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Electric Road Systems

Modelling & simulation research at the CSRF / University of Cambridge

Presented by: **Christopher de Saxe** (Zeus Labs, UK)
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Other team members:
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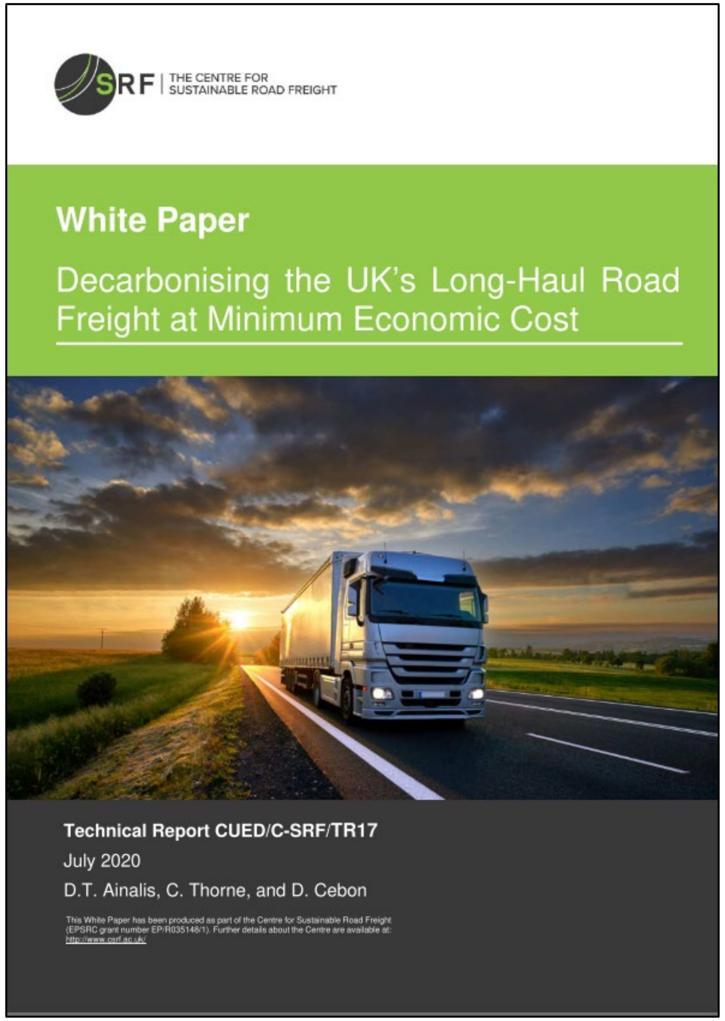
Electric Road Systems

- An **Electric Road System (ERS)** is an economically attractive solution to decarbonise Heavy Goods Vehicles (HGVs) HGVs in the UK
- An ERS **reduces the battery capacity** needed for many journeys vs. “big-battery” trucks
- This reduces:
  - Vehicle cost, weight & efficiency
  - Embodied emissions
  - Peak loading on the electricity grid
- Objectives:
  - Techno-economic comparison with BEV/FCEV
  - Quantify impact on battery sizes
  - Country-agnostic ERS investment model

UK ERS research overview

2020 CSRF White Paper



SRF | THE CENTRE FOR SUSTAINABLE ROAD FREIGHT

White Paper

Decarbonising the UK's Long-Haul Road Freight at Minimum Economic Cost

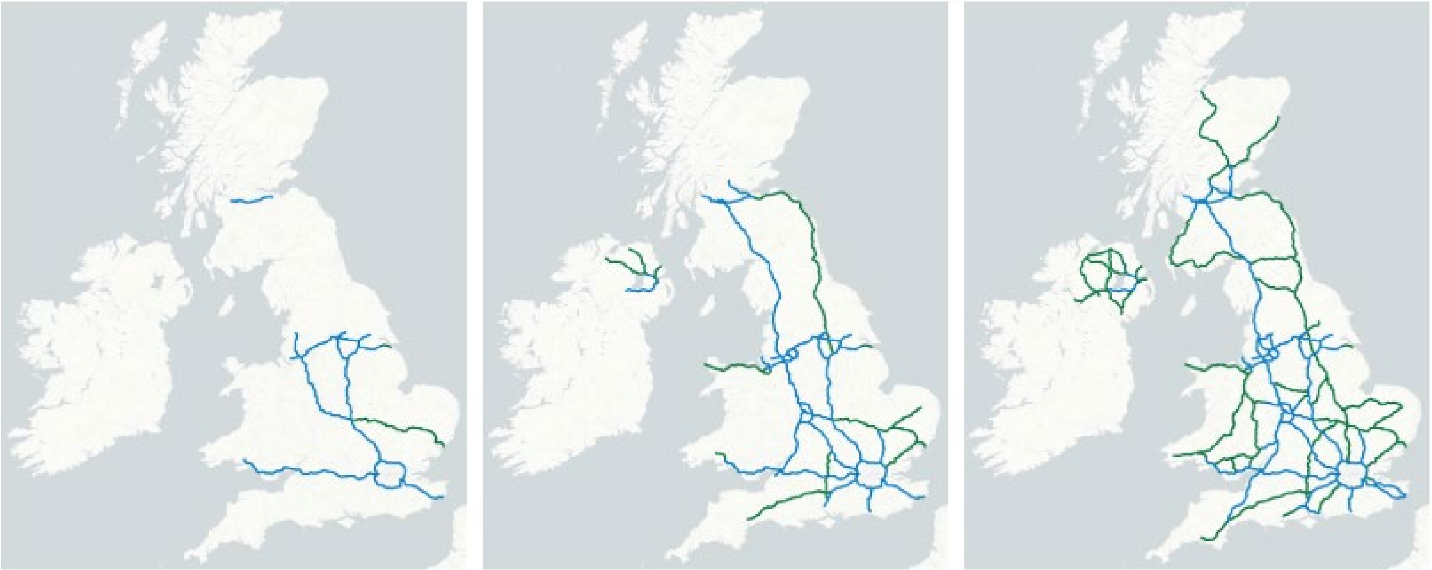
Technical Report CUED/C-SRF/TR17

July 2020

D.T. Ainalis, C. Thorne, and D. Cebon

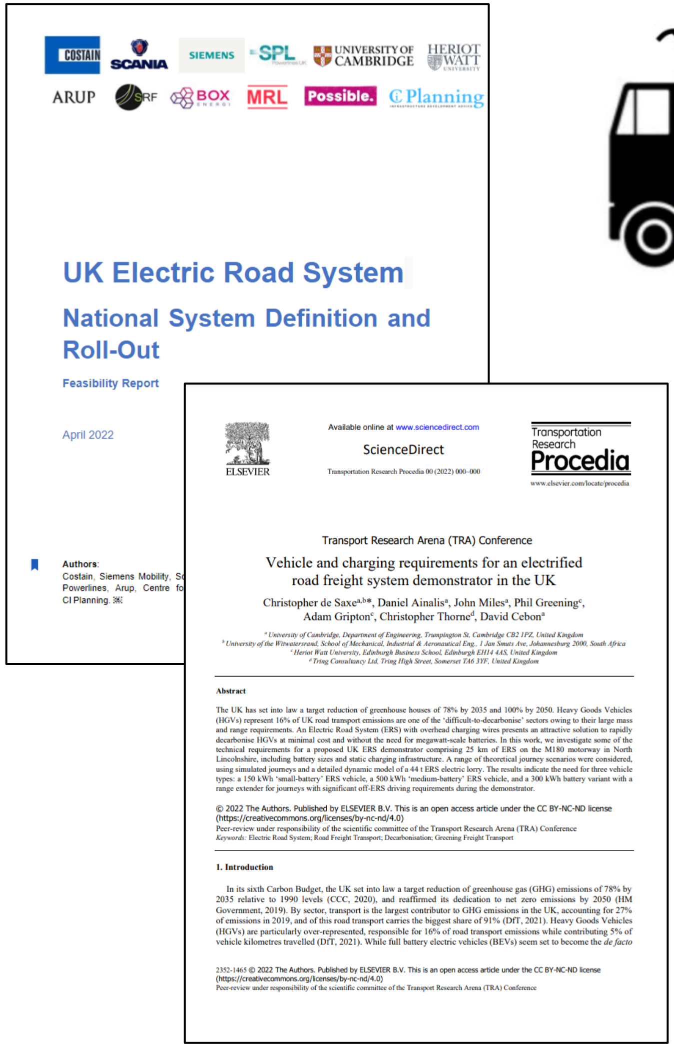
This White Paper has been produced as part of the Centre for Sustainable Road Freight (EPSRC grant number EP/R035148/1). Further details about the Centre are available at: http://www.csrf.ac.uk/

- Three ERS "phases" / topographies identified
- Infrastructure cost of £19.4 billion over 8 years
- Attractive payback period for operators & infrastructure providers
- Government recoups 100 % of diesel tax revenues



Ainalis, D. T., Thorne, C., & Cebon, D. (2020). White Paper: Decarbonising the UK 's Long-Haul Road Freight at Minimum Economic Cost. Technical Report CUED/C-SRF/TR17. Centre for Sustainable Road Freight.

2021/2022 UK ERS demonstrator feasibility study



UK Electric Road System

National System Definition and Roll-Out

Feasibility Report

April 2022

Authors:
Costain, Siemens Mobility, ...
Powerlines, Arup, Centre fo...
CI Planning.

Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2022) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

Transport Research Arena (TRA) Conference

Vehicle and charging requirements for an electrified road freight system demonstrator in the UK

Christopher de Saxe[a,b]*, Daniel Ainalis[a], John Miles[a], Phil Greening[c], Adam Gripton[c], Christopher Thorne[d], David Cebon[a]

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Abstract

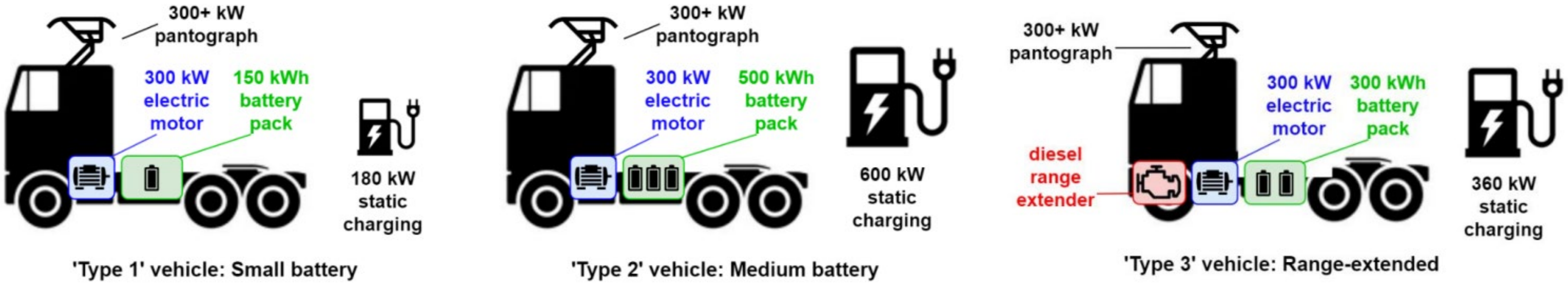
The UK has set into law a target reduction of greenhouse houses of 78% by 2035 and 100% by 2050. Heavy Goods Vehicles (HGVs) represent 16% of UK road transport emissions are one of the 'difficult-to-decarbonise' sectors owing to their large mass and range requirements. An Electric Road System (ERS) with overhead charging wires presents an attractive solution to rapidly decarbonise HGVs at minimal cost and without the need for megawatt-scale batteries. In this work, we investigate some of the technical requirements for a proposed UK ERS demonstrator comprising 25 km of ERS on the M180 motorway in North Lincolnshire, including battery sizes and static charging infrastructure. A range of theoretical journey scenarios were considered, using simulated journeys and a detailed dynamic model of a 44 t ERS electric lorry. The results indicate the need for three vehicle types: a 150 kWh 'small-battery' ERS vehicle, a 500 kWh 'medium-battery' ERS vehicle, and a 300 kWh battery variant with a range extender for journeys with significant off-ERS driving requirements during the demonstrator.

Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference
Keywords: Electric Road System; Road Freight Transport; Decarbonisation; Greening Freight Transport

1. Introduction

In its sixth Carbon Budget, the UK set into law a target reduction of greenhouse gas (GHG) emissions of 78% by 2035 relative to 1990 levels (CCC, 2020), and reaffirmed its dedication to net zero emissions by 2050 (HM Government, 2019). By sector, transport is the largest contributor to GHG emissions in the UK, accounting for 27% of emissions in 2019, and of this road transport carries the biggest share of 91% (DfT, 2021). Heavy Goods Vehicles (HGVs) are particularly over-represented, responsible for 16% of road transport emissions while contributing 5% of vehicle kilometres travelled (DfT, 2021). While full battery electric vehicles (BEVs) seem set to become the *de facto*

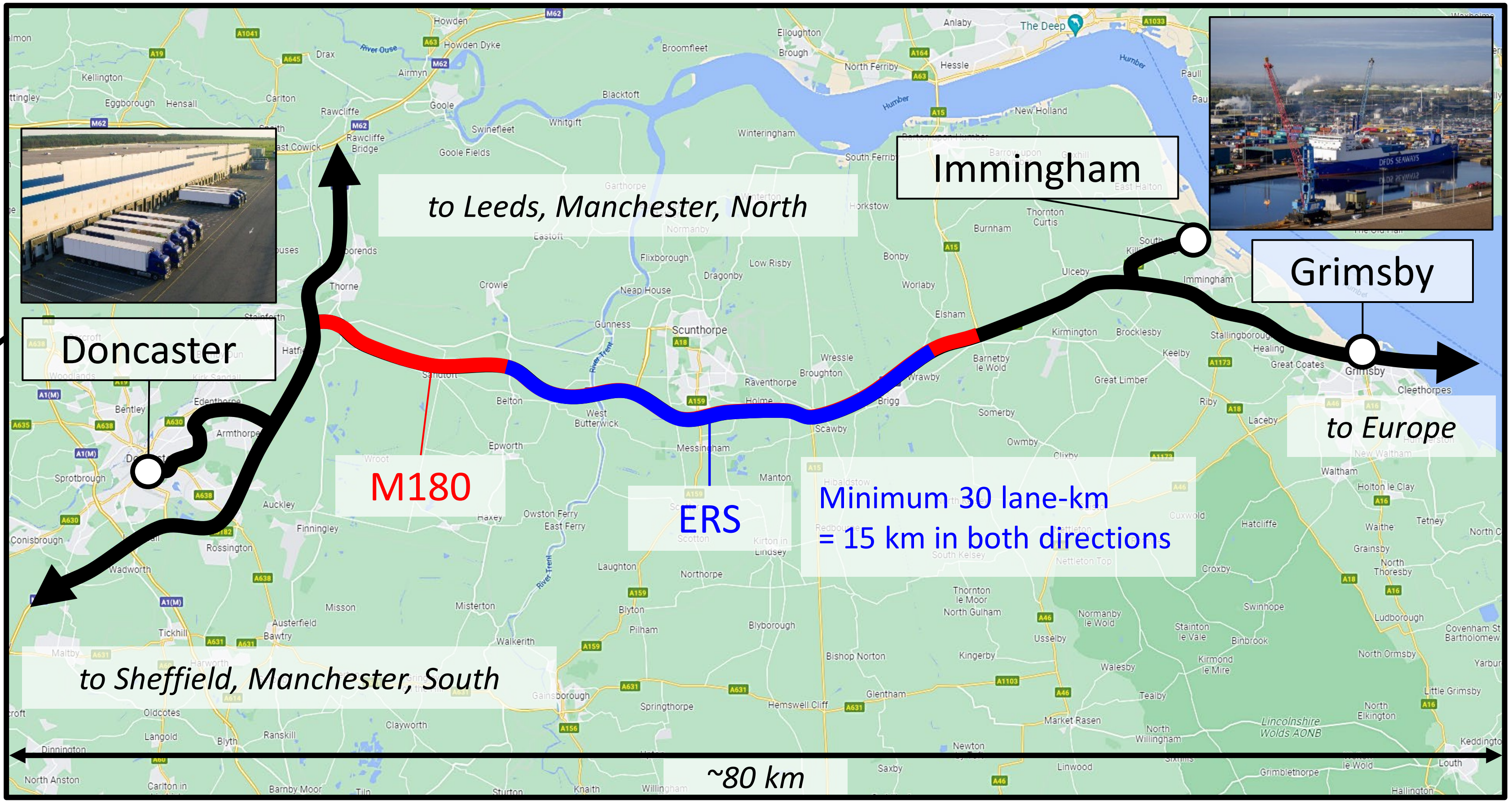
Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference



- National system specification, cost & delivery plan
- Embodied carbon emissions study
- Design of a 30 lane-km demonstrator on the M180
- Demonstrator vehicle and charging needs identified

C de Saxe, D Ainalis, J Miles, P Greening, A Gripton, C Thorn, D Cebon, "Vehicle & charging requirements for an electrified road freight system demonstrator in the UK", Transport Research Arena, Lisbon, 14-17 Nov. 2022

M180 demonstrator



2022 Technoeconomic comparison with HFCEV

Research in Transportation Business & Management 48 (2023) 100914

Contents lists available at ScienceDirect

Research in Transportation Business & Management

journal homepage: www.elsevier.com/locate/rtbm

Technoeconomic comparison of an electric road system and hydrogen for decarbonising the UK's long-haul road freight

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ARTICLE INFO

Keywords:
Sustainable road freight
Electrification
Hydrogen
Electric road system
Heavy goods vehicles
Technoeconomic analysis

ABSTRACT

Long-haul Heavy Goods Vehicles (HGVs) are a significant source of carbon emissions, accounting for around 5% of the UK's total. If the UK is to meet its net zero mandate, it is vital to have a zero-emissions alternative to the traditional diesel-powered HGVs that is cost-effective and widespread in the 2040s. This paper presents a technoeconomic comparison of two solutions for decarbonising long-haul heavy goods vehicles in the UK: electric HGVs with an electric road system (overhead catenary) along the major road network, and fuel cell HGVs with public refuelling stations supplying green hydrogen. The results of the technoeconomic analysis show that overhead catenaries and compatible HGVs are the more energy-efficient and cost-effective solution to decarbonise the UK's long-haul road freight network and would provide both the infrastructure provider and fleet operators with competitive payback periods. With this approach, there is a potential to reclaim 30–80% of the diesel tax revenue currently earned by the UK government from HGVs, depending on the price of electricity. Conversely, the green hydrogen solution will require substantial government subsidies, particularly during the 2030s, to encourage fleet operators to purchase and use hydrogen fuel cell HGVs.

1. Introduction

The UK's Climate Change Act introduced legislation in 2008 to reduce its Greenhouse Gas (GHG) emissions in 2050 by 80% compared to 1990, and was revised in July 2019 to reach net zero emissions by 2050 (UK Government, 2008). Achieving net zero is a considerable challenge and requires wholesale changes to all facets of the energy system. One sector that requires substantial changes is surface transport – vital to the economy but currently the largest GHG emitting sector in the UK as shown in Fig. 1, accounting for 25% of UK emissions in 2018 (DBEIS, 2021). This increase is due not only to rising transport demand offsetting efficiency gains, but also the decarbonisation progress made in other sectors, notably in power generation as the UK electricity grid transitions from coal to natural gas and renewables.

To decarbonise freight transport, there has been a significant increase in the electrification of light duty urban delivery vehicles in recent years. While initially limited to vans and home delivery vehicles, there are an increasing number of larger Battery Electric Vehicles (BEVs) available such as delivery vehicles up to 26 t, buses, and refuse collection vehicles. There are numerous reasons why BEVs are well-suited to urban logistics. The daily mileages of these vehicles are relatively low (typically <100 km), which reduces the battery size, mass, and cost to acceptable levels without disrupting operations. As they operate in urban areas where they frequently stop and start, the ability to reuse electricity through regenerative braking provides a significant improvement in energy efficiency. It is expected that BEVs for urban delivery will become widespread in the UK over the next 10 years, particularly due to the pressure of air quality regulations in cities (clean air zones). Urban and regional delivery accounts for around one-third of all road freight tonne-km in England, with the remaining two-thirds of long-haul freight primarily largely traveling on the Strategic Road Network (SRN) (Peluffo, 2015). Deploying BEVs for long-haul Heavy Goods Vehicle (HGV) operations has several challenges due to significant quantities of power and energy required for commercial operations (discussed in the following section in further detail). These HGVs currently produce around 5% of the UK's total GHG emissions alone, and so finding a suitable solution to decarbonise long-distance HGVs is imperative to achieve net zero (DBEIS, 2021).

Several technologies have been proposed to decarbonise the long-haul road freight sector. These include BEVs with large batteries, BEVs supported by an Electric Road System (ERS), hydrogen, biofuels, and synthetic fuels. An evaluation of the various powertrain solutions for

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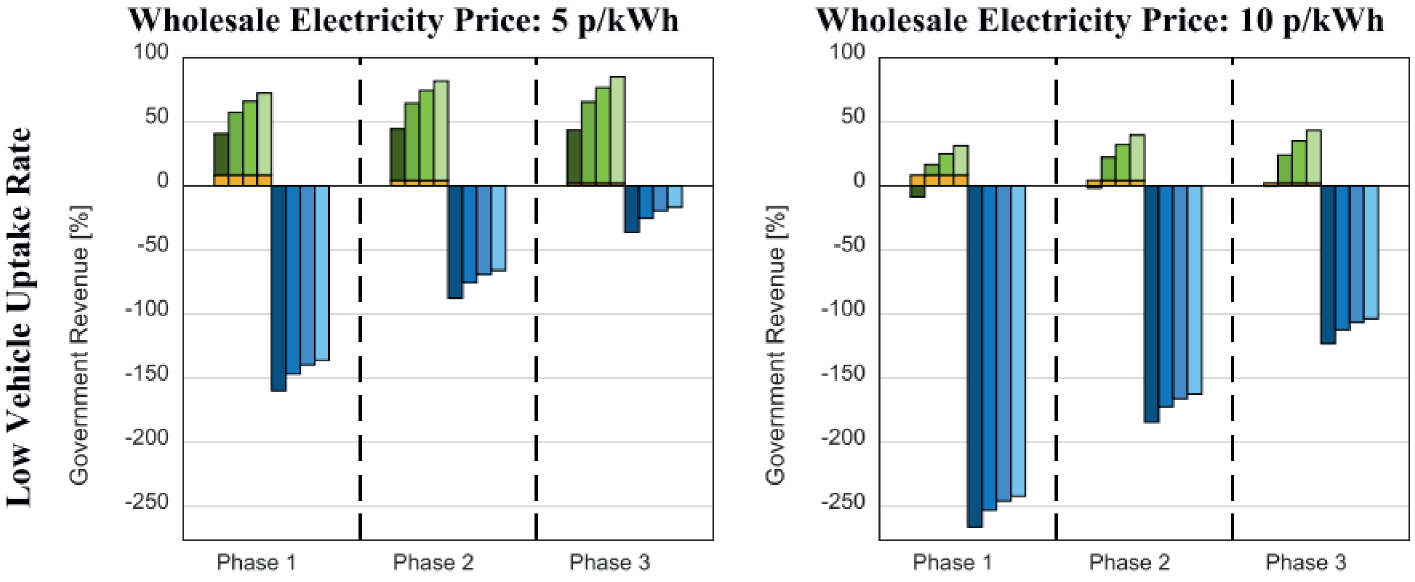
- Extension and formalization of the white paper study
- Confirms beneficial economics of ERS



Ainalis, D., Thorne, C., & Cebon, D. (2022). Technoeconomic comparison of an electric road system and hydrogen for decarbonising the UK's long-haul road freight. Research in Transportation Business & Management, 100914.

2023 ERS vs “big-battery” simulations

Transportation Engineering 14 (2023) 100210

Contents lists available at ScienceDirect

Transportation Engineering

journal homepage: www.sciencedirect.com/journal/transportation-engineering

An electric road system or big batteries: Implications for UK road freight

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[d] Tring Consultancy Ltd, United Kingdom

ARTICLE INFO

Keywords:
Electric road systems
Heavy goods vehicles
Battery electric vehicles
Charging infrastructure

ABSTRACT

An Electric Road System (ERS)—comprising a network of overhead cables to charge Heavy Goods Vehicles (HGVs) via a pantograph pick-up—is a cost-competitive solution to rapidly decarbonise the UK road freight sector. A major benefit over conventional battery electric HGVs is the reduction in battery capacities needed to fulfil logistics needs. In this study, we develop a detailed vehicle simulation model and use it to calculate the battery capacity requirements of real UK logistics journeys against a range of ERS network sizes and on-route static charging options. The results show that, averaged over all static charging scenarios, ERS reduces battery sizes by 41 %, 62 %, and 75 % for the 'Light' (2,750 km), 'Medium' (5,500 km) and 'Heavy' (8,500 km) ERS scenarios. Of the static charging scenarios, drop-off charging is shown to be more effective than rest stop charging at reducing battery sizes.

Introduction

Background

The climate crisis is arguably the defining challenge of our age. The Intergovernmental Panel on Climate Change (IPCC) predicts the earth's average temperature will likely exceed the critical threshold of 1.5 °Celsius within the early 2030s relative to pre-industrial levels [32]. This can only be averted through urgent and drastic interventions in the most carbon-intensive sectors of society. In the UK, while the energy sector has been steadily decarbonising over the last 20 years, emissions from the transport sector have remained relatively stable, such that transport now represents the largest contributor to greenhouse gas (GHG) emissions in the UK at 27 % of the total in 2019 [17]. Road transport carries the biggest share of transport emissions at 91 %. Heavy Goods Vehicles (HGVs) account for 16 % of road transport emissions despite accounting for only 5 % of vehicle kilometres travelled [17].

The UK government has committed in law to a reduction of GHG emissions of 78 % by 2035 relative to 1990 levels [11], with a target of net zero emissions by 2050 [27]. As part of this plan, it has pledged to end the sale of non-zero emission HGVs by 2040, with those 26 t or less being phased out by 2035 [18]. The HGV sector is one of the most 'difficult-to-decarbonise' sectors [10], given the vehicles' significant power and energy requirements. (The total energy footprint of HGVs in the UK is estimated to be 8.2 gigawatts [12], around two and a half times the planned capacity of the UK's Hinkley Point C nuclear power station.) These targets present a significant challenge for the sector, and drastic solutions will be required at scale in a relatively short timeframe.

Recent trends and research have highlighted three likely solutions for zero-emission HGVs:

- **'Big-battery' electric vehicles (B-BEVs)**, with battery capacities of the order of 500–1000 kWh, and a supporting network of high-powered static chargers potentially including those which meet the 'Megawatt Charging System' (MCS) standard (1000+ kW). Examples of first-generation 'big-battery'" BEVs include the 44-tonne-rated Volvo FMX electric (up to 540 kWh, with charging at up to 250 kW) [57], the 65-tonne rated Scania (up to 624 kWh, with charging at up to 375 kWh) [47], and the 37-tonne-rated Nikola Tre (733 kWh, with charging up to 350 kW) [39].
- **Hydrogen fuel cell electric vehicles (FCEVs)**, with large fuel cell stacks, hydrogen tanks (storing either liquid or gaseous hydrogen), and relatively small battery packs. A near-production example is the 37-tonne rated Nikola Tre FCEV, which is reported to have 70 kg of

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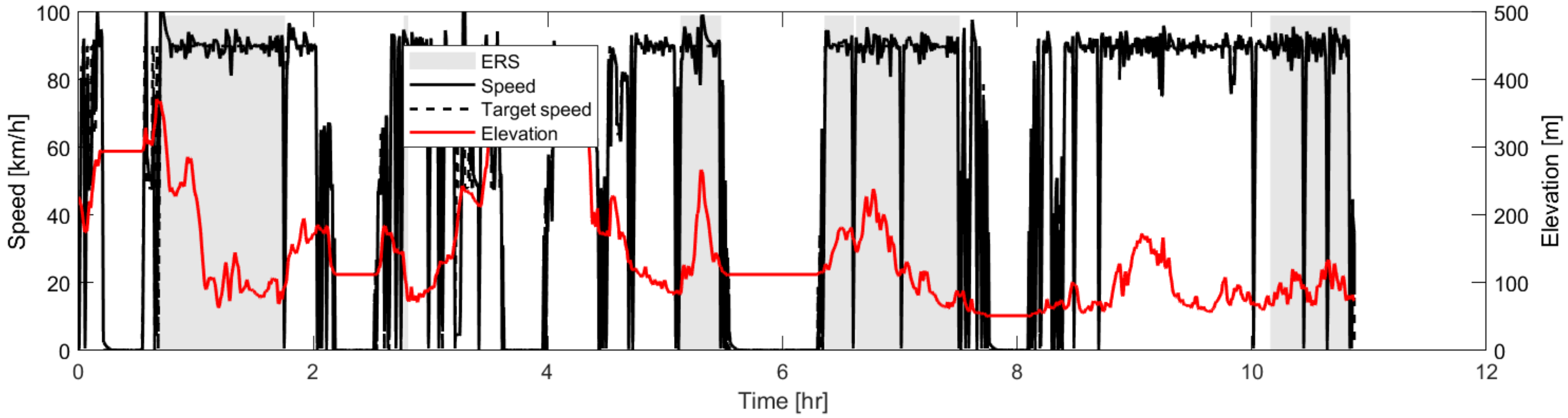
Available online 24 October 2023

- Validated driving cycle simulation model
- Real-world edge-case logistics journeys
- Battery sizes determined for a range of charging scenarios

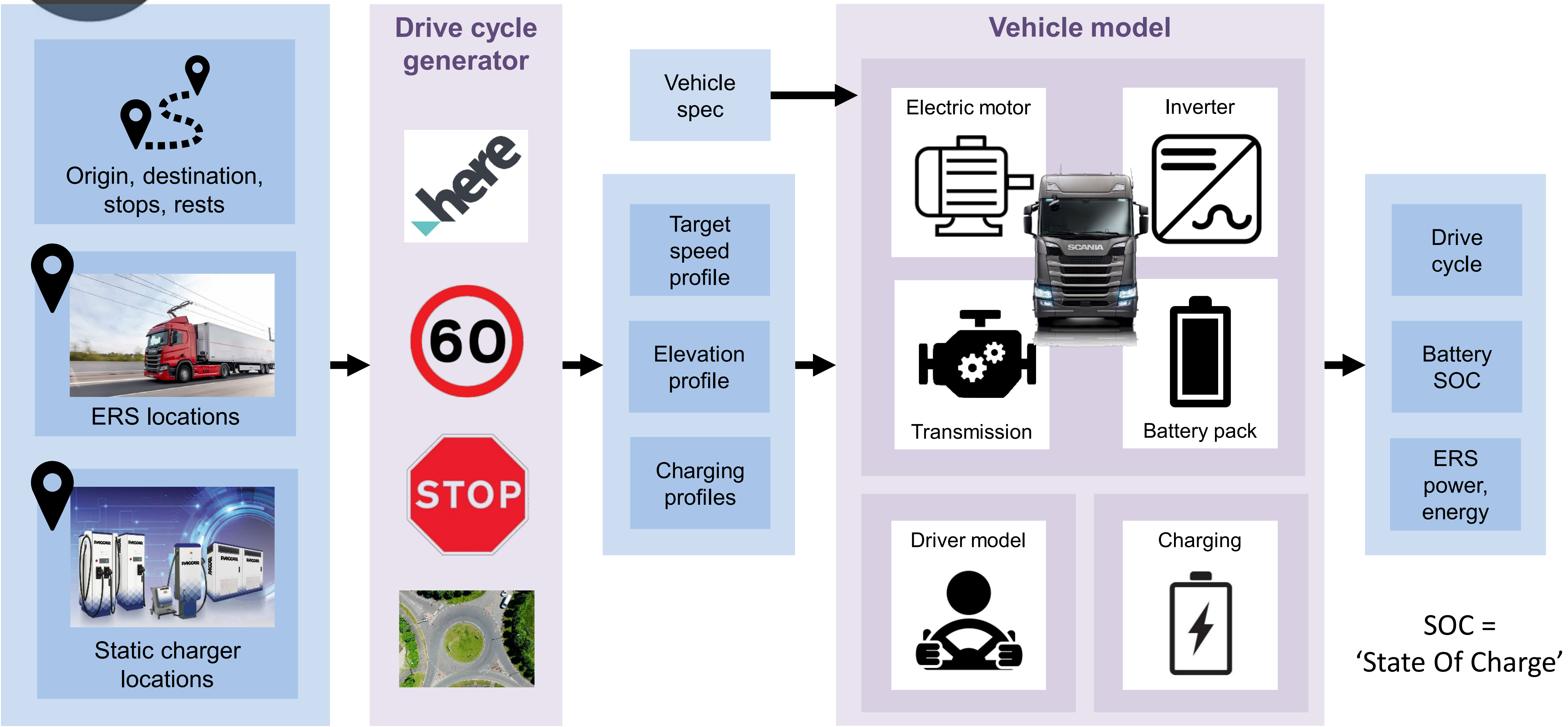


C de Saxe, D Ainalis, J Miles, P Greening, A Gripton, C Thorne, D Cebon, "Battery and charging requirements for a UK electric road freight system", Transportation Engineering, vol. 14, pp. 100210, 2023.

Driving cycle simulations

C de Saxe, D Ainalis, J Miles, P Greening, A Gripton, C Thorne, D Cebon, "Battery and charging requirements for a UK electric road freight system", Transportation Engineering, vol. 14, pp. 100210, 2023.

Detailed drive cycle simulation model



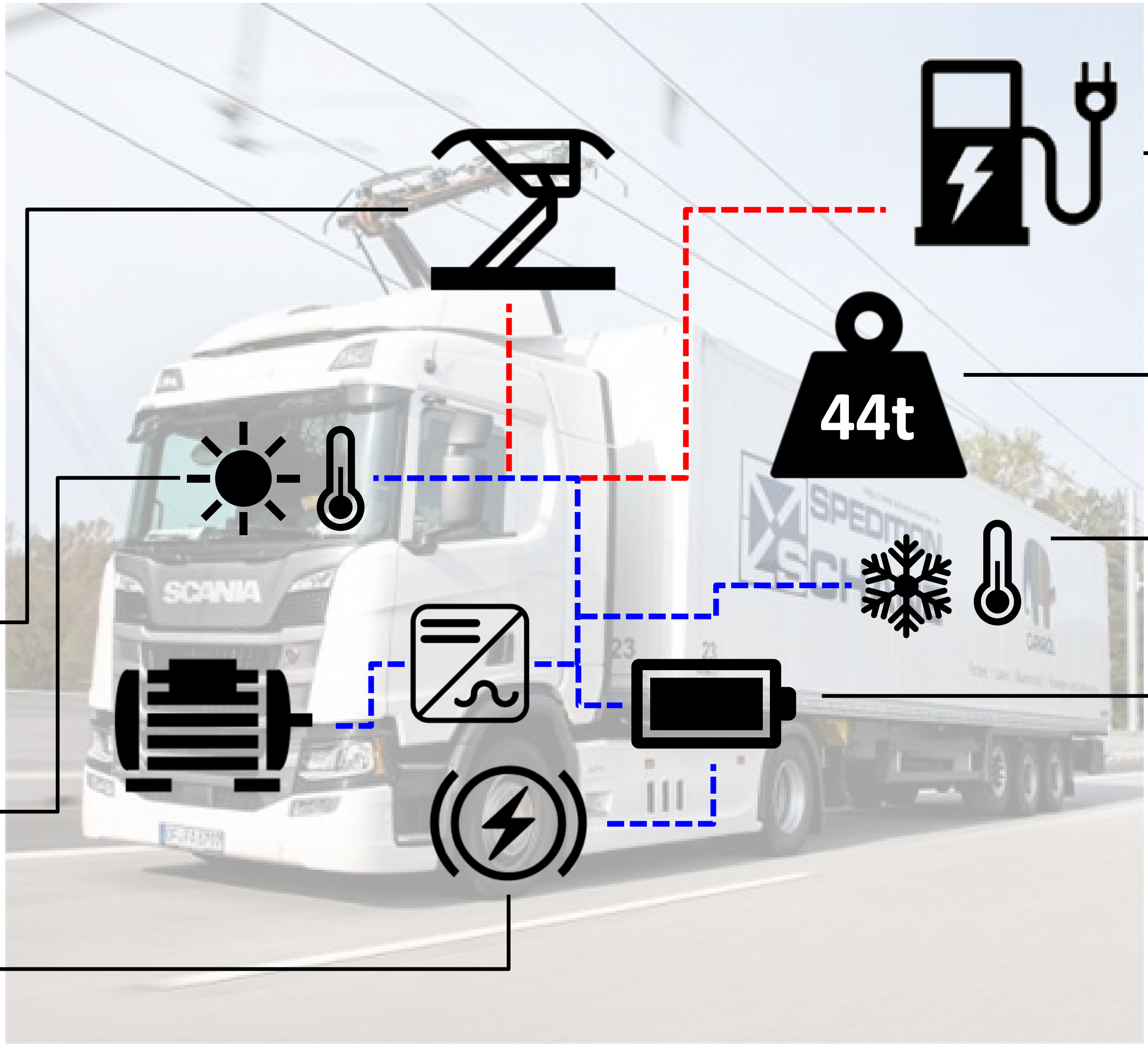
Detailed drive cycle simulation model

- Based on (Madhusudhanan & Na, 2020)
- Updated in consultation with Scania & Siemens.
- Validated against German ERS data with 1.3% error.

ERS supplies power needs and charges battery at ~**150 kW**

Cabin heating (1-3 kW)

Regenerative braking



Static charging:
100 kW @ depots
600 kW @ drop/rest

Maximum permitted combination mass 44t

Trailer refrigeration (8-16kW on/off)

Useable state-of-charge = 20-100%

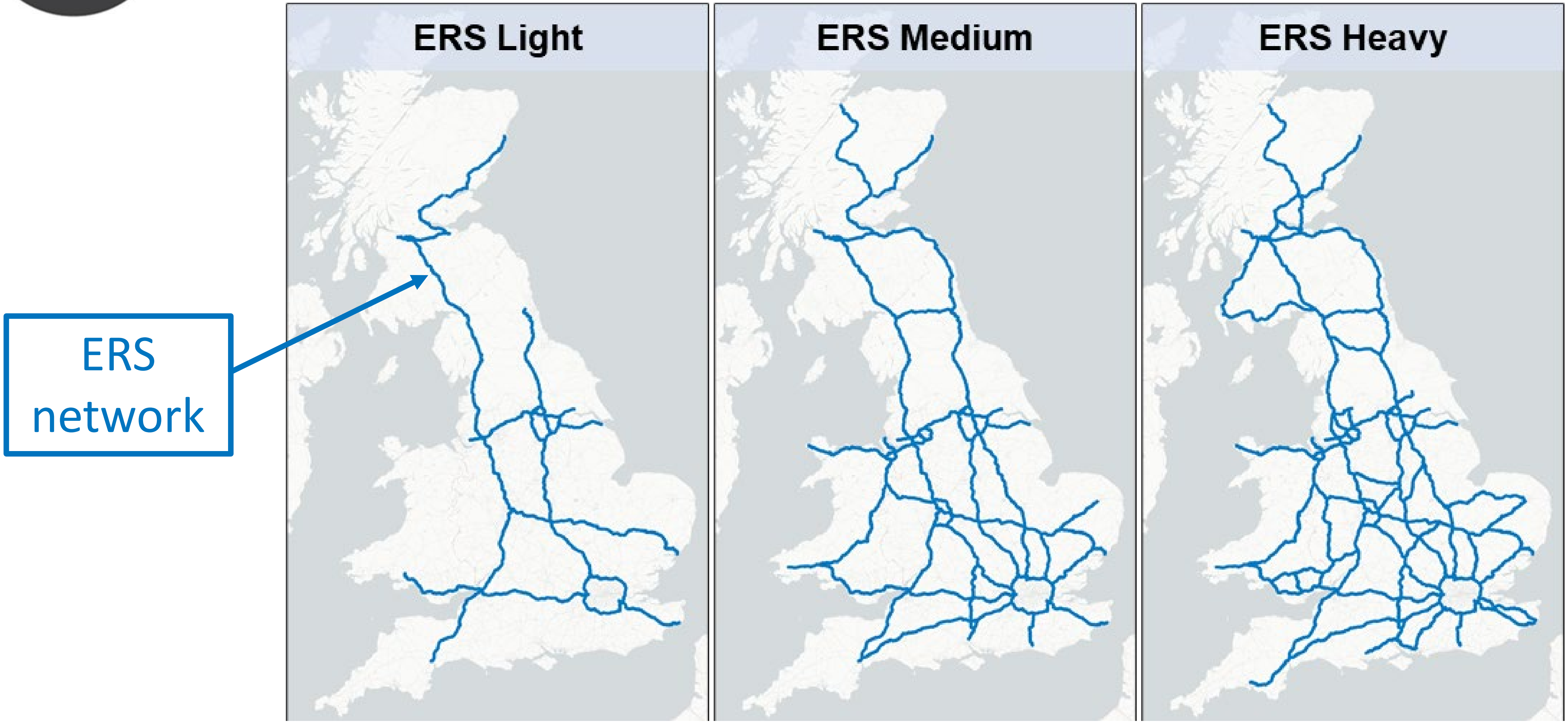
SCANIA

SIEMENS

Driving cycle simulations

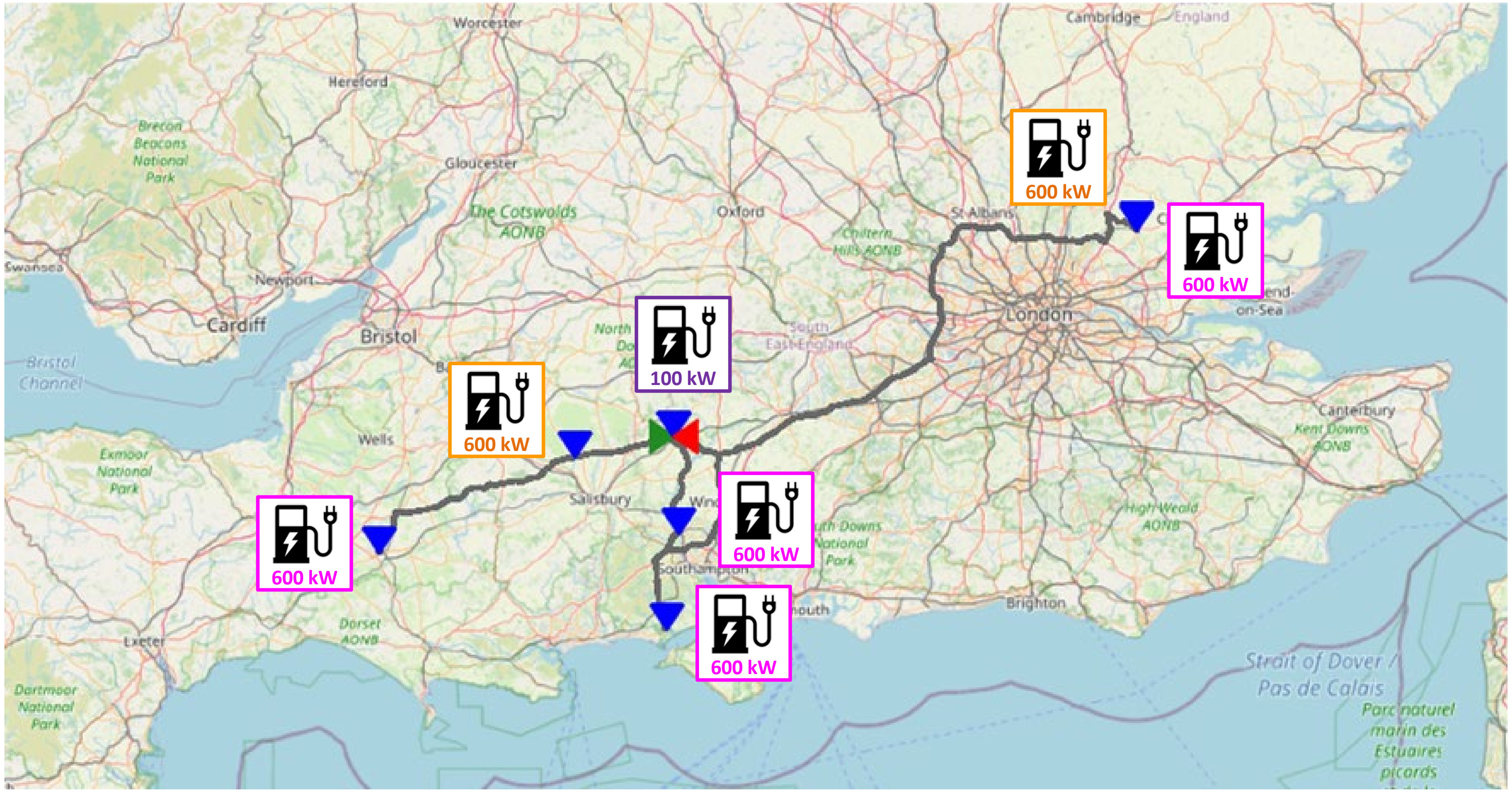
Scenarios & journeys

ERS scenarios



Length (2-way):	2,750 km	5,500 km	8,500 km

Static charging scenarios



▶ Origin ▼ Drop/rest ◀ Destination

1. Depot charging (all scenarios)

2. Drop-off charging (20 min)

3. Rest stop charging (45 min)

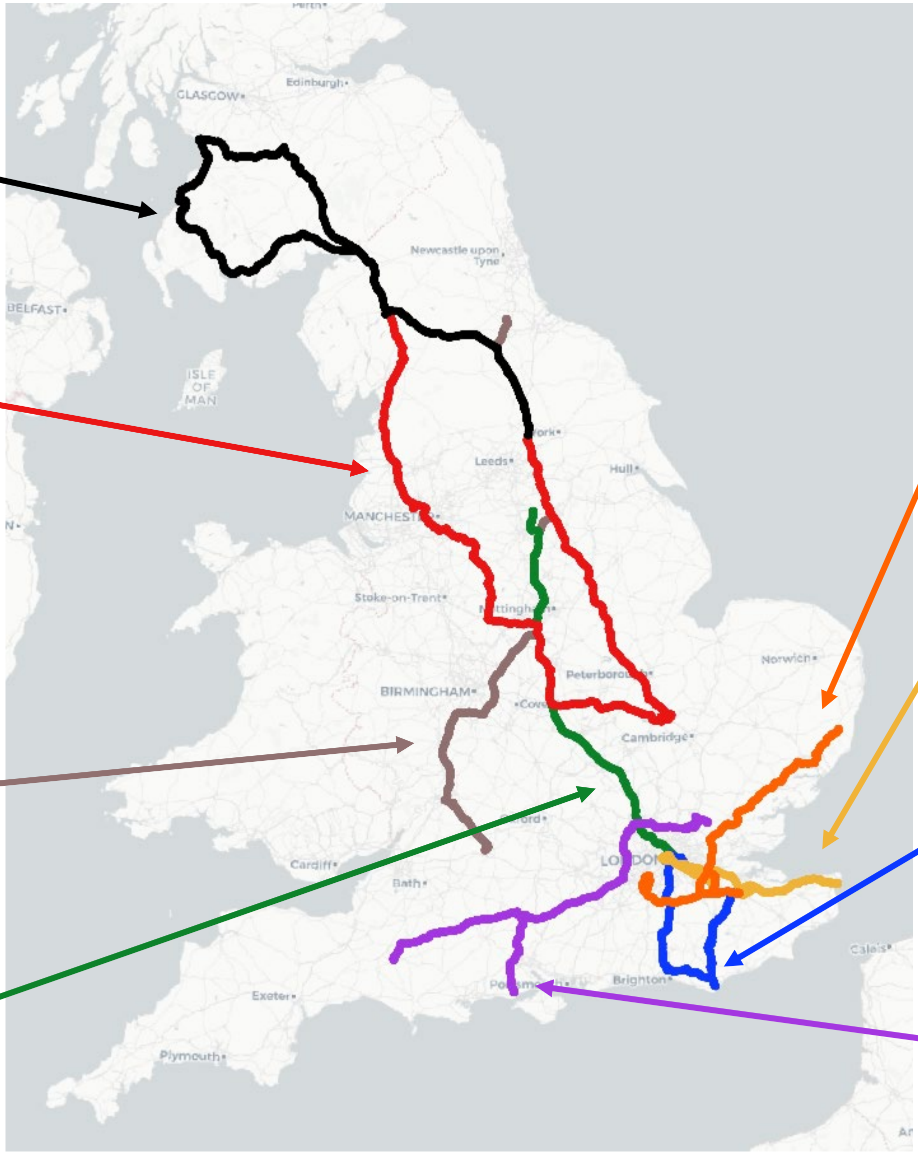
Journeys

<u>Tramping day 2</u>
Wetherby (overnight), Newton Stewart, Girvan, Irvine, Tirril

<u>Tramping day 1</u>
Tirril, Shap, Bolton, Buxton, St Ives (Cambs), Wetherby (overnight)

<u>Warehouse-to-warehouse</u>
Swindon to Newton Aycliffe

<u>Warehouse-to-warehouse</u>
Royal London Hospital to Wath-upon-Dearne



<u>Summary</u>
8 trips across England
Distances of **290 – 690 km**
Durations of **3.6 – 15 hr**

<u>Multi-drop</u>
Aylesford, Saxmundham, Woodbridge, Kingston-upon-Thames, Aylesford

<u>Multi-drop</u>
Aylesford, Bloomsbury, Kensington Gardens, Ramsgate, Aylesford

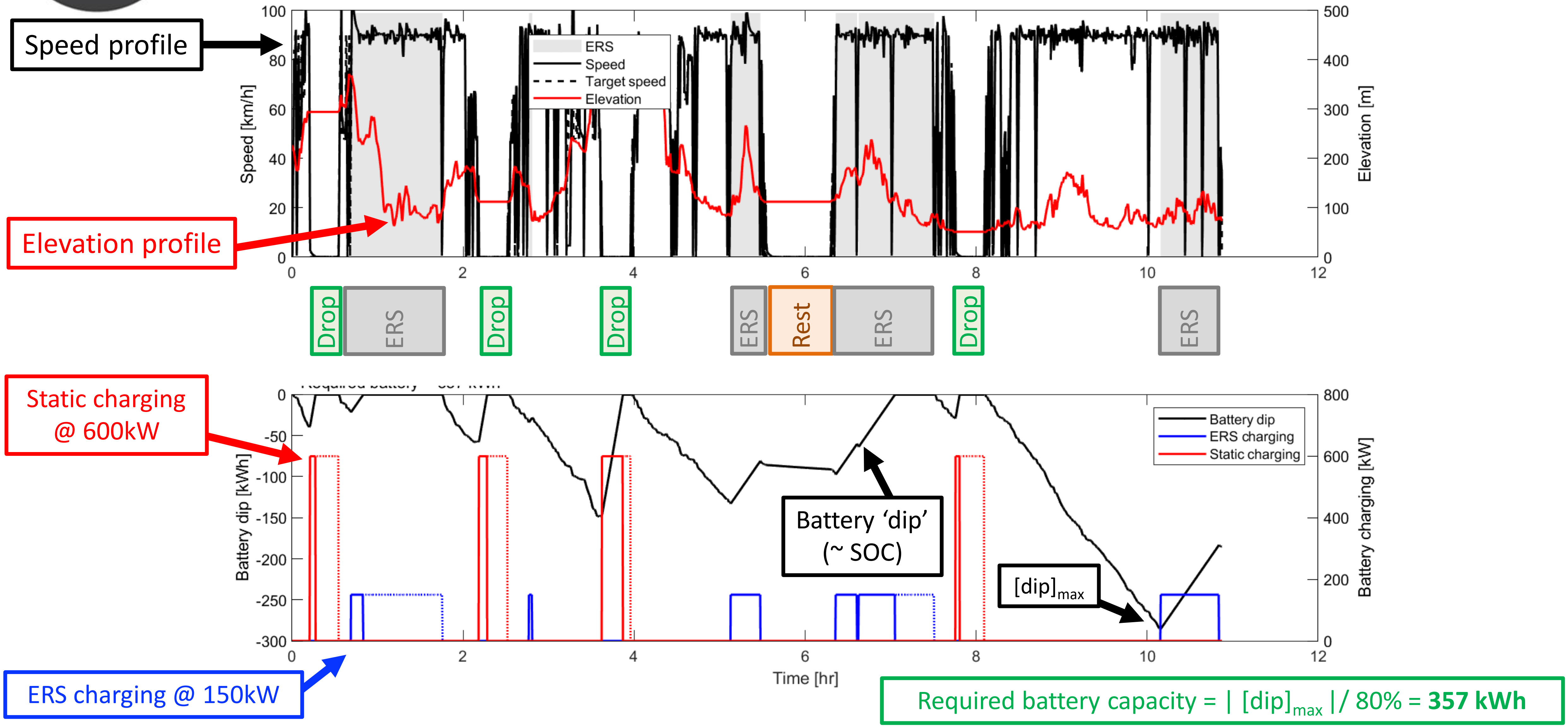
<u>Multi-drop</u>
Aylesford, Eastbourne, Lewes, Marylebone, Aylesford

<u>Multi-drop</u>
Andover, Lymington, Romsey, Andover, Yeovil, Ongar, Andover

Driving cycle simulations

Results

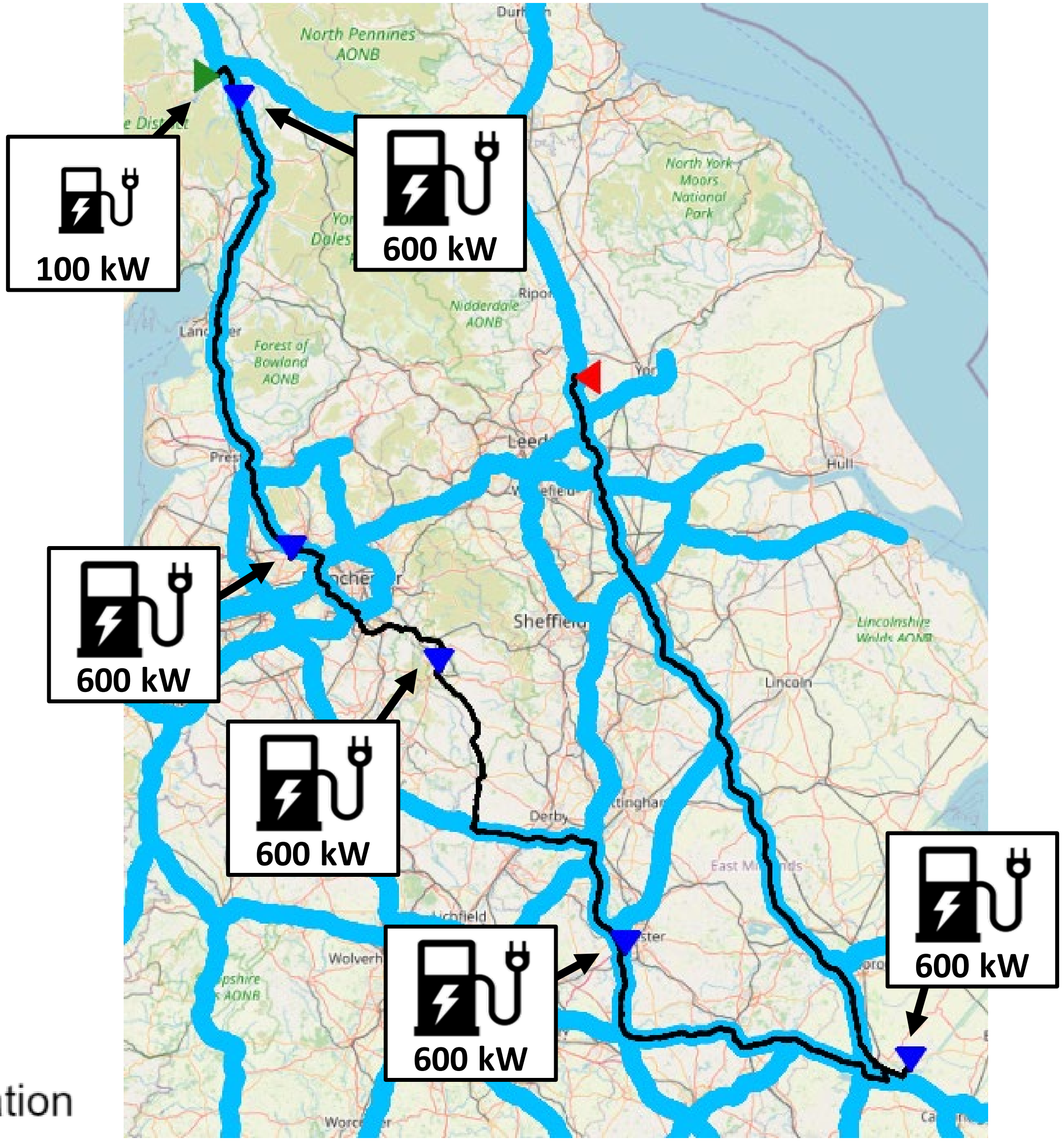
Drive cycle (Tramping Day 1, ERS L + drop-off charging)



Journey matrix (battery sizes) (Tramping Day 1)

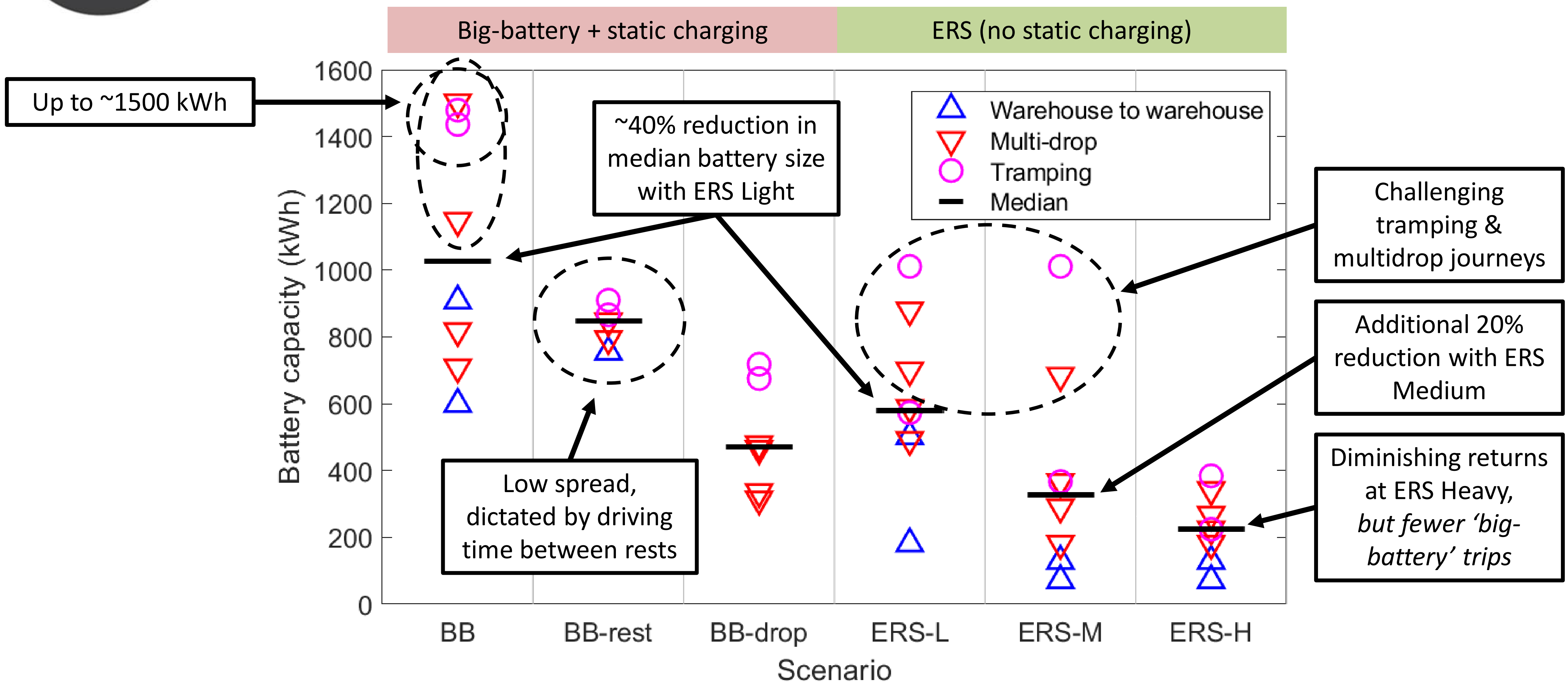
Tirril → Shap → Bolton → Buxton → Leicester (rest) → St Ives (Cambs) → Wetherby (overnight)

Tramping Day 1		ERS topography			
		None	L	M	H
Static charging	None	1479	573	367	224
	Drop-off	718	357	167	122
	Rest stops	910	429	367	224



▶ Origin ▼ Drop/rest ◀ Destination

ERS vs. 'big-battery' scenarios



Battery reductions relative to 'big-battery' scenario

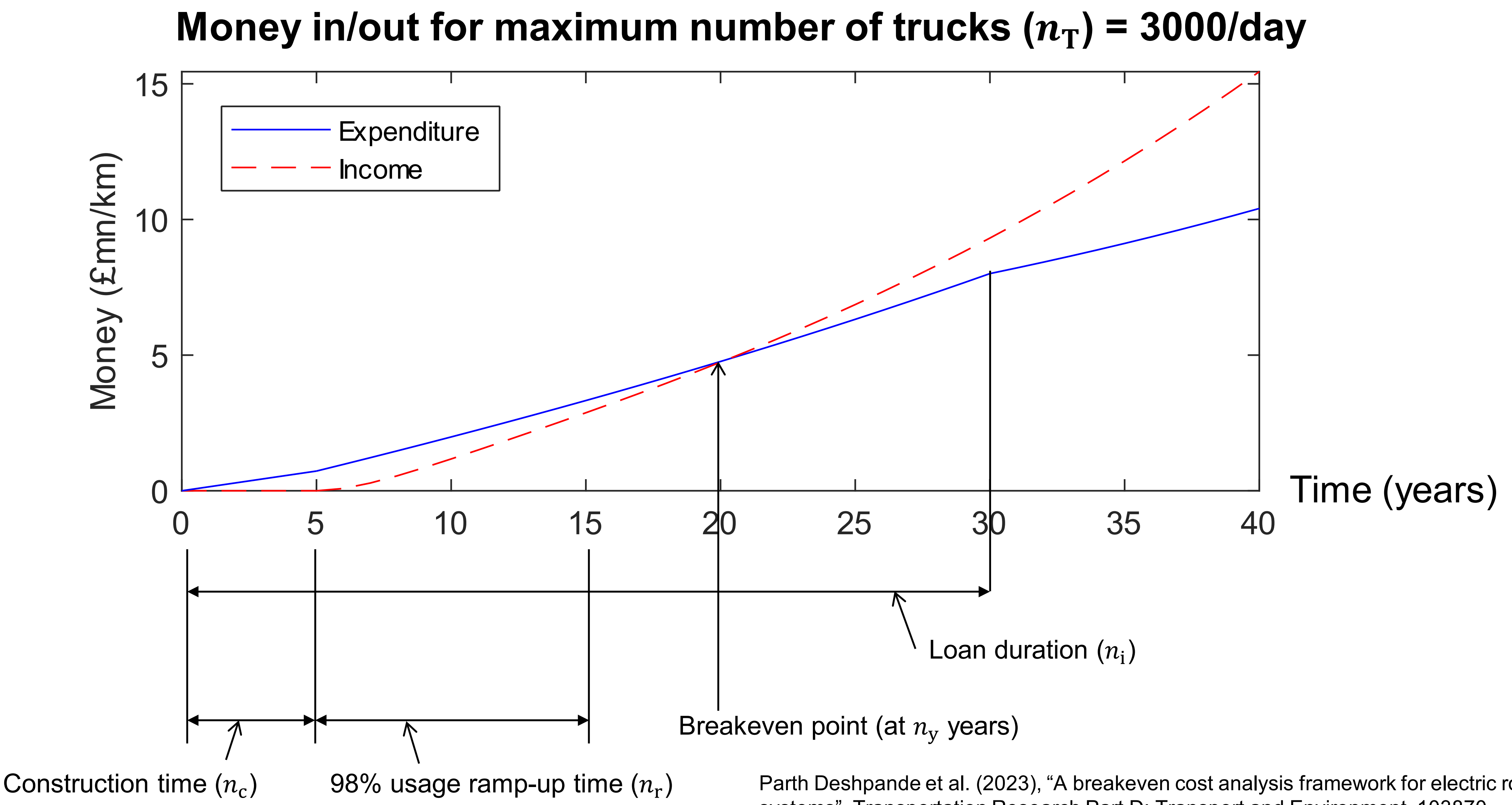
Ave. battery size reductions (%)		ERS topography L	ERS topography M	ERS topography H
Static charging	None	43%	64%	79%
	Drop-off	38%	58%	71%
	Rest stops	42%	64%	74%
Average reduction:		41%	62%	75%

ℹ 1st generation 40t BEVs are ~£300k…
A large portion of this is battery cost!

An ERS economic model for any country

Parth Deshpande et al. (2023), “A breakeven cost analysis framework for electric road systems”, Transportation Research Part D: Transport and Environment, 103870.

ERS cost breakeven model



Parth Deshpande et al. (2023), "A breakeven cost analysis framework for electric road systems", Transportation Research Part D: Transport and Environment, 103870.

ERS cost breakeven model

- Aim: To determine number of trucks required for cost breakeven
- For 1 km of ERS:
  - Expenditure:
    - Infrastructure (£2m) on loan
    - Maintenance (5%)
  - Profit:
    - Electricity selling (7p/kWh)
      - Depends on number of trucks

$$n_T = \frac{C_{ERS}\left[n_y \frac{r_i(1+r_i)^{n_i}}{(1+r_i)^{n_i}-1} + f\left(\frac{(1+r_z)^{(n_y-n_c)}-1}{r_z}\right)\right]}{\frac{\Delta r_e}{100} e_{tr} n_d \left(1 - e^{\frac{-4(n_y-n_c)}{n_r}}\right)\left(\frac{(1+r_z)^{(n_y-n_c)}-1}{r_z}\right)}$$

- n_T: Maximum number of trucks
- C_{ERS}: Capital cost of ERS (£/km)
- n_y: Number of years for breakeven
- $\frac{r_i(1+r_i)^{n_i}}{(1+r_i)^{n_i}-1}$: Annual loan instalment fraction
- f: Annual maintenance cost fraction
- n_c: Number of years for ERS construction
- $\frac{(1+r_z)^{(n_y-n_c)}-1}{r_z}$: Sum of inflation terms over $(n_y - n_c)$ years
- Δr_e: Electricity profit margin (pence/kWh)
- e_{tr}: Energy transferred per vehicle (kWh/km) (= Max. power / average speed)
- n_d: Number of days of ERS use per year
- $1 - e^{\frac{-4(n_y-n_c)}{n_r}}$: Ramp-up curve for number of trucks using the ERS
- n_r: Number of years for 98% ERS usage

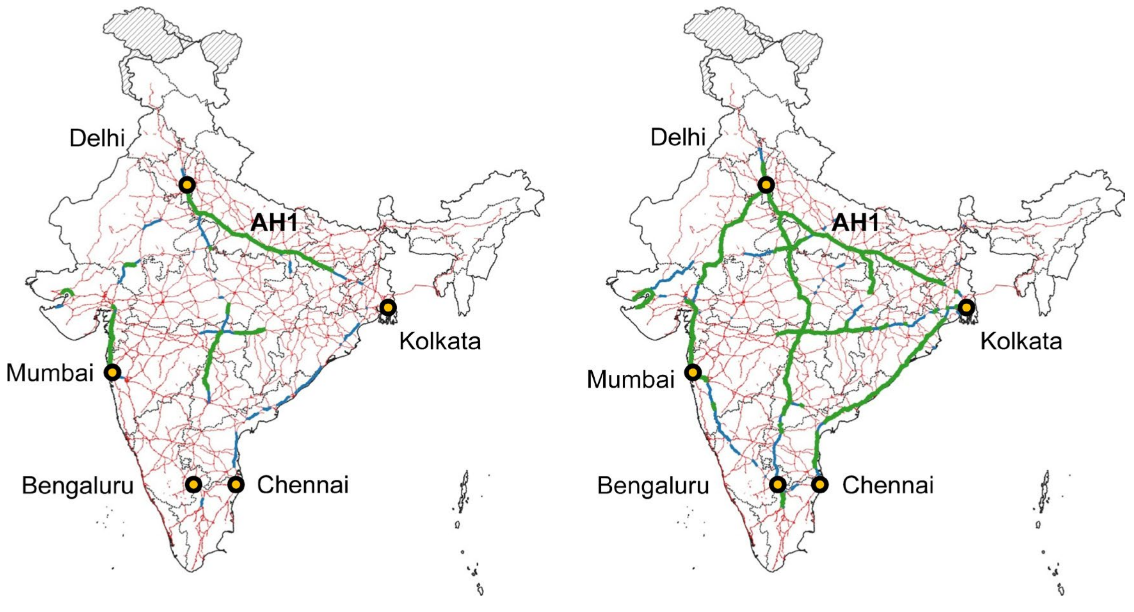
$$Q_T = \frac{e_{tr} n_T n_d}{E_T}$$

- Q_T: Annual freight flow (t/year)
- e_{tr}: Energy transferred per vehicle (kWh/km)
- n_T: Max. number of trucks (1/day)
- n_d: Number of days of ERS usage (days/year)
- E_T: Energy efficiency of freight (kWh/t-km)

^ In terms of freight flow

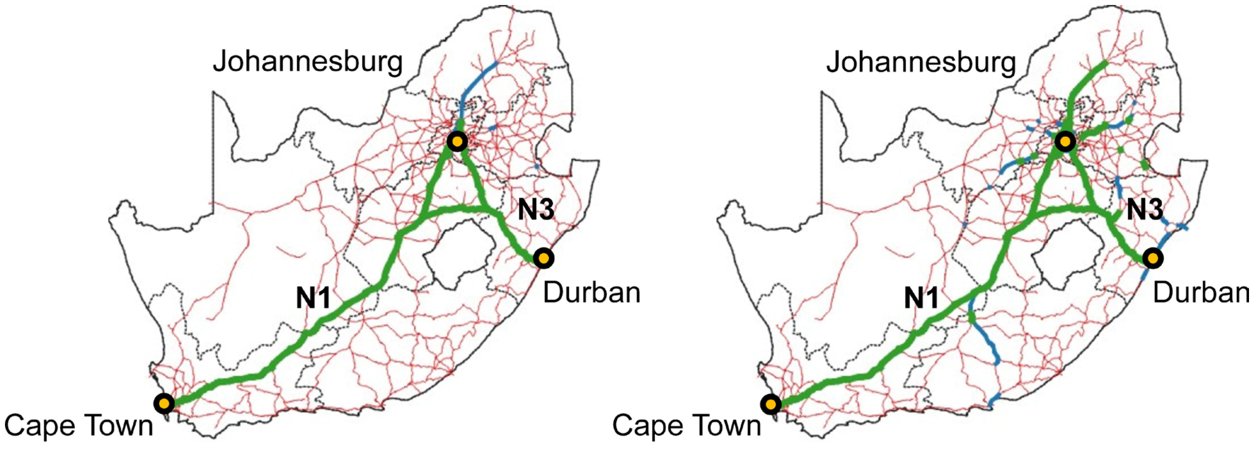
Parth Deshpande et al. (2023), “A breakeven cost analysis framework for electric road systems”, Transportation Research Part D: Transport and Environment, 103870.

Country results



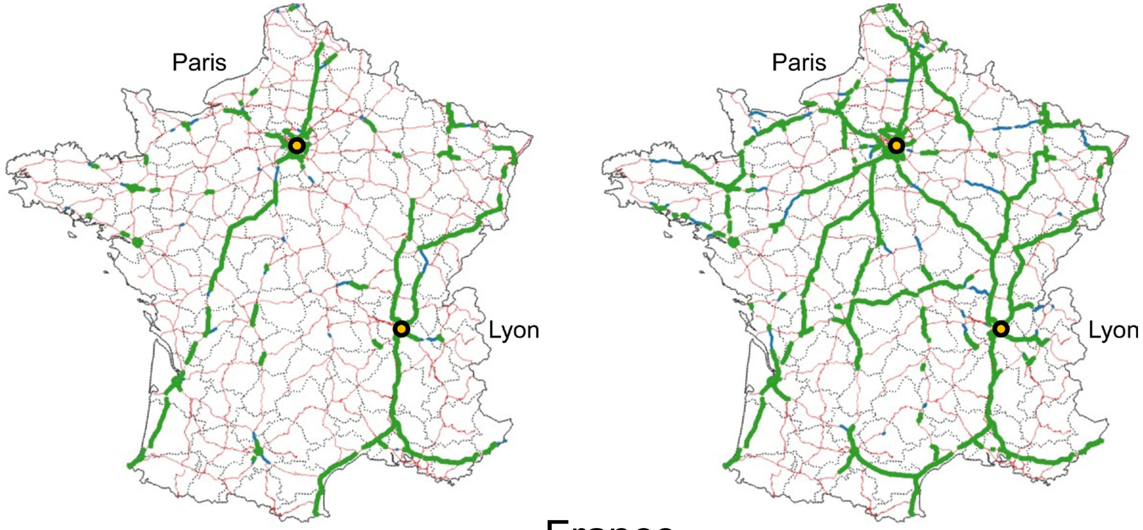
(a) (b)

India



(a) (b)

South Africa



France

(a) (b)

Breakeven duration

< 20 years 20 - 30 years > 30 years

Conclusions

Conclusions

- ERS is the lowest cost and emissions solution for decarbonising HGVs in the UK
- This is backed by robust economic modelling and simulation studies
- The driving cycle simulation model has assessed the real-world “on-the-ground” implications for UK logistics
- An investment model suitable for all countries has been developed (requires HGV traffic data)
- UK announcement on UK ZERFD ERS trial…?

Funding

UKRI Innovate UK

Collaborators

COSTAIN SRF ARUP

SCANIA SIEMENS MRL

SPL Powerlines UK

Possible.

Thank you!

Contact:

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