FEVER

Future Electric Vehicle Energy networks supporting Renewables

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Sustainable Electric Vehicle Stations: An Introduction to the Future Electric Vehicle Energy Networks Supporting Renewables Research Project

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8 July 2024

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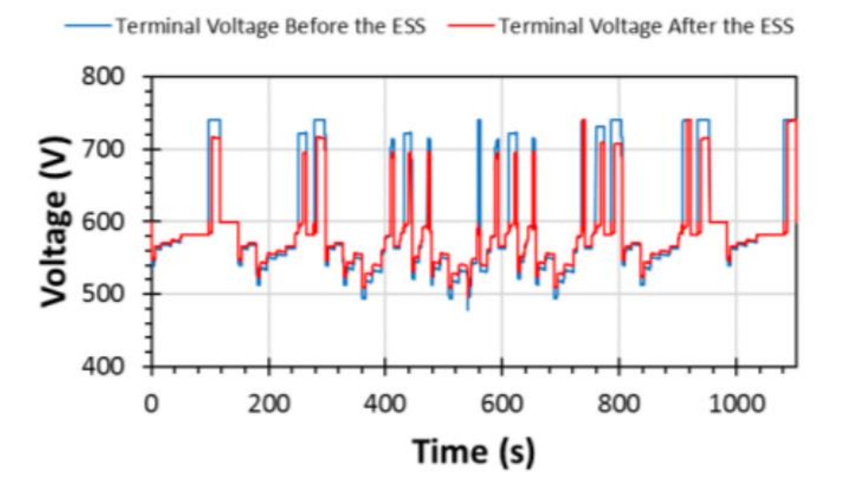
FEVER: A quick overview

FEVER | Future Electric Vehicle Energy networks supporting Renewables

- FEVER: Future Electric Vehicle Networks supporting Renewables
- Aim is to develop an EV charging solution that can deliver fully grid-independent, renewably powered charging
- £6.6 m EPSRC programme grant between (EP/W005883/1)
  - Southampton (lead institution)
  - Sheffield
  - Portsmouth
  - Surrey
- 5 years in duration
  - Started Sept 2022, ending August 2027

Prior related projects

- Willenhall Energy Storage System
  - Grid connected battery research platform
    - 2 MW, 1 MWh
  - Funded by EPSRC (£4.9 m) under Capital for Great Technologies
- TransEnergy: Road to rail
  - Trackside energy storage for rail/metro network to capture regen
  - Funded by EPSRC £1.5 m (EP/N022289/1)
- AdD HyStor
  - Demonstration of dynamic grid stabilisation with an Adaptive-flywheel/battery Hybrid energy Storage system in Ireland and UK
  - Horizon 2020 Framework Programme €3.9 m



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EV charging
National content

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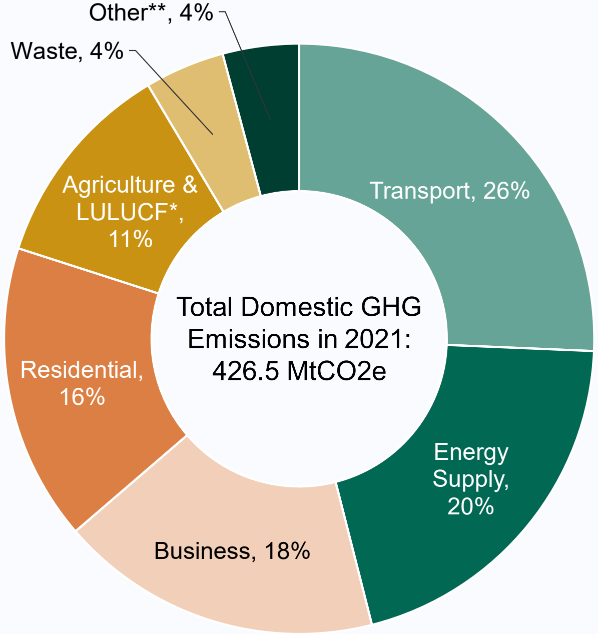
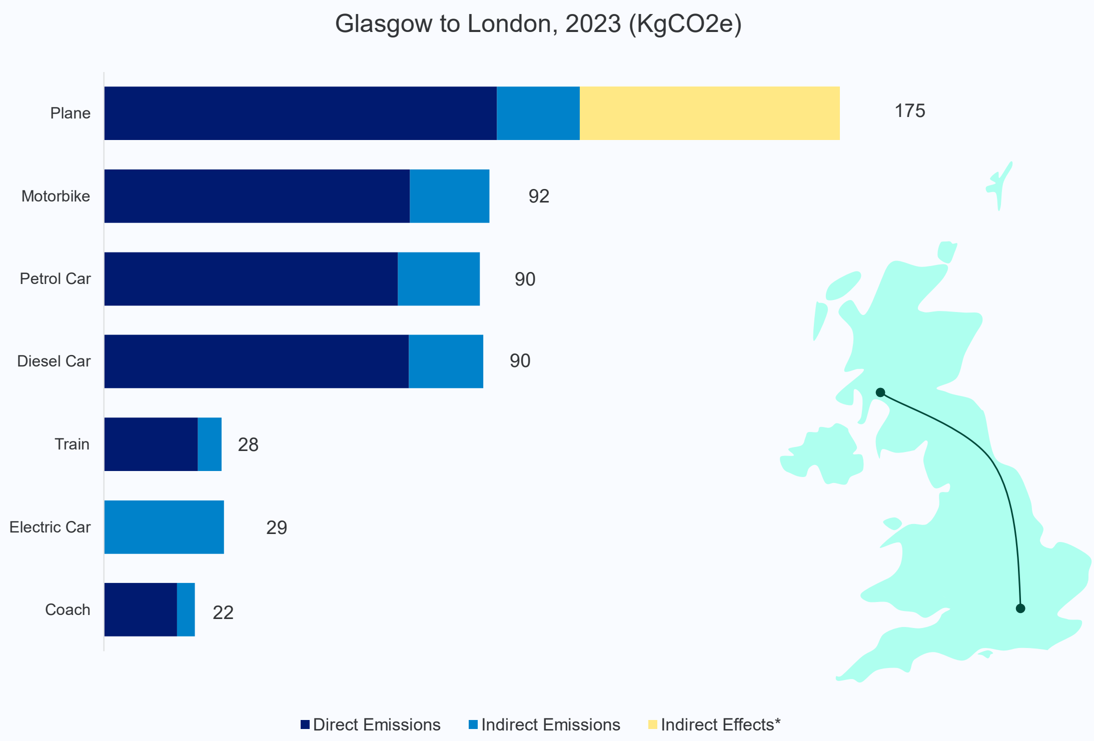
Case for electrification of transport

- Greener, more efficient, quieter, fewer pollutants
- Journey from Glasgow to London
  - ICE 90 kgCO2e
  - EV 29 kgCO2e (reduced by factor of 3)
- Transport accounts for 26% GHG emissions

GHG emissions by sector, 2021, by proportion



Indicative GHG emissions (kgCO2e) for a single passenger on example journeys



https://www.gov.uk/government/statistics/transport-and-environment-statistics-2023/transport-and-environment-statistics-2023

UK Government Strategy

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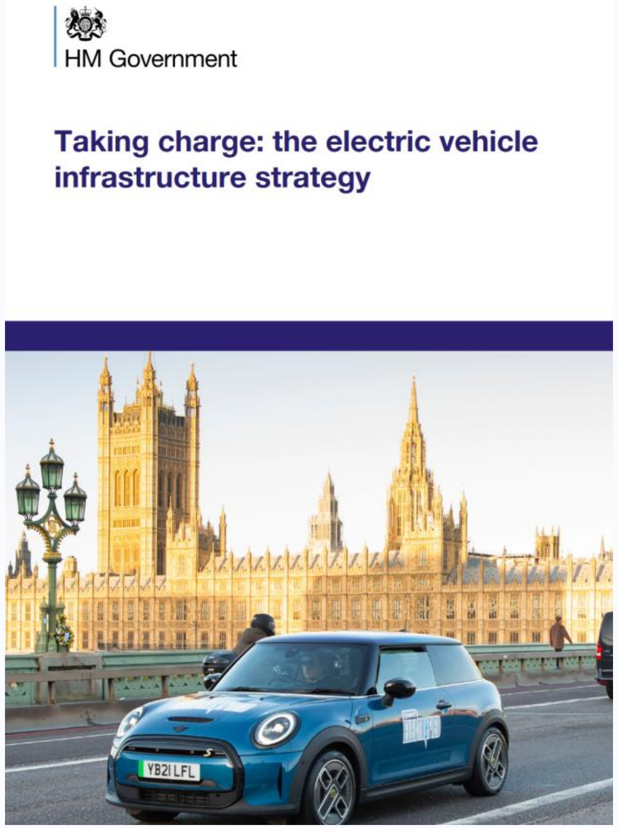
https://www.gov.uk/government/publications/uk-electric-vehicle-infrastructure-strategy, March 2022



- UK Government anticipates 300,000 public charging points by 2030 (minimum, if there is a high proportion of workplace charge points and consumer adopt efficient charging behaviour and lower mileage)
- However up to, potentially, 700,000 public charging points would be needed if there is higher proportion of on-street chargers, consumers drive more and have relatively inefficient charging behaviours
- In May 2024 there were 62,536 public charge points (ZapMap)
- (SMMT) expects that 1.7 million public charge points will be required by 2030 and 2.8 million by 2035 https://www.smmt.co.uk/2020/09/billions-invested-in-electric-vehicle-range-but-nearly-half-of-uk-buyers-still-think-2035-too-soon-to-switch/

Number of EV public charge points

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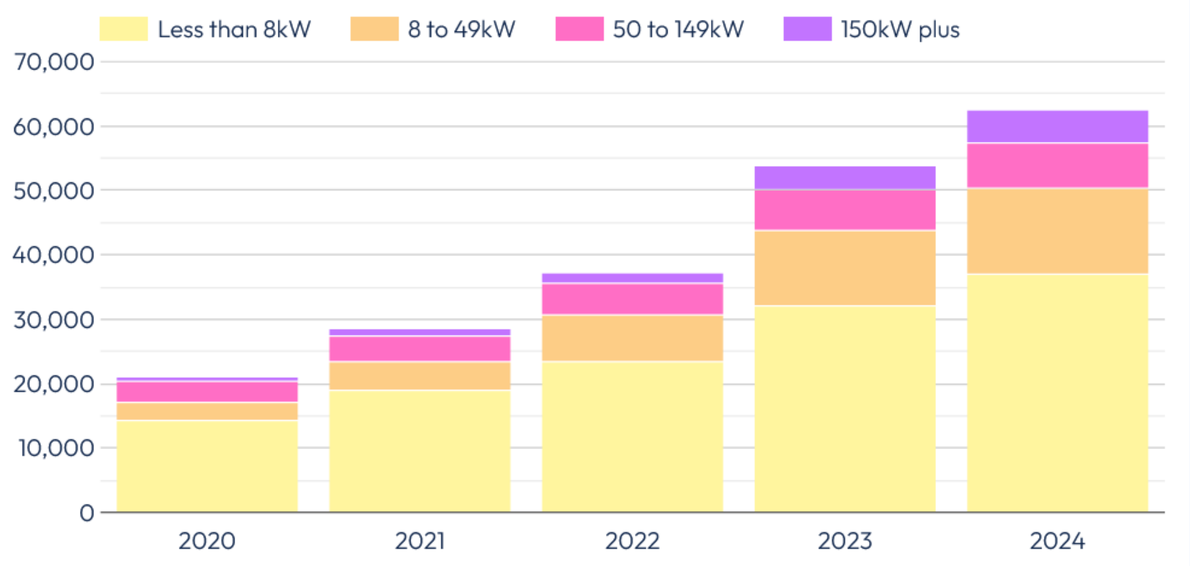
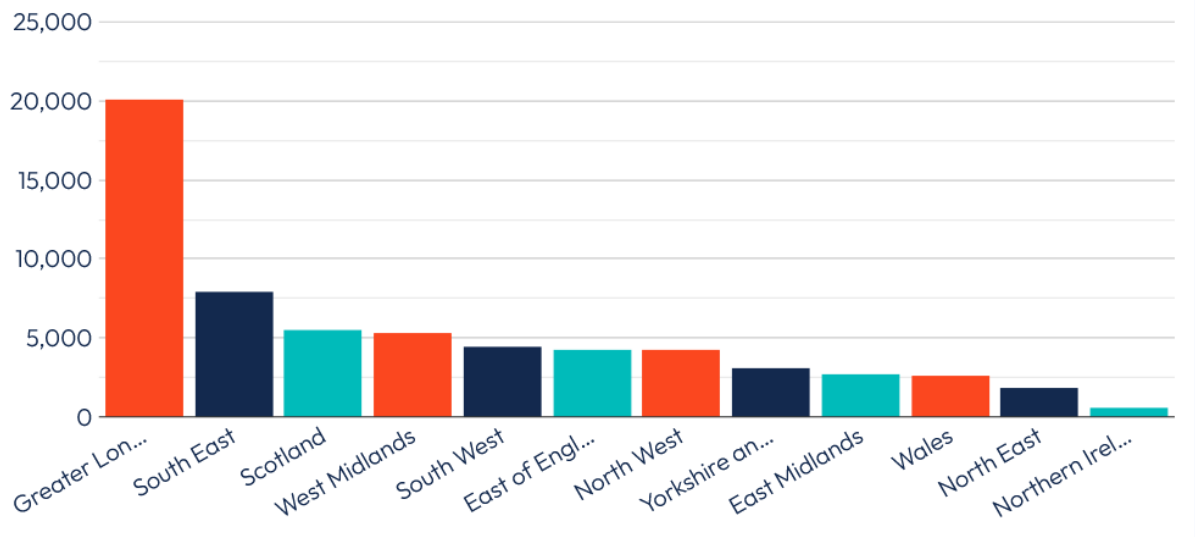
- Statistics from ZapMap May 2024

https://www.zap-map.com/ev-stats/how-many-charging-points

Public charge points by power rating



Public charge points by region



Grid constraints

- Transition to EV will require more electricity generation
- UK needs more renewable generation to growth in EV charging demand
- Some substations have limited capacity for generation

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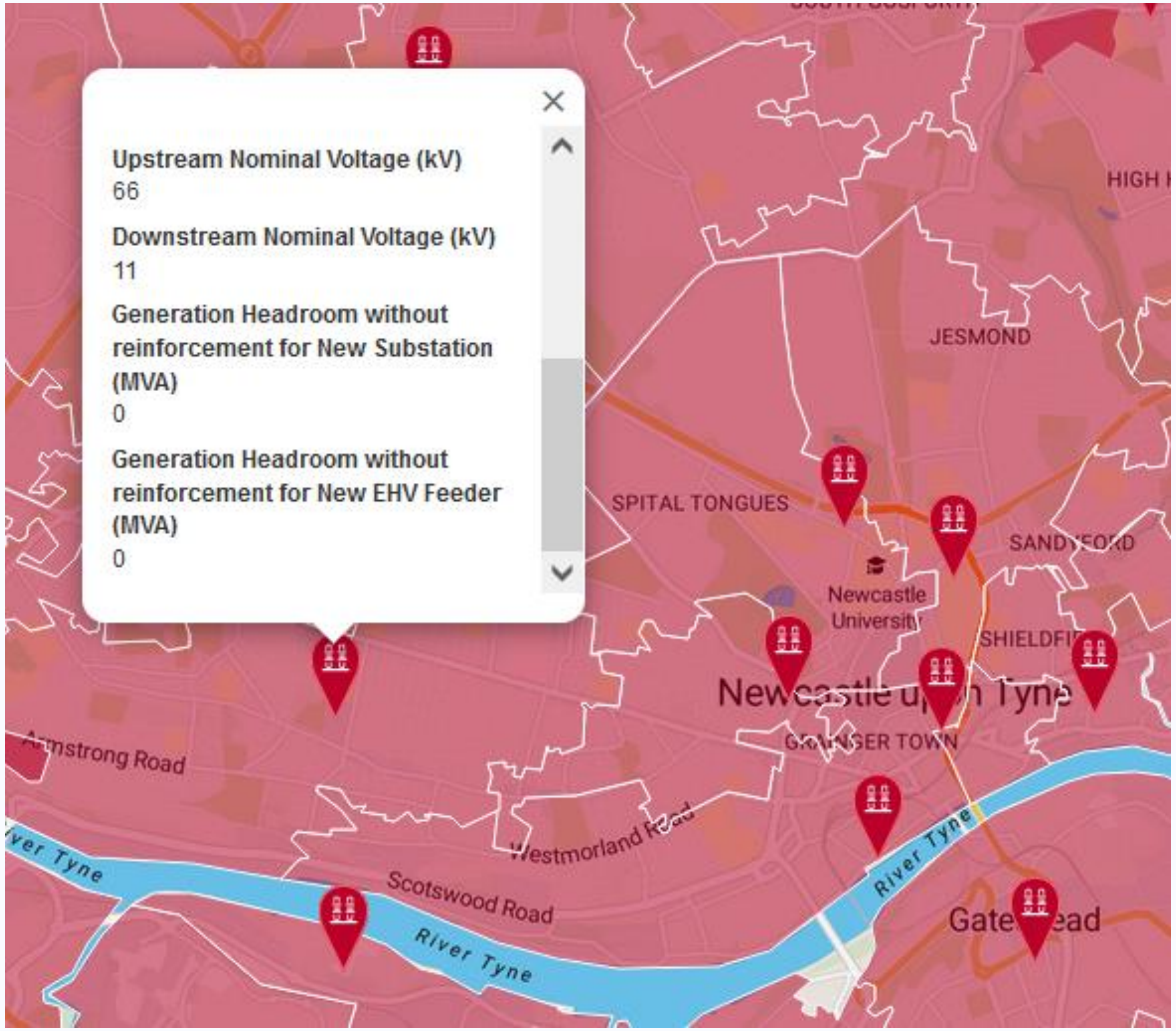
Science & Environment

Renewable energy projects worth billions stuck on hold

Billions of pounds' worth of green energy projects are on hold because they cannot plug into the UK's electricity system, BBC research shows.

Some new solar and wind sites are waiting up to 10 to 15 years to be connected because of a lack of capacity in the system - known as the "grid".



https://www.bbc.co.uk/news/science-environment-65500339

https://northernpowergrid.opendatasoft.com/pages/network_heatmaps/

National Context

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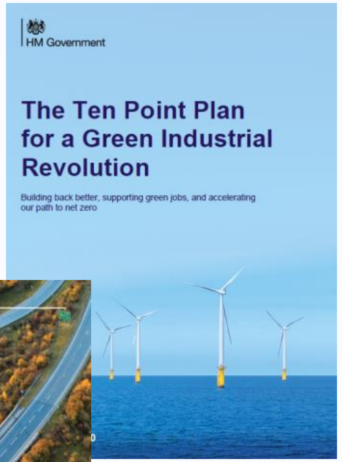
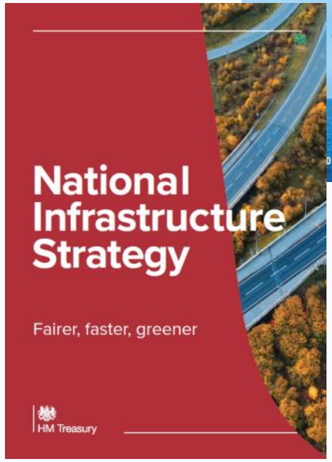
- FEVER proposes a novel solution to the current trilemma of achieving significant growth in EV charging infrastructure, facilitating continued development of on-shore renewable generation and mitigating electricity grid constraints
- The UK transport sector became the largest contributor to the nation's carbon emissions back in 2016
- FEVER clearly supports the 'Ten Point Plan for a Green Industrial Revolution', Point 4 – Accelerating the Shift to Zero Emission Vehicles
- Also supports the National Infrastructure Strategy which will invest £1.3 billion in EV charging infrastructure



Nov 2020



Nov 2020

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FEVER – the concept

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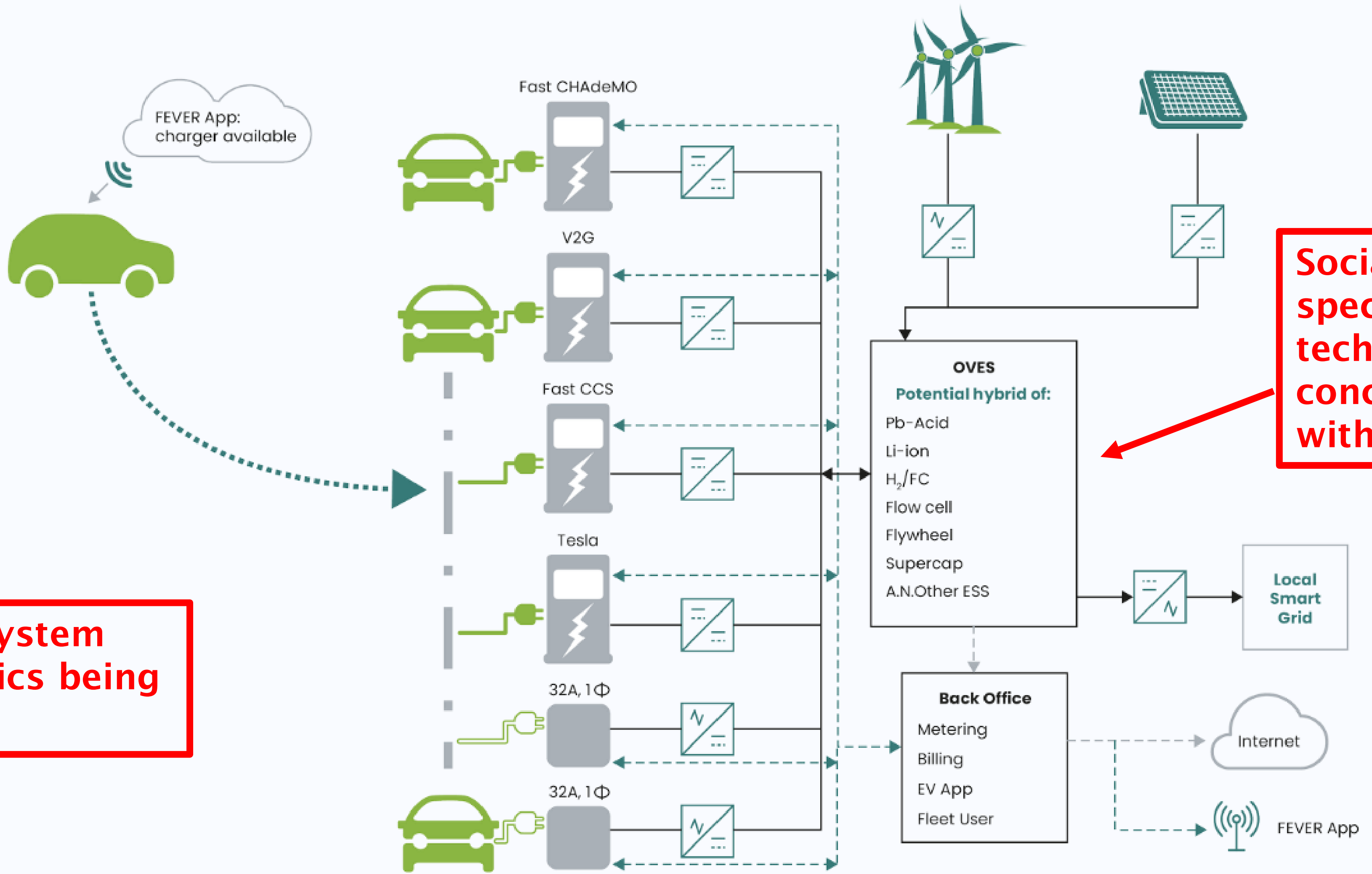
The FEVER concept

FEVER Future Electric Vehicle Energy networks supporting Renewables

- To create a new EV charging solution that can deliver fully grid-independent, renewable energy powered charging using novel Off Vehicle Energy Stores (OVES)
- Investigate the barriers and drivers affecting the development of fully grid-independent, renewables powered OVES based EV charging stations
- Design, develop and trial viable, low-cost, and socially-endorsed solutions to this problem via the novel combination of energy storage technologies
- Construct two functioning demonstrations of an optimised OVES concept
  - explore opportunities to create local ‘smart grids’ to support wider local demand for electricity from homes, industry and business
- Investigate key factors affecting the social acceptability and acceptance of the FEVER concept among key stakeholder groups and individuals (e.g. policy makers, the public)

FEVER - Concept



Social acceptance of the specific ESS technologies and FEVER concept being studied with stakeholders

Whole system economics being studied

Team

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Management structure

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PI Prof Andrew Cruden
University of Southampton

Prof David Stone
University of Sheffield

Dr Chris Jones
University of Portsmouth

Dr Mona Chitnis
University of Surrey

Partnership organisations

CREDS Centre for Research into Energy Demand Solutions

Dialogue Matters

GS YUASA

cenex nederland

The Faraday Institution

Hive Energy

Catapult Connected Places

Shell

SIEMENS

Supergen Energy Storage

wood.

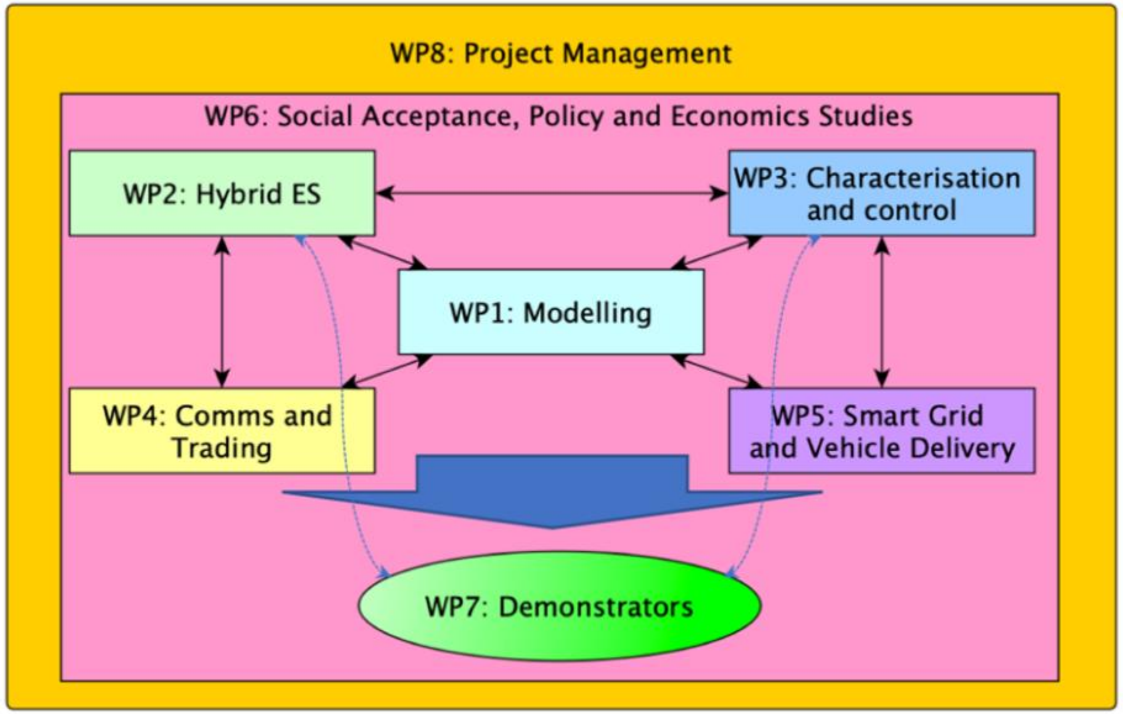
Work packages

- Modelling and design methodology
  - FEVER energy system modelling
  - Specific site modelling and analysis
- Hybrid off-vehicle energy store
  - Hybrid OVES operation, safety and maintenance
  - Economic analysis of OVES
- Characterisation and control
  - New and aged battery packs
  - Fault and system reconfiguration
- Communications and trading
  - Smart charging apps and incentives
  - Deployment and communications
- Social acceptance, policy and economics
  - Co-creation workshops
  - Consumer preferences
  - Community engagement
- Demonstrators
  - Laboratory based technology demonstration
  - FEVER charger station

Work package summary

FEVER Future Electric Vehicle Energy networks supporting Renewables

- Investigate the barriers and drivers affecting the development of fully grid-independent, renewables powered OVES based EV charging stations.
- Design, develop and trial viable, low-cost, and socially-endorsed solutions to this problem via the novel combination of energy storage technologies
- Construct two functioning demonstrations of an optimised OVES concept (i.e. FEVER)
- Explore opportunities to create local 'smart grids' to support wider local demand for electricity from homes, industry and business
- Investigate key factors affecting the social acceptability and acceptance of the FEVER concept among key stakeholder groups and individuals (e.g. policy makers, the public)



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Energy modelling and demonstrator design

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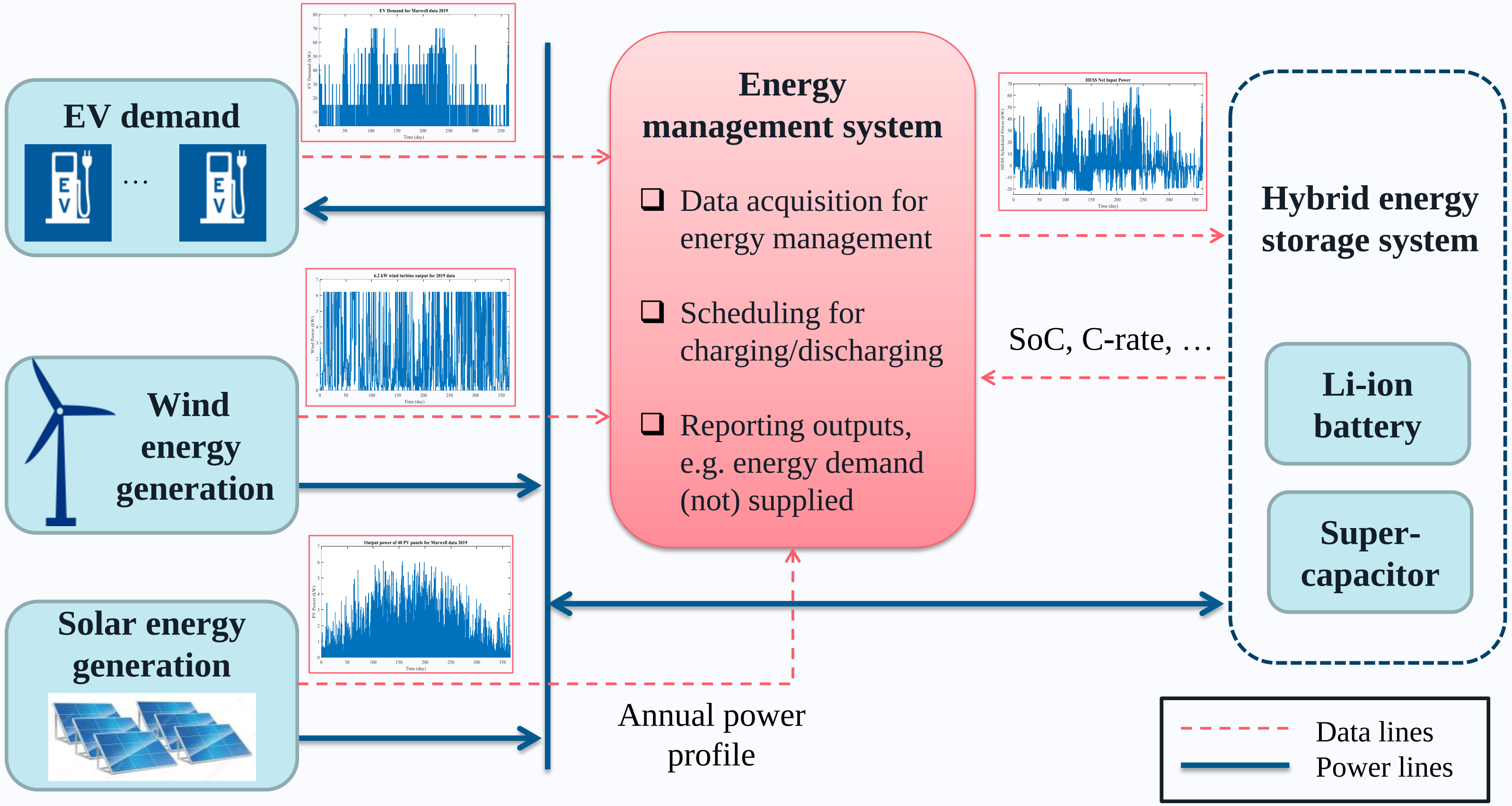
Energy requirements modelling

- For a given EV charging demand, what energy sources and stores are required to meet demand?

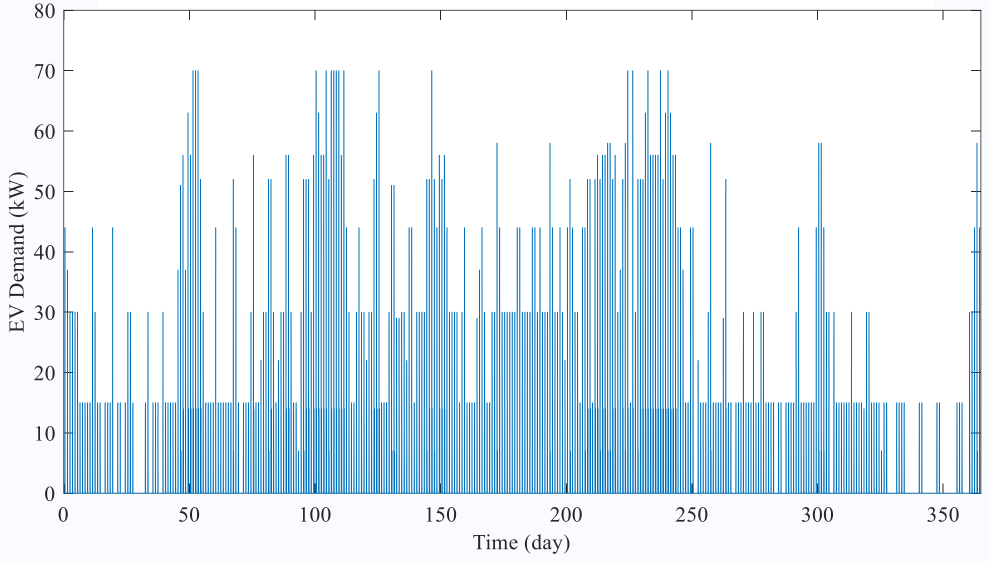


EV charging station microgrid modelling: Zoo

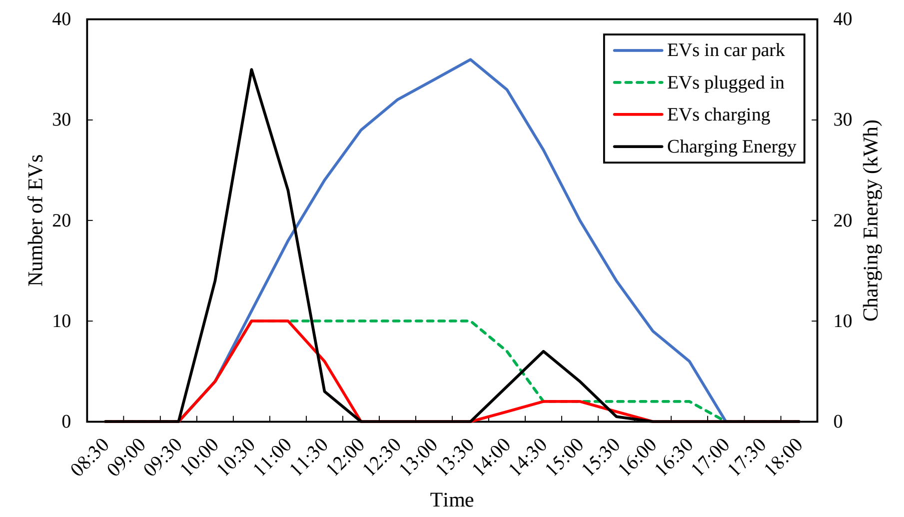
EV load demand modelling

- EVs plug-in and charge from **10 am until 5 pm**
- Charging station has **10 uncontrolled 7 kW AC chargers**
- Daily energy demand for charging the EVs was calculated using the chargers' usage profile based on the **total number of visitors** arriving each day in 2019 and the **hourly visitors' arrival profile**
- Assume four visitors per car, with **3% of these cars being EVs**
- Vehicles parked **4 hours**
- Assume the average efficiency of an EV is **4 miles per kWh** and needs to charge to cover a total distance of **30 miles**

The car park EV power demand for the data of number of visitors and their arrival time in 2019



EVs behaviour and load demand for an example day (20th of April)



EV charging station microgrid modelling

Solar generation unit modelling

- Solar power output calculation by transforming solar irradiance into power

$$P_{pv}\,[kW] = G_{\beta} \times \eta_i \times \eta_p \times p_d \times N_{pv}$$

η_i: inverter efficiency

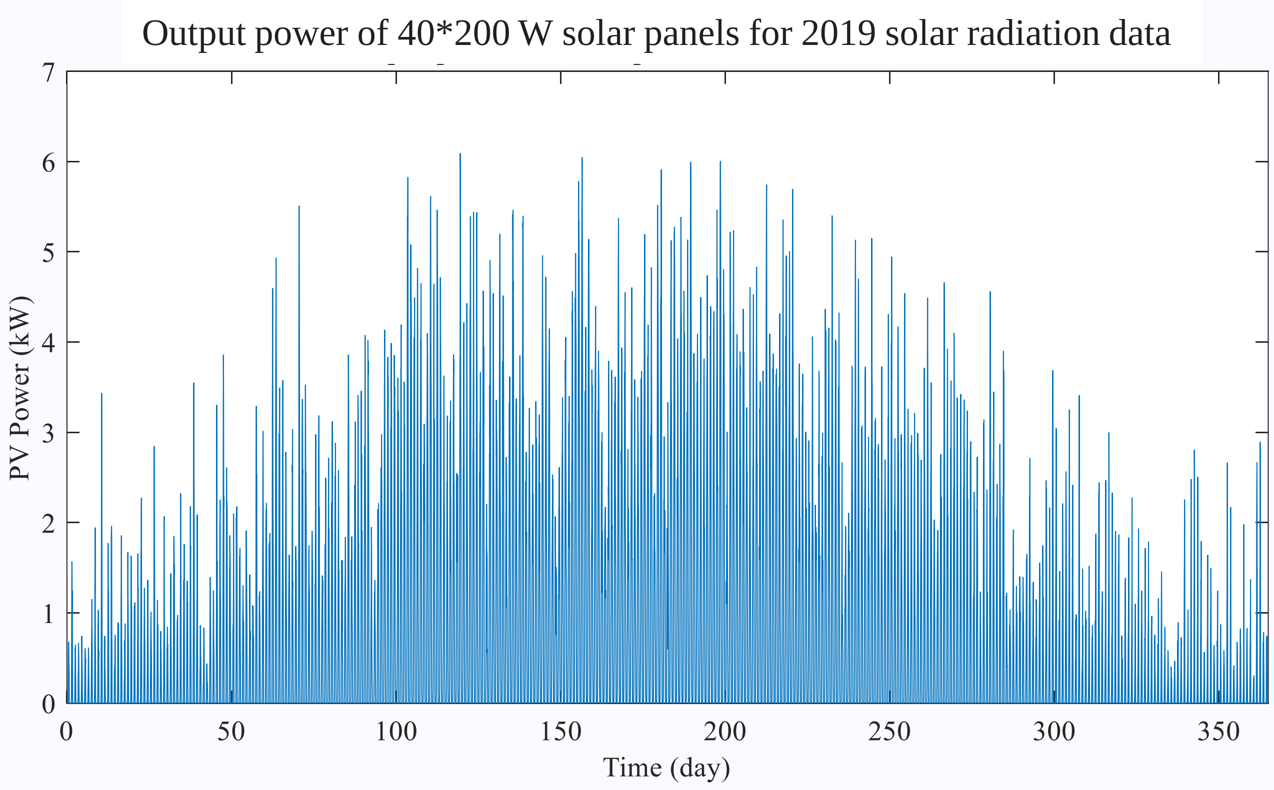
η_p: panel efficiency

p_d: panel dimension (m^2)

G_{β}: solar irradiance on inclined surfaces (kW/m^2)

N_{PV}: Number of panels

- G_{β} has been estimated by using a solar model developed in MATLAB
- The input data for the model (i.e., global horizontal solar irradiation) was obtained through the Centre for Environmental Data Analysis (CEDA) archive.

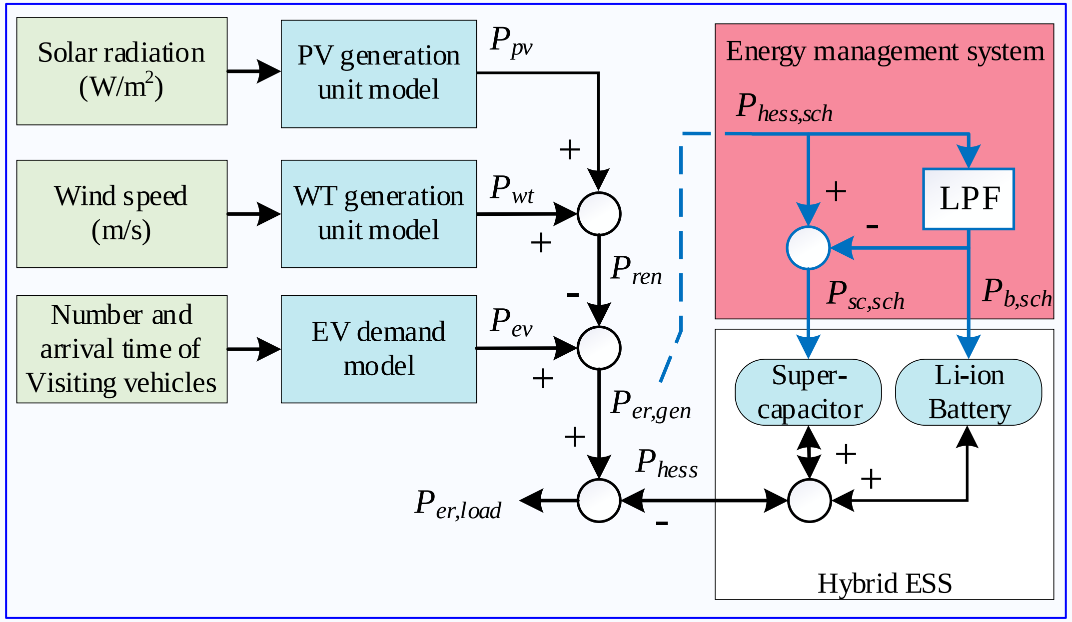


EV charging station microgrid modelling

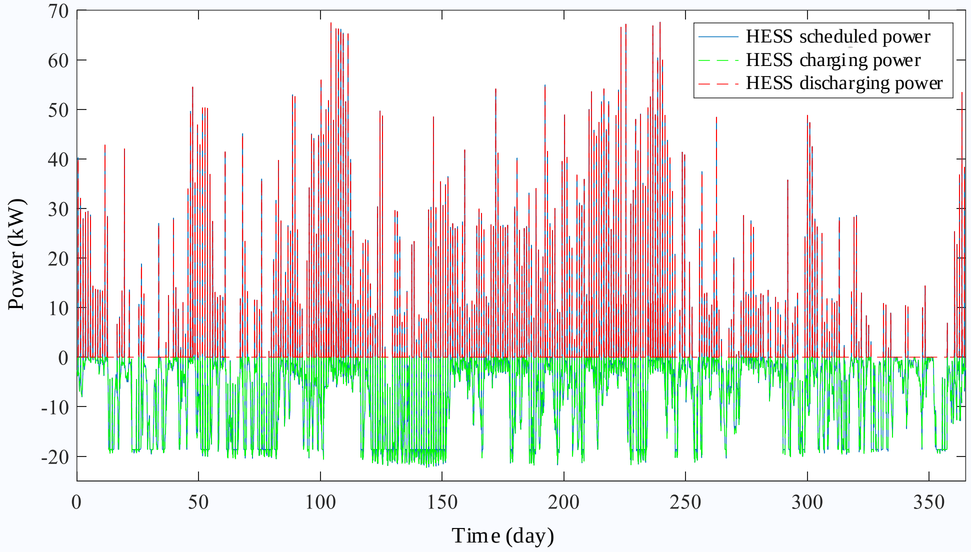
Overall microgrid modelling

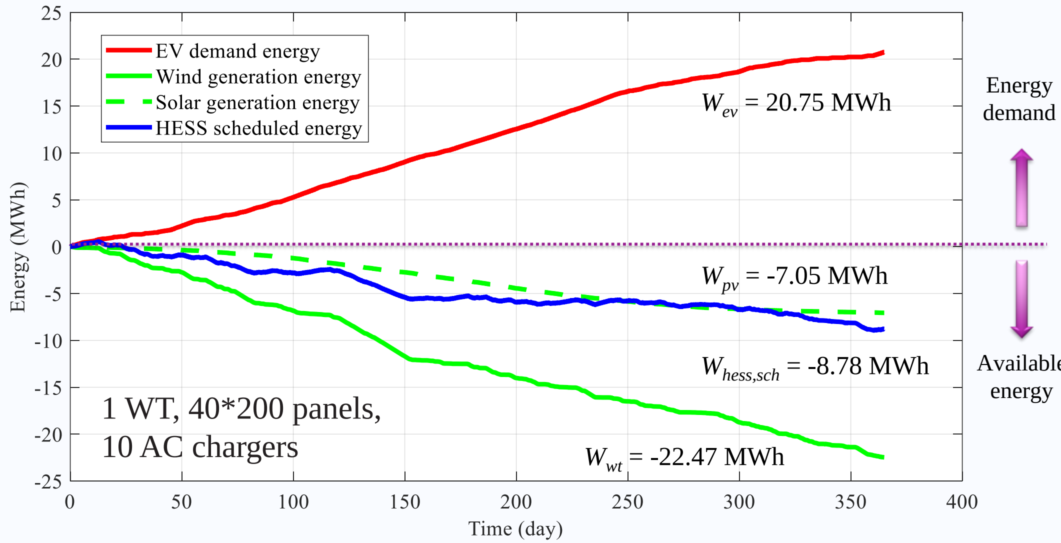
- After modelling the MG modules separately, they should be configured into the entire MG system
- According to the ESS/HESS model assumptions, the load demand is considered as positive values, and the renewable generation is denoted with negative values

Overall model of the studied microgrid



Annual power and energy profiles of demand, renewable generation, and the HESS





Demonstrator site design study

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- Identified several possible locations for demonstrators:
  - Southampton university site to demonstrate hybrid energy storage system featuring lithium, lead-acid and lead soluble flow battery technologies
  - Zoo/animal park providing visitors with charging during their visit
  - Hospital
    - Up to three possible locations with existing onsite renewables
  - Logistics site in the Midlands
    - Conversion of existing carparks into 'FEVER' carparks

- Energy model is used to evaluate combinations of energy source and storage subject to site constraints such as localized shadowing and planning restrictions
- Output informs a further study on economic viability
- Discussions are currently on-going with several parties

Publications

FEVER Future Electric Vehicle Energy networks supporting Renewables

energies MDPI

Article

Techno-Economic Planning of a Fully Renewable Energy-Based Autonomous Microgrid with Both Single and Hybrid Energy Storage Systems

Mobin Naderi [1,*], Diane Palmer [1], Matthew J. Smith [1], Erica E. F. Ballantyne [2], David A. Stone [1], Martin P. Foster [1], Daniel T. Gladwin [1], Amirhossein Khazali [3], Yazan Al-Wreikat [3], Andrew Cruden [3] and Ewan Fraser [3]

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* Correspondence: m.naderi@sheffield.ac.uk

Abstract: This paper presents both the techno-economic planning and a comprehensive sensitivity analysis of an off-grid fully renewable energy-based microgrid (MG) intended to be used as an electric vehicle (EV) charging station. Different possible plans are compared using technical, economic, and techno-economic characteristics for different numbers of wind turbines and solar panels, and both single and hybrid energy storage systems (ESSs) composed of new Li-ion, second-life Li-ion, and new lead-acid batteries. A modified cost of energy (MCOE) index including EVs' unmet energy penalties and present values of ESSs is proposed, which can combine both important technical and economic criteria together to enable a techno-economic decision to be made. Bi-objective and multi-objective decision-making are provided using the MCOE, total met load, and total costs in which different plans are introduced as the best plans from different aspects. The number of wind turbines and solar panels required for the case study is obtained with respect to the ESS capacity using weather data and assuming EV demand according to the EV population data, which can be generalized to other case studies according to the presented modelling. Through studies on hybrid-ESS-supported MGs, the impact of two different global energy management systems (EMSs) on techno-economic characteristics is investigated, including a power-sharing-based and a priority-based EMS. Single Li-ion battery ESSs in both forms, new and second-life, show the best plans according to the MCOE and total met load; however, the second-life Li-ion shows lower total costs. The hybrid ESSs of both the new and second-life Li-ion battery ESSs show the advantages of both the new and second-life types, i.e., deeper depths of discharge and cheaper plans.

Keywords: cost of energy; electric vehicles; energy storage system; microgrid planning; renewable energy

check for updates

Citation: Naderi, M.; Palmer, D.; Smith, M.J.; Ballantyne, E.E.F.; Stone, D.A.; Foster, M.P.; Gladwin, D.T.; Khazali, A.; Al-Wreikat, Y.; Cruden, A.; et al. Techno-Economic Planning of a Fully Renewable Energy-Based Autonomous Microgrid with Both Single and Hybrid Energy Storage Systems. *Energies* **2024**, 17, 788. https://doi.org/10.3390/en17040788

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1. Introduction

The number of electric vehicles (EVs) is expected to increase significantly in developed countries to both decrease fossil fuel usage and achieve healthier and less polluted air in urban areas. This is supported by government policies on different scales. As an example, the United Kingdom (UK) government announced that all new passenger cars will be zero-emissions vehicles (ZEVs) at the tailpipe from 2035 to reduce the transport sector emissions [1], which is now the highest emitting sector in the UK, having overtaken the energy sector [2]. Additionally, the UK's introduction of the ZEV mandate in 2024 requires

Energies **2024**, 17, 788. https://doi.org/10.3390/en17040788 https://www.mdpi.com/journal/energies

PCIM Europe 2024, 11– 13 June 2024, Nuremberg DOI: 10.30420/566262118

pcim EUROPE

Modelling and Sizing Sensitivity Analysis of a Fully Renewable Energy-Based Electric Vehicle Charging Station Microgrid

Mobin Naderi[1], Diane Palmer[1], Maria N. Munoz[2], Yazan Al-Wreikat[3], Matthew Smith[1], Ewan Fraser[3], Erica E. F. Ballantyne[2], David A. Stone[1], Daniel T. Gladwin[1], Martin P. Foster[1]

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Abstract

This paper presents long-term modelling and second-by-second simulation of an autonomous microgrid (MG), including only renewable energy sources (RESs) and a hybrid energy storage system (HESS) as energy provider, and an electric vehicle (EV) Charging Station as a group load. The model uses forecast data for wind speed and solar radiation to provide wind turbine (WT) and photovoltaic (PV) generated powers, and statistical data for vehicles within a defined car park to model the EV demand. It is flexible and can support varying several planning parameters, e.g. varying sizes of WT and PV generation as well as various capacities of energy storage systems (ESSs). Therefore, in order to examine the impact of variations in RESs and ESS sizes, as well as the impact of EV demand uncertainties on the performance and efficiency of the MG, e.g. EV unmet energy, several sensitivity analyses are provided. Based on sensitivity analysis results, one can find reasonable ranges of MG module sizes, and make a decision for sizing of the overall system. For the case study represented here, results show that at least one WT is required, increasing PV panels is more effective to meet the midday EV load in at the target location, and a lower level of Li-ion ESS capacity is sufficient storage for the charging/discharging of the EVs.

1 Introduction

The United Kingdom (UK) government is set to end the sale of new petrol and diesel vehicles by 2030 and only allow the sales of zero-emissions vehicles from 2035 to reduce transport sector emissions [1]. Charging electric vehicles (EVs) from electricity networks powered by renewable energy has the potential to maximise the decarbonisation plan for road transport. As the number of EVs grow in the UK, the rise in charging infrastructure is projected to increase to meet the demand to charge these vehicles, reaching a minimum number of 300,000 public charging points by 2030 [2]. Nevertheless, some challenges, like grid demand increase and supplying EVs by fossil fuels via converting to electrical energy, increases the importance of grid-isolated renewable energy-based charging stations.

The solution proposed here is a fully grid-independent EV charging station powered exclusively by renewable energy. This solution is developed as part of Future Electric Vehicle Energy networks supporting Renewables (FEVER) project [3]. RES generation, such as by solar and wind, supply EV chargers via an off-vehicle energy store (OVES), containing at least one energy storage technology to provide a cost-effective alternative to a high power, high-cost grid connection. Future publications will describe more hybrid OVESs with multiple ESS technologies.

In design and construction of electrical systems, e.g. the FEVER microgrid (MG), sizing of elements, particularly large elements, has a significant importance. On the other hand, MG planning and element sizing studies require

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Hybrid Energy Storage System – for off-vehicle energy store (OVES)

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Hybrid energy storage systems

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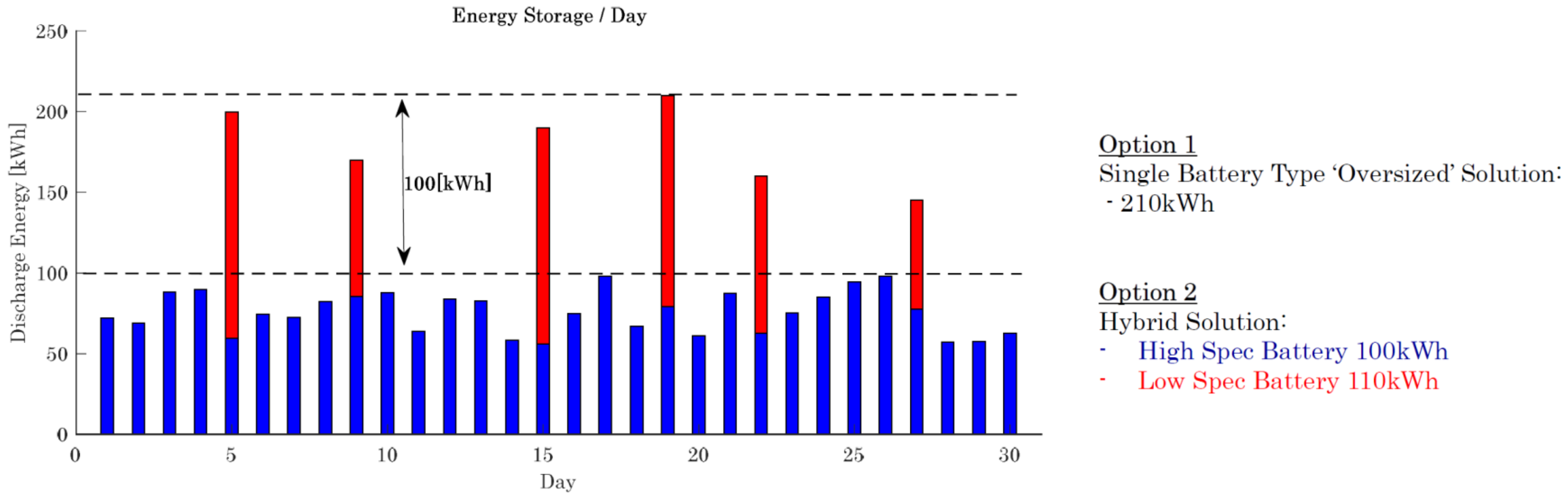
- Short-term and long-term requirements due to seasonality, demand and availability of generation
- Investigate of different energy storage technologies
  - Battery (li-ion, lead, flow type)
  - Fuel cells
  - Bio-fuels
- Considerations
  - CAPEX and OPEX
  - Availability of energy
  - Size of installation
  - Complexity
  - Control



1. Split capacity types and, ideally, cost via hybridisation

2. Opportunity for more sustainable solution?

Li-ion & Lead-acid hybrid system – Dual Chemistry System

Lithium ion strengths

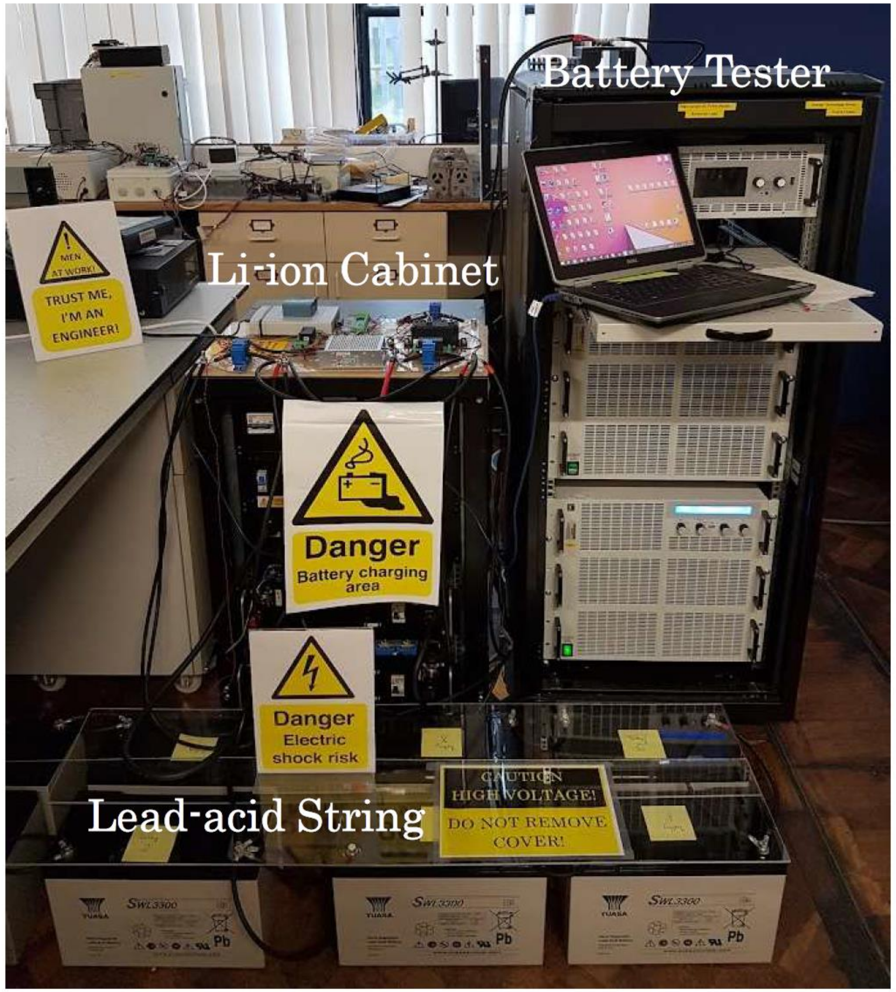
- Cycle Life
- High Discharge Rate
- High Charge Rate
- Partial SOC operation
- High Efficiency
- High Energy Density

Lead acid strengths

- Economical
- Simple Control
- Abuse Tolerant
- Sustainable Materials
- Abundant Raw Materials
- Low Embodied Energy

1. **Has reduced li-ion capacity and cost via hybridisation**
2. **Offers percentage of highly recyclable BESS - more sustainable**

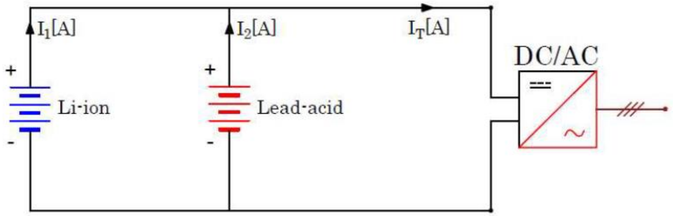
Hybrid BESS – Experimental Testing

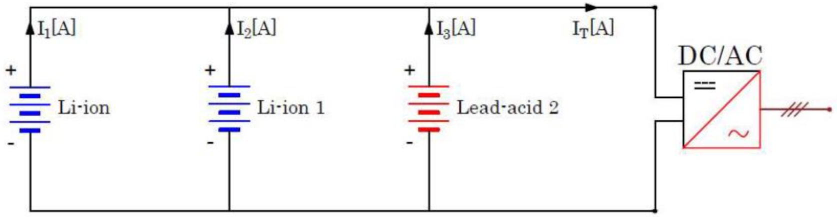


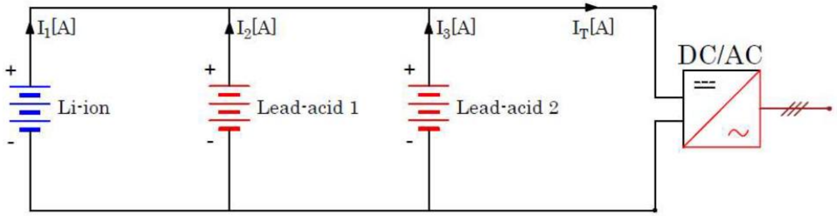
Lab Based Hybrid Battery System

SWR3300 Battery

LIM50 Battery Cell







Hybrid BESS – Experimental Testing

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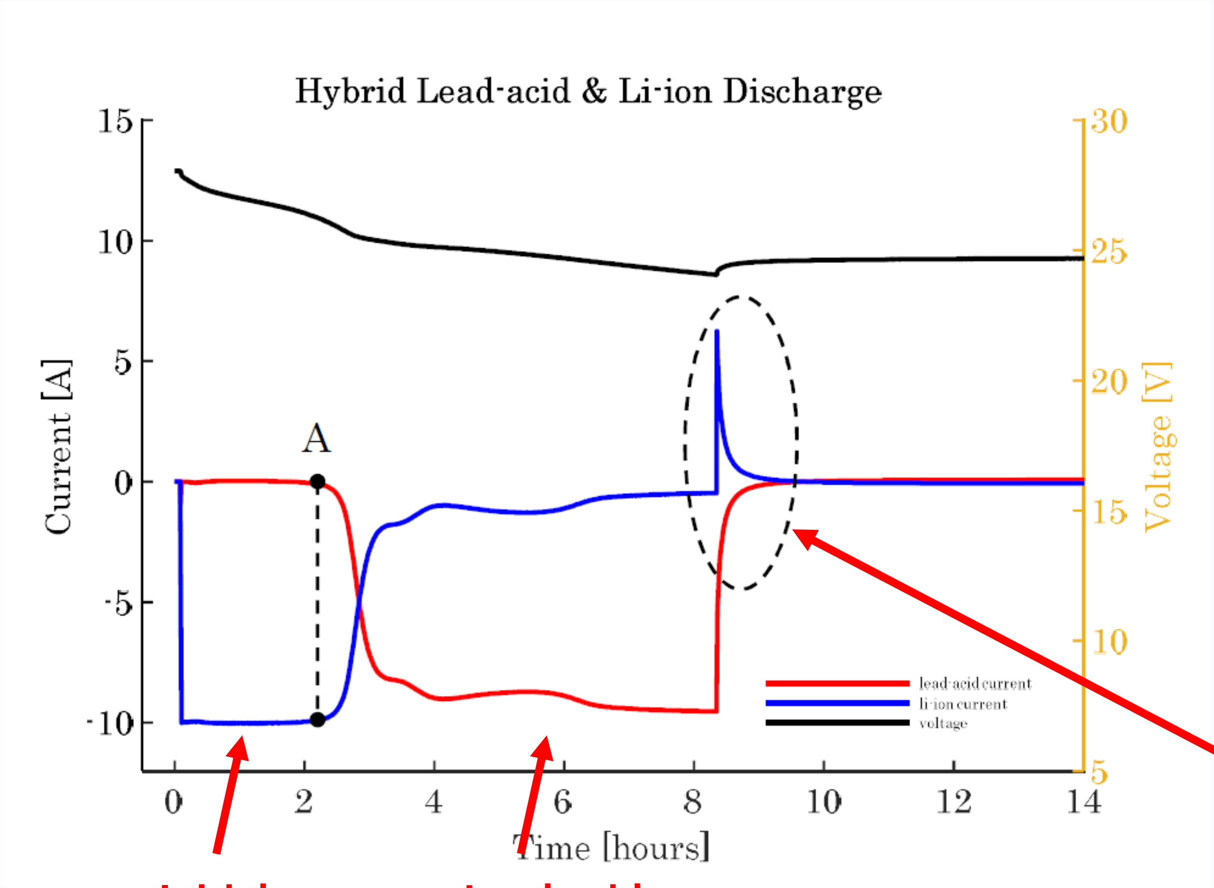
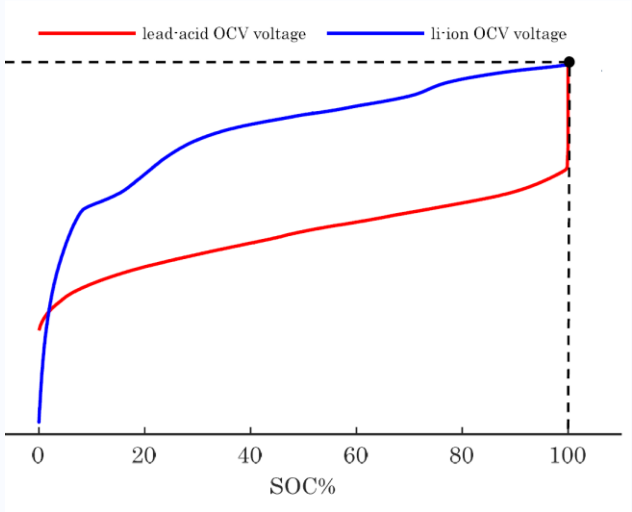


Initial discharge only Li-ion

Lead-acid then takes over

At the end of discharge there are circulating currents



Recall voltage versus SoC characteristic of Hybrid ESS

Communications and trading

Develop underlying ICT system for OVES charging stations

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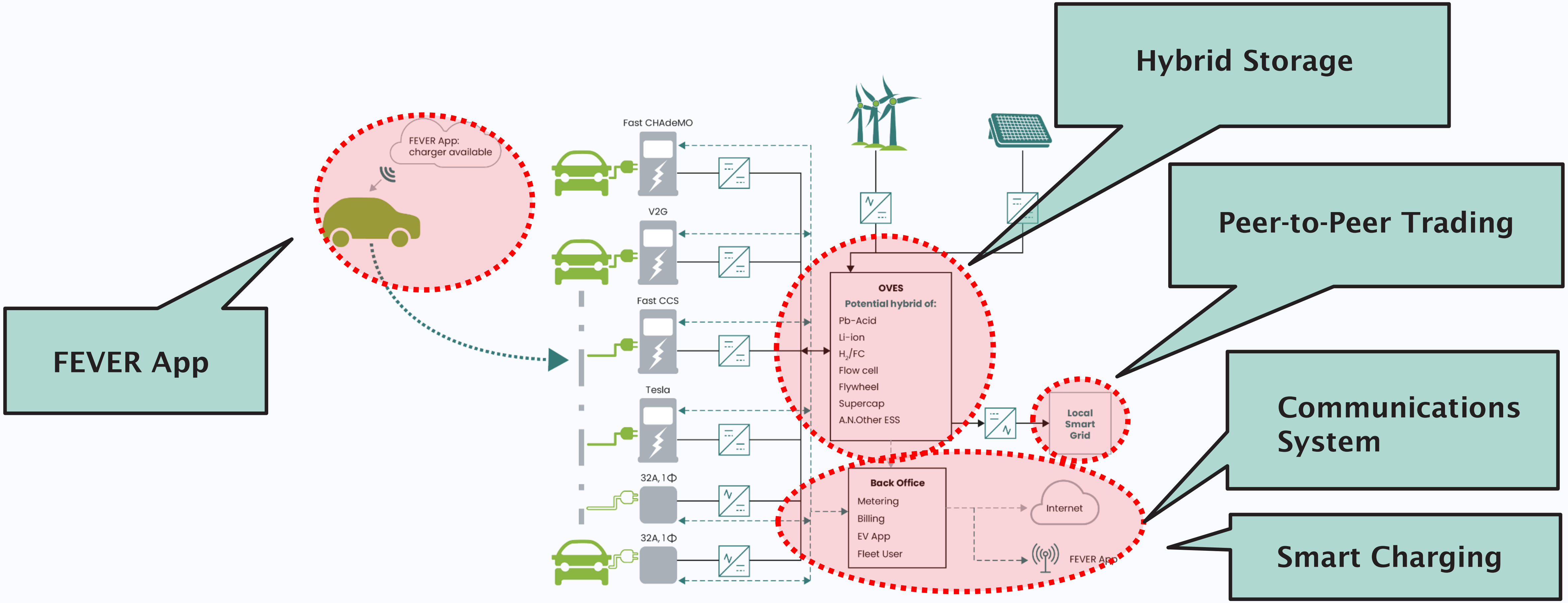
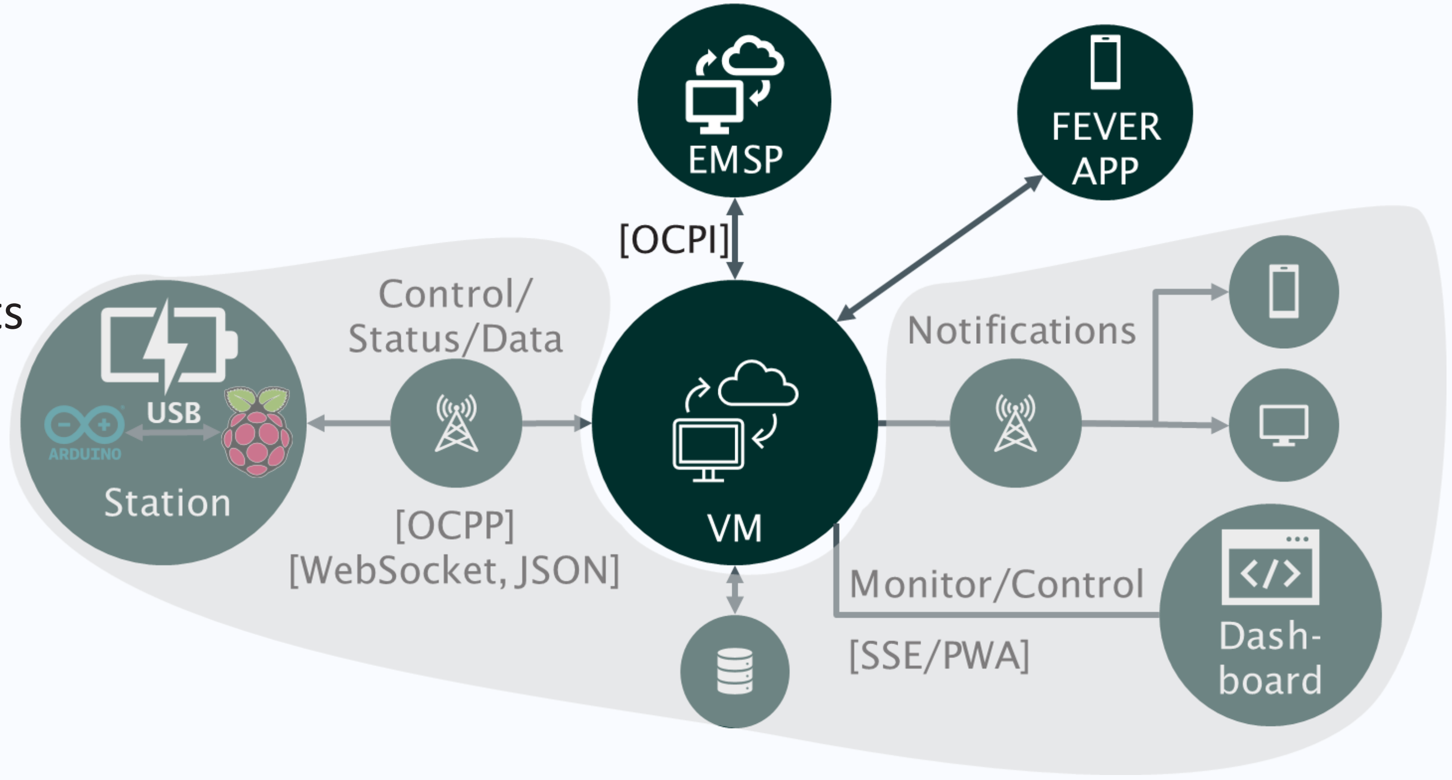


Data connectivity

- E-mobility provider/Roaming Provider requirements
- Open Charge Point Interface (OCPI)
- Customer integration
- Billing
- Report Requirements
- Potentially reliability requirements



FEVER app

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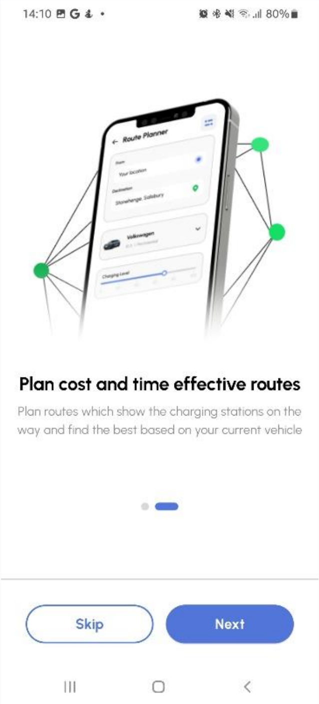

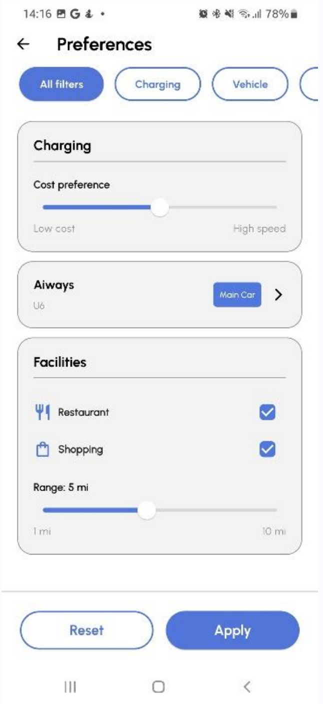

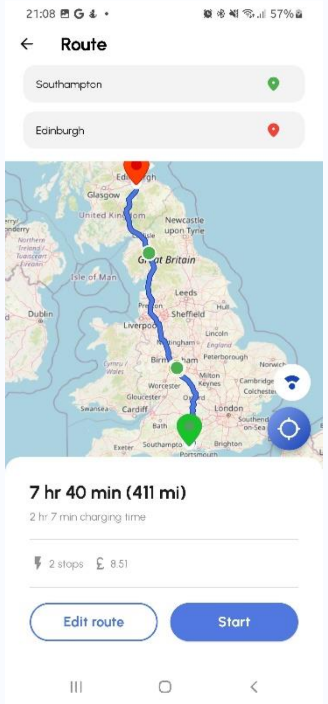

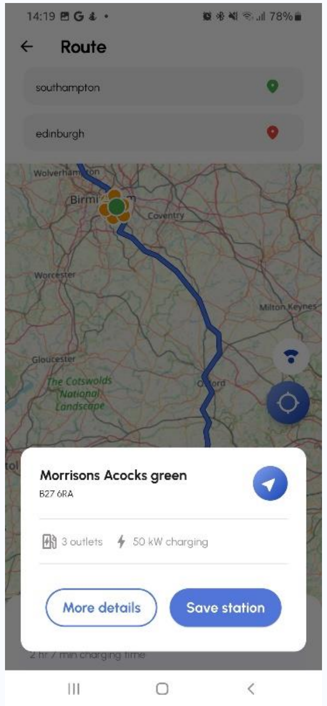

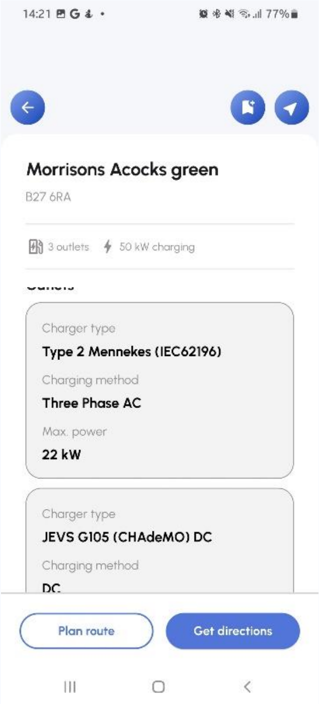

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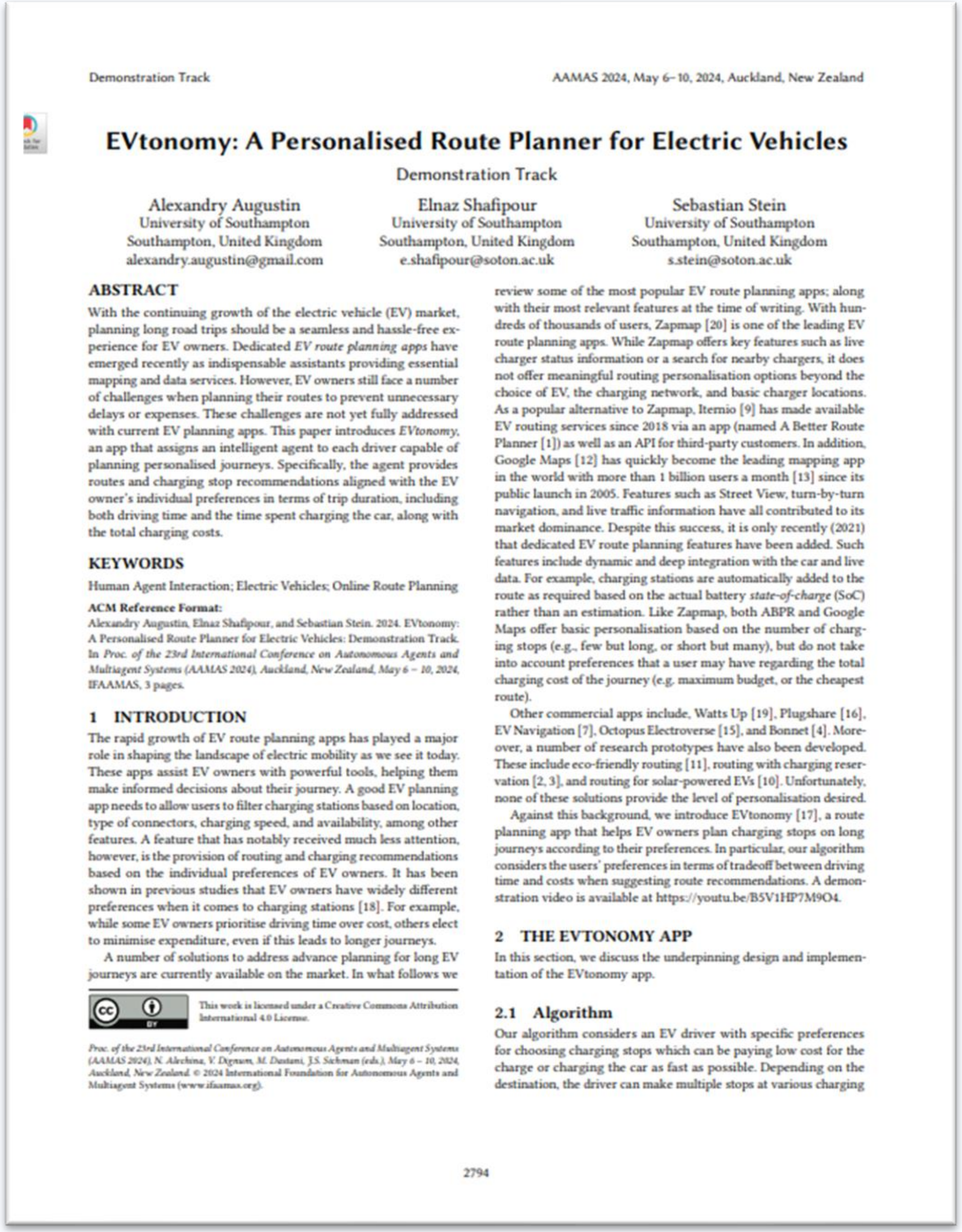

EVtonomy: A Personalised Route Planner for Electric Vehicles

Demonstration Track

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ABSTRACT

With the continuing growth of the electric vehicle (EV) market, planning long road trips should be a seamless and hassle-free experience for EV owners. Dedicated *EV route planning apps* have emerged recently as indispensable assistants providing essential mapping and data services. However, EV owners still face a number of challenges when planning their routes to prevent unnecessary delays or expenses. These challenges are not yet fully addressed with current EV planning apps. This paper introduces *EVtonomy*, an app that assigns an intelligent agent to each driver capable of planning personalised journeys. Specifically, the agent provides routes and charging stop recommendations aligned with the EV owner's individual preferences in terms of trip duration, including both driving time and the time spent charging the car, along with the total charging costs.

KEYWORDS

Human Agent Interaction; Electric Vehicles; Online Route Planning

ACM Reference Format:
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1 INTRODUCTION

The rapid growth of EV route planning apps has played a major role in shaping the landscape of electric mobility as we see it today. These apps assist EV owners with powerful tools, helping them make informed decisions about their journey. A good EV planning app needs to allow users to filter charging stations based on location, type of connectors, charging speed, and availability, among other features. A feature that has notably received much less attention, however, is the provision of routing and charging recommendations based on the individual preferences of EV owners. It has been shown in previous studies that EV owners have widely different preferences when it comes to charging stations [18]. For example, while some EV owners prioritise driving time over cost, others elect to minimise expenditure, even if this leads to longer journeys.

A number of solutions to address advance planning for long EV journeys are currently available on the market. In what follows we review some of the most popular EV route planning apps; along with their most relevant features at the time of writing. With hundreds of thousands of users, Zapmap [20] is one of the leading EV route planning apps. While Zapmap offers key features such as live charger status information or a search for nearby chargers, it does not offer meaningful routing personalisation options beyond the choice of EV, the charging network, and basic charger locations. As a popular alternative to Zapmap, Iternio [9] has made available EV routing services since 2018 via an app (named A Better Route Planner [1]) as well as an API for third-party customers. In addition, Google Maps [12] has quickly become the leading mapping app in the world with more than 1 billion users a month [13] since its public launch in 2005. Features such as Street View, turn-by-turn navigation, and live traffic information have all contributed to its market dominance. Despite this success, it is only recently (2021) that dedicated EV route planning features have been added. Such features include dynamic and deep integration with the car and live data. For example, charging stations are automatically added to the route as required based on the actual battery *state-of-charge* (SoC) rather than an estimation. Like Zapmap, both ABPR and Google Maps offer basic personalisation based on the number of charging stops (e.g., few but long, or short but many), but do not take into account preferences that a user may have regarding the total charging cost of the journey (e.g. maximum budget, or the cheapest route).

Other commercial apps include, Watts Up [19], Plugshare [16], EV Navigation [7], Octopus Electroverse [15], and Bonnet [4]. Moreover, a number of research prototypes have also been developed. These include eco-friendly routing [11], routing with charging reservation [2, 3], and routing for solar-powered EVs [10]. Unfortunately, none of these solutions provide the level of personalisation desired.

Against this background, we introduce EVtonomy [17], a route planning app that helps EV owners plan charging stops on long journeys according to their preferences. In particular, our algorithm considers the users' preferences in terms of tradeoff between driving time and costs when suggesting route recommendations. A demonstration video is available at https://youtu.be/B5V1HP7M9O4.

2 THE EVTONOMY APP

In this section, we discuss the underpinning design and implementation of the EVtonomy app.

2.1 Algorithm

Our algorithm considers an EV driver with specific preferences for choosing charging stops which can be paying low cost for the charge or charging the car as fast as possible. Depending on the destination, the driver can make multiple stops at various charging

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FEVER Joint Stakeholder Workshop – Fleet and Commercial Users

FEVER Joint Stakeholder Workshop

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- Held 15th of May 2024 in Rugby
- Supported by the Chartered Institute of Logistics & Transport (CILT) UK
- Dr Erica Ballantyne led the workshop and presented an overview of EV charging for commercial fleet
- Dr Iain Mosely from Nyobolt discussed challenges and opportunities for high-power fleet charging
- Dr Nick Head introduced the sustainability roadmap at XPO and discussed issues regarding feasibility and practicality associated with the electrification of HGVs
- 30 stakeholders participated in workshop discussions
  - Electric fleet operations
  - Integration of hydrogen into an off-grid charging solution
  - Social acceptance and economic views
  - EV charger power

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Roundtable
The regulatory impact of offgrid Electric Vehicle (EV) charging

University of Southampton
University of Sheffield
University of Surrey
University of Portsmouth
UKRI Engineering and Physical Sciences Research Council

Roundtable event held in Westminster

FEVER Future Electric Vehicle Energy networks supporting Renewables

- Policy event in London on 18th April 2024
- Opportunity to
  - Share our early findings on how the technological, social and regulatory aspects of independent EV charging are developing
  - Get your thoughts on the future challenges to inform our work
- Attended Ofgemm, Sussex Climate Commission, an MP, OZEV and Southampton City Council
- Output from the event written up into a 3 page policy brief

FEVER Future Electric Vehicle Energy networks supporting Renewables | UKRI Engineering and Physical Sciences Research Council

Policy Brief: The regulatory impact of off-grid Electric Vehicle (EV) charging

The Electric Vehicle (EV) policy landscape will need to continue evolving to enable EV adoption targets, in particular to unlock the rollout of new inclusive and equitable charging infrastructure.

Electric vehicle (EV) ownership and domestic and commercial use in the United Kingdom (UK) is increasing rapidly, with 41% growth in plug-in cars registered from 2022 to 2023 and 28.3% of all new cars sold in December 2023 being either fully electric or plug-in hybrids. Predicted energy demand resulting from the growth in EVs in the UK is anticipated to reach around 30 TWh by 2030, and around 65-100 TWh by 2050.

Roundtable: The regulatory impact of off-grid Electric Vehicle (EV) charging

Agenda:

9:45 – 10am	*Arrival and refreshments*
10:00-10:30am	**Intro to FEVER –** • What, Why and How? • What scenarios might it be deployed? • Share draft Policy Brief
10:30-11:30am	**Unpicking the EV policy landscape -** • What is the EV charging infrastructure policy landscape and adoption targets? • What policies are currently in development or under consideration/consultation? • Who are the different key stakeholders in the value chain and what powers do they have to enable or challenge deployment of new infrastructure, e.g. DfT, OZEV, DNOs, Ofgem, Local Authorities.
11:30-11:40pm	*Short refreshment break*
11:40-12:30pm	**How could FEVER be deployed to address EV infrastructure challenges?** • Mapping of different deployment scenarios • What do the different deployment scenarios mean for policy and national EV infrastructure, Bridging infrastructure for National Highways, agricultural setting to charge plant equipment, community ownership of assets. • Role of the regulator
12:30-1:00pm	**Planning for future collaboration –** • Summary of discussion and agreement of next steps captured • Group Input into the policy brief • Policy maker feedback on the future research direction for the FEVER project

Final words

Concluding words

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- Two years into a five project

- Started technology evaluations and establishing laboratory demonstrators

- In discussions with location owners for potential demonstrator sites

- Major next step is to select the demonstrators

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YOUR QUESTIONS

www.fever-ev.ac.uk

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