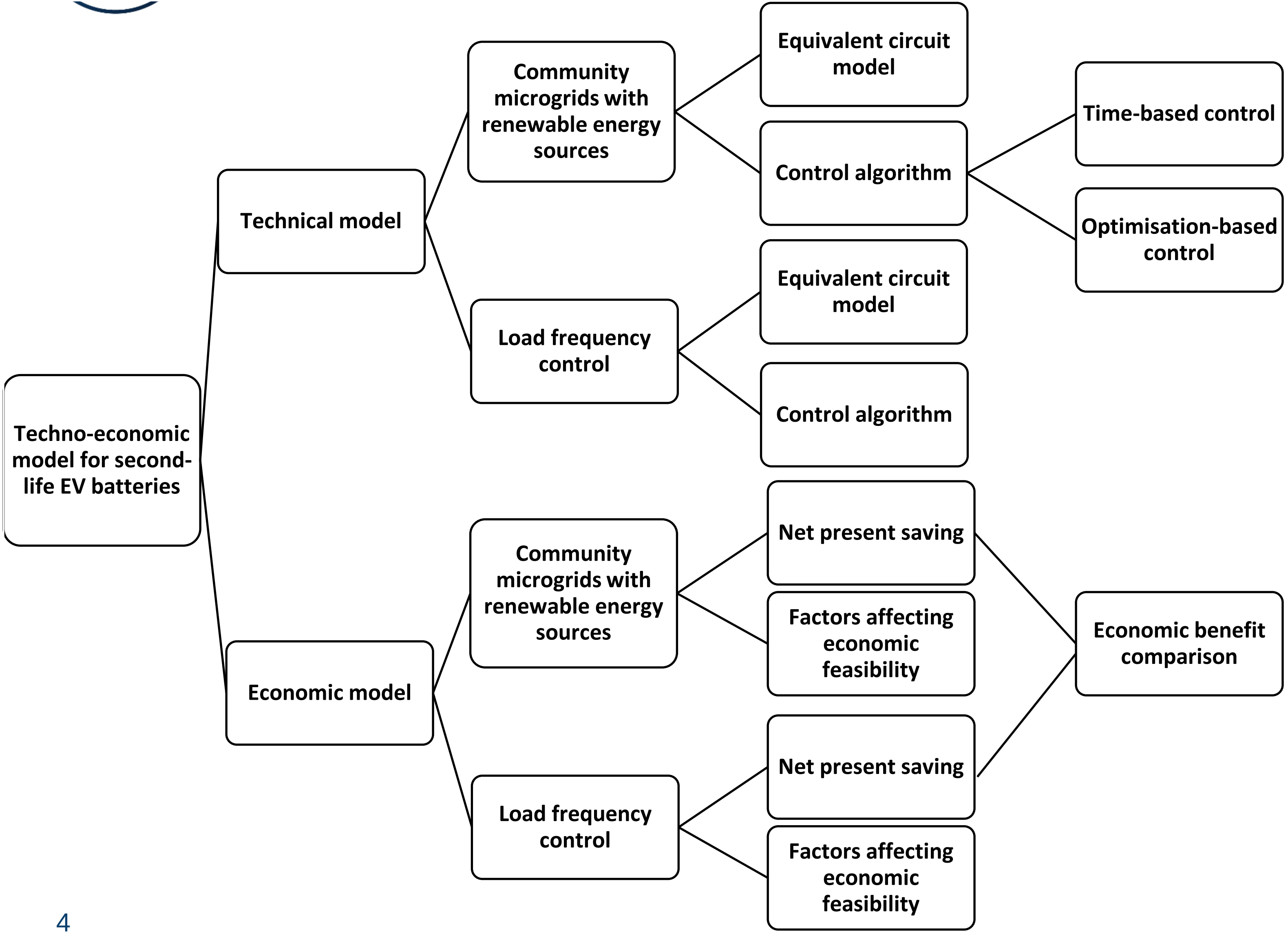
Circular economy of EV batteries (4 stages)

Overall Aim and Individual Objectives

Aim to investigate the technical and economic feasibility of using SLBs for community microgrids and ancillary services.

1. To evaluate the technical and economic feasibility of utilizing second-life EV batteries for community microgrids with renewable energy sources (application 1).
2. To evaluate the technical and economic feasibility of utilizing second-life EV batteries for load frequency control (application 2).
3. To develop the most effective control algorithms for utilizing second-life EV batteries for both applications (application 1 and 2).
4. To analyse the factors that affect the economic benefits and technical performance of second-life batteries for both applications (application 1 and 2).

Methodology approach – Block diagram



Techno-economic model for second-life EV batteries

Technical model

Community microgrids with renewable energy sources

Equivalent circuit model

Control algorithm

Time-based control

Optimisation-based control

Load frequency control

Equivalent circuit model

Control algorithm

Economic model

Community microgrids with renewable energy sources

Net present saving

Factors affecting economic feasibility

Economic benefit comparison

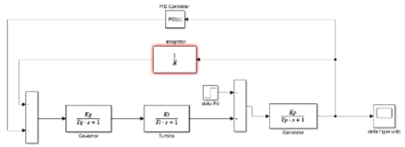
Load frequency control

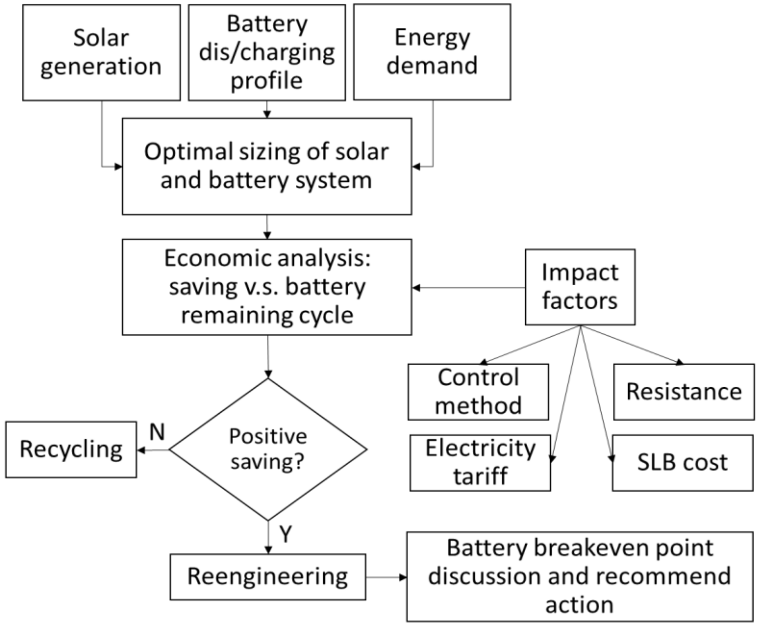
Net present saving

Factors affecting economic feasibility

$$x = linprog(f, A, b, Aeq, beq, lb, ub)$$

$$NPV = \sum_{t=o}^{n} \frac{S_{year}(t)}{(1+i)^t}$$





Methodology approach for application 1– Community microgrids with renewable energy sources

Time-based control

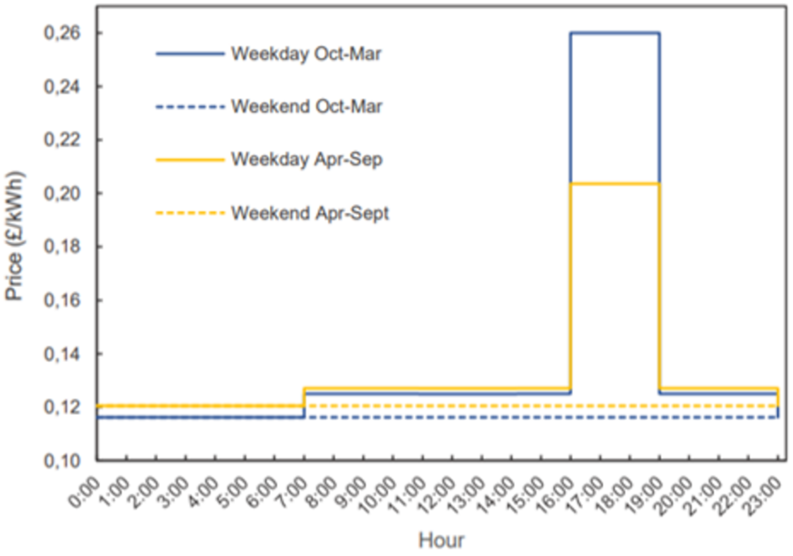
Battery action schedule :

$$P_B = \begin{cases} P_{Char} & t = t_{off-peak} \\ P_{Dis} & t = t_{peak} \end{cases}$$

Total savings:

$$S_{tot} = \sum (P_{disc} C_{peak} \Delta t - P_{char} C_{offpeak} \Delta t)$$

Electricity prices in Cranfield University



Optimisation based control

Objective function:

$$C_{tot} = min \sum_{i=1}^{24} (C_{imp} E_{imp} + C_{exp} E_{exp})$$

Constraints:

$$E_{imp}(i) + E_{solar}(i) + E_{dis}(i) = E_{exp}(i) + E_{load}(i) + E_{char}(i)$$

System's energy balance equation

$$E_B(i) = E_B(i-1) + E_{char}(i) - E_{dis}(i)$$

Batterie's energy balance equation

$$E_{char} = P_{char} t\eta$$

$$E_{disc} = \frac{P_{char} t}{\eta}$$

Batterie's charging and discharging losses

$$E_{char}^{min} < E_{char}(i) < E_{char}^{max}$$

$$E_{dis}^{min} < E_{dis}(i) < E_{dis}^{max}$$

$$E_{imp}^{min} < E_{imp}(i) < E_{imp}^{max}$$

$$E_{exp}^{min} < E_{exp}(i) < E_{exp}^{max}$$

Boundaries for each input factor

Case Study 1 - Community microgrids with renewable energy sources

Part of an IUK project: SLB4ComEU

- Project funded by IUK (October 2010 to July 2021) with Brill Power Ltd and AceOn Group Ltd.
- The IUK project has been working on the reassembling of batteries from 1 Cranfield electric bus and installing the second-life batteries at Cranfield DARTeC building and total capacity is 100kWh.
- The daily electricity demand and solar generation data in Cranfield University are also collected.

Stationary energy storage

Electricity buses from Cranfield University

Methodology for application 2 – LFC

Provide stationary energy storage (SLBs)

Electricity system operator test stationary energy storage

Bid in the trading platform and be the most economical tender

Getting paid

- To be paid for using battery energy storage for load frequency control in the UK is through participation in the National Grid's Balancing Mechanism (BM).
- Battery energy storage providers can bid to provide frequency response services to the BM and get paid for their participation.
- The residual value versus remaining life cycles is used to show the feasibility of second-life applications.

$$R = -\alpha + \beta - \eta$$

R: *Residual value*
α: *EV battery residual value*
β: *BESS saving*
η: *reengineering cost*

Case Study 2 - LFC

Use SLBs for LFR (100kWh)

- LFC price: 0.002£/kWh/h
- Assumption: 260 cycle/year (1 cycle/workday)
- Saving/day: 0.48£

March 2021	**Primary Volume (MWh)**	**Secondary Volume (MWh)**	**High Volume (MWh)**
Price band (£/MW/h range)			
0 to 2	167,097	164,768	1,938
2 to 4	85,242	26	191,061
4 to 6	35,614	27,150	183,258
6 to 8	6,077	0	8,728
Greater than 8	2,336	2	7,926
Total volume	**296.4 GWh**	**191.9 GWh**	**392.9 GWh**
Cost	**0.80 £m**	**0.38 £m**	**1.60 £m**
Total Frequency Response Holding Volume			**881.2 GWh**
Total Frequency Response Holding Cost			**2.78 £m**

March 2021 UK LFC market information

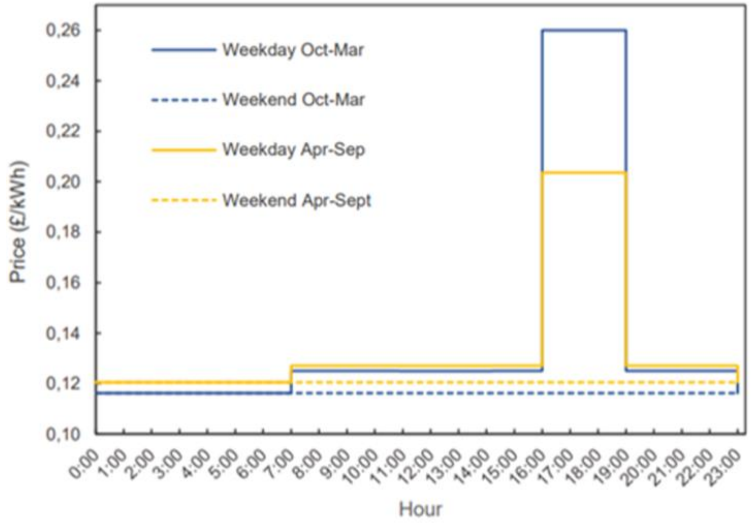
Key findings - 1

Time-based charging and discharging profile (100kWh battery):

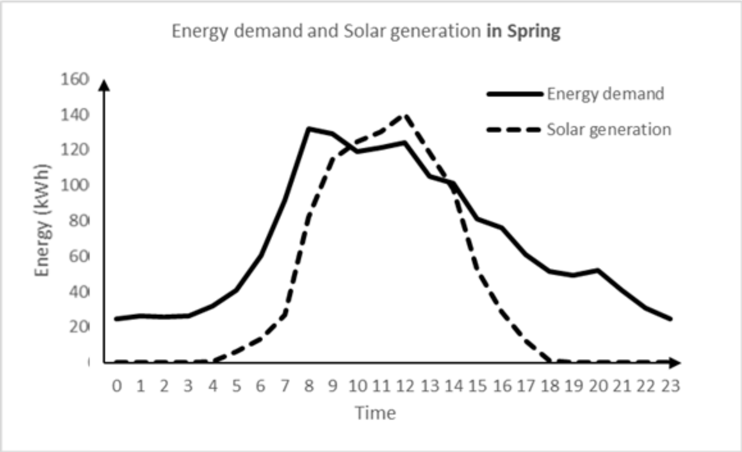
Time-based charging and discharging schedules

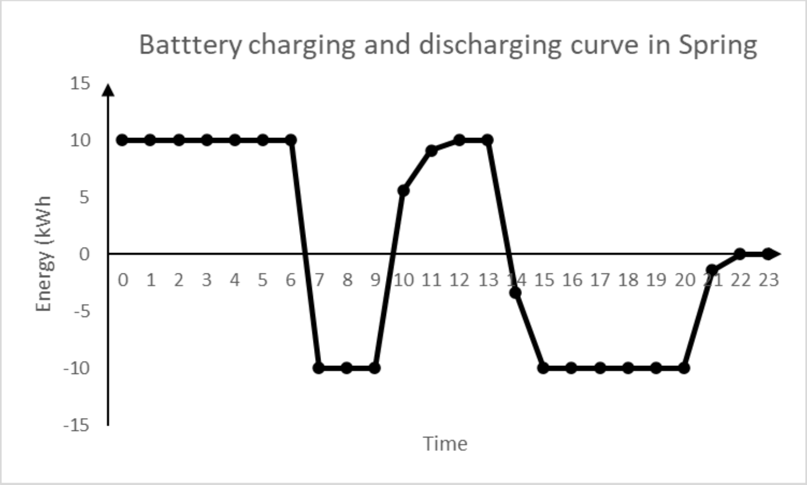
Charging	Weekdays 08:00-10:00	£0.125/kWh	£0.127/kWh
Discharging	Weekdays 16:00-19:00	£0.26/kWh	£0.204/kWh
Idle	Weekend	-	

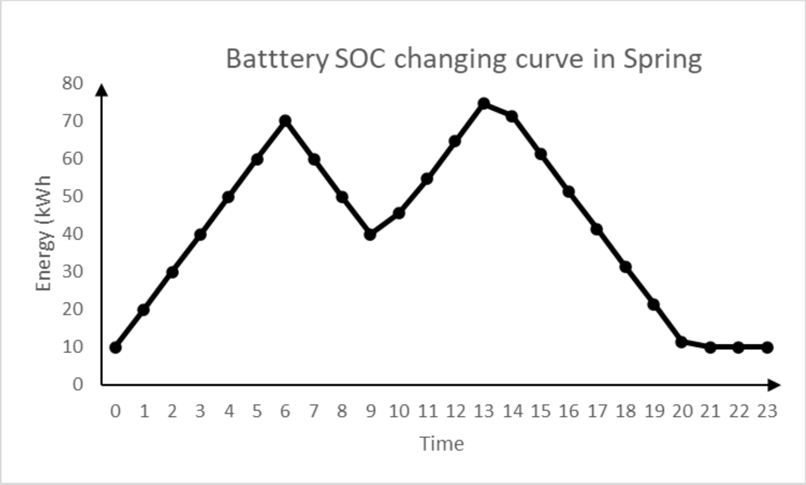
Electricity prices in Cranfield University



Optimised charging and discharging profile (100kWh battery):

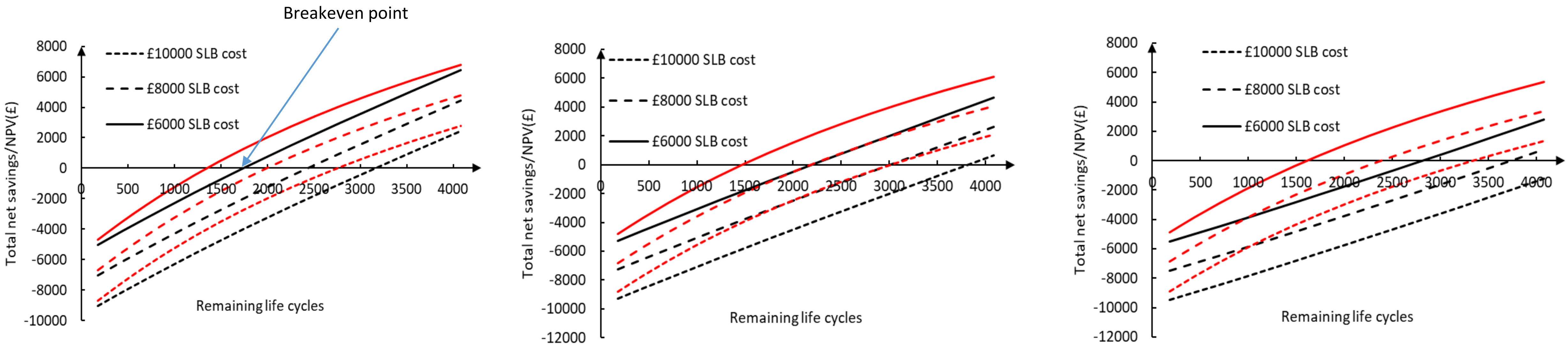

Energy demand and Solar generation in Spring


Batttery charging and discharging curve in Spring


Batttery SOC changing curve in Spring

One day in Spring is used for example

Key findings -1


Breakeven point

Breakeven point (remaining cycle no.)	£6000	£8000	£10000
Initial resistance 0.2Ω	1350	2000	2800
Initial resistance 0.4Ω	1480	2250	3050
Initial resistance 0.6Ω	1550	2500	3400

Time-based control

Breakeven point (remaining cycle no.)	£6000	£8000	£10000
Initial resistance 0.2Ω	1750	2500	3200
Initial resistance 0.4Ω	2250	3000	3850
Initial resistance 0.6Ω	2780	3800	>4000

Optimisation-based control

- Total net saving vs. remaining life cycles (When the internal resistance is the same at 0.2Ω/ 0.4Ω/ 0.6Ω, the comparison between different SLB costs, red lines are the results from optimization-based control, black lines are the results from time-based control)

Key findings - 2

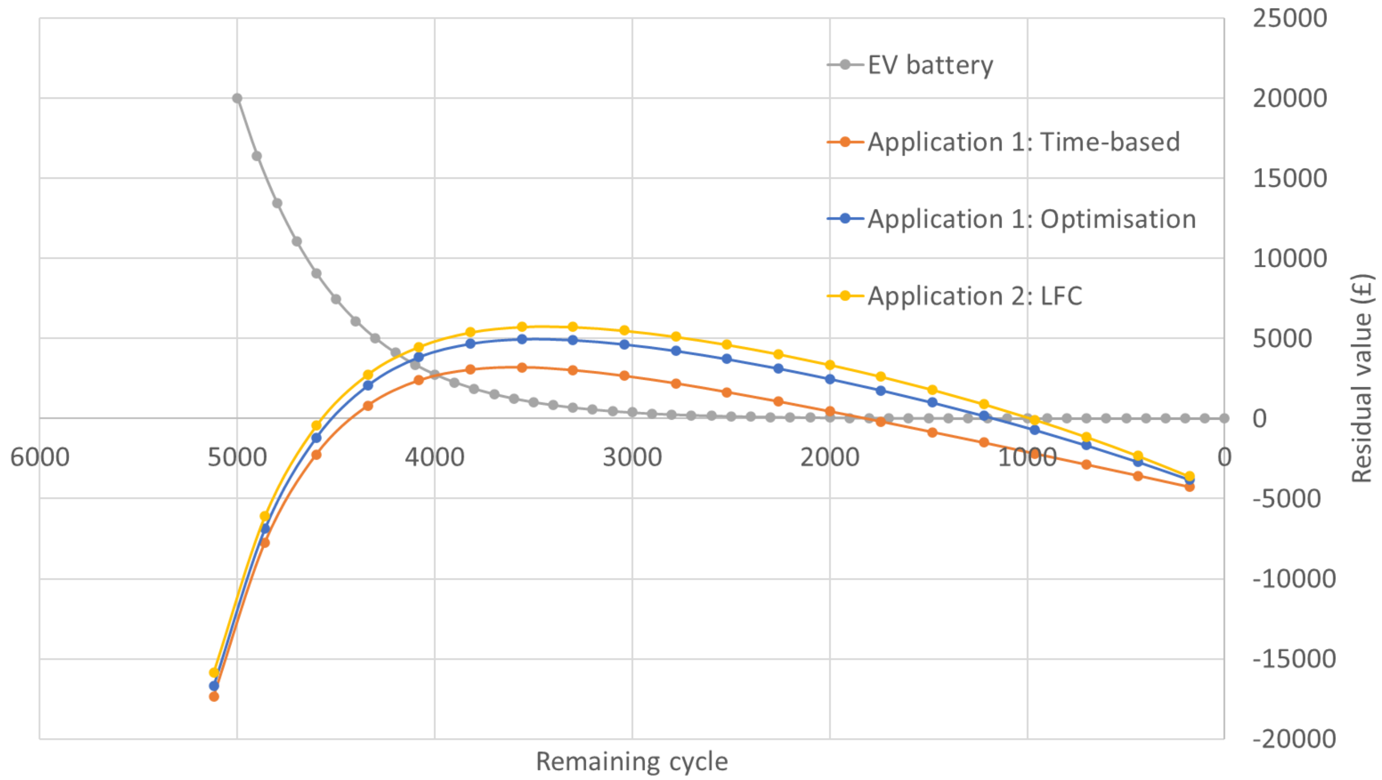
Use SLBs for LFC (100kWh)

SLBs:

- Battery internal resistance: 0.2Ω
- Battery reengineering cost: 6000£

Stage 3 (remaining cycle):

- Linear: 3018 - 4700
- Op.: 2636 - 4750
- LFC: 2500 - 4790



Techno-economic model represented by residual value vs. remaining cycle

Conclusion and discussion

- It presents a comprehensive analysis of the economic feasibility of using second-life EV batteries as stationary energy storage. The study examines the economic benefits of three different control algorithms: time-based control, optimization-based control, and load frequency control, to manage the local generation, energy demand, and battery charging and discharging.

- The study presents a method for evaluating the economic value of second-life EV batteries based on the total residual value versus remaining life cycles. This method provides a new perspective on the residual value of second-life EV batteries throughout their lifespan, from their initial use as EV batteries to their second life and eventual recycling.

- The findings suggest that load frequency control is the most feasible and economically beneficial algorithm, followed by optimization-based control and time-based control. These insights can inform the development of more efficient and cost-effective in the future.