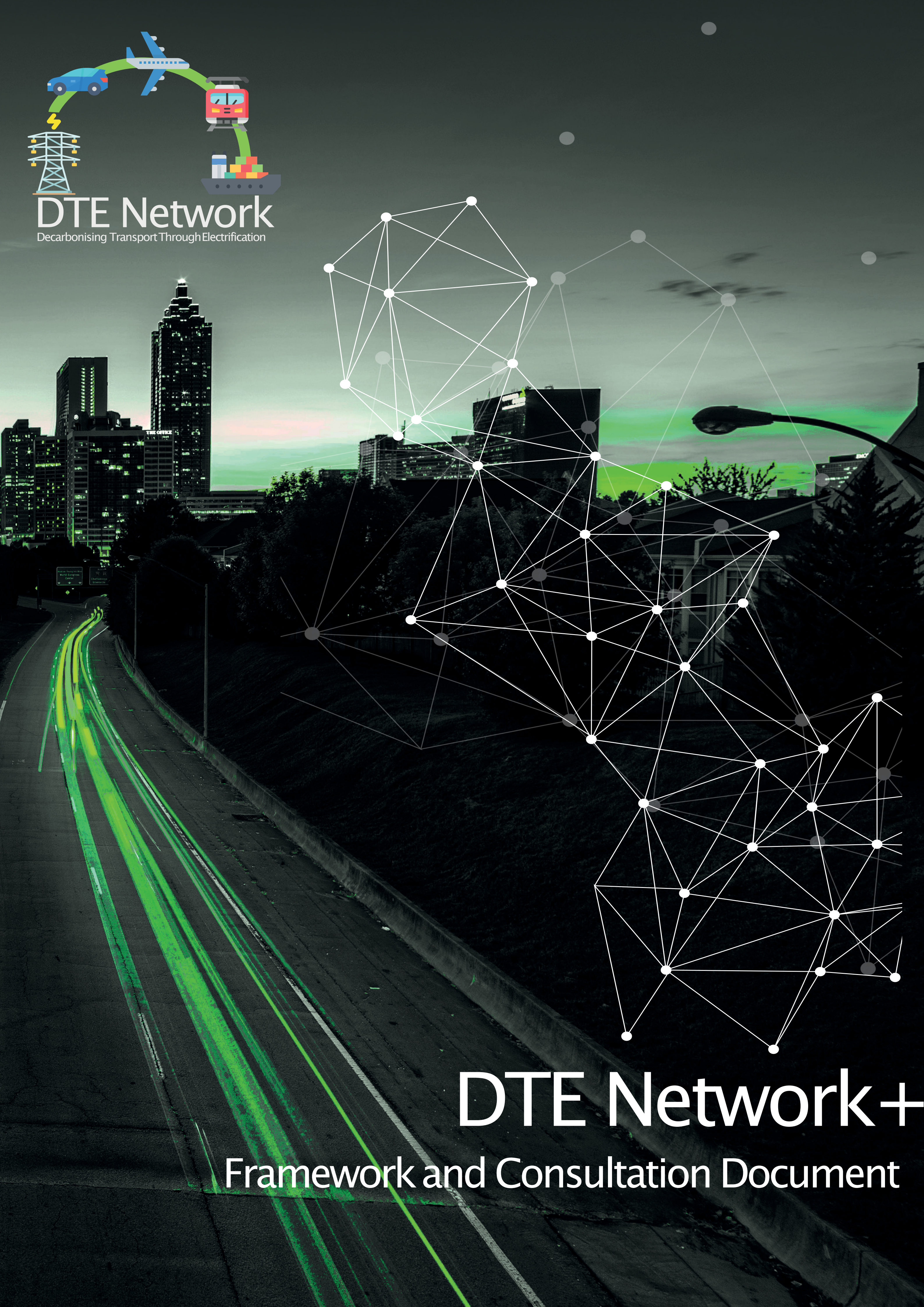
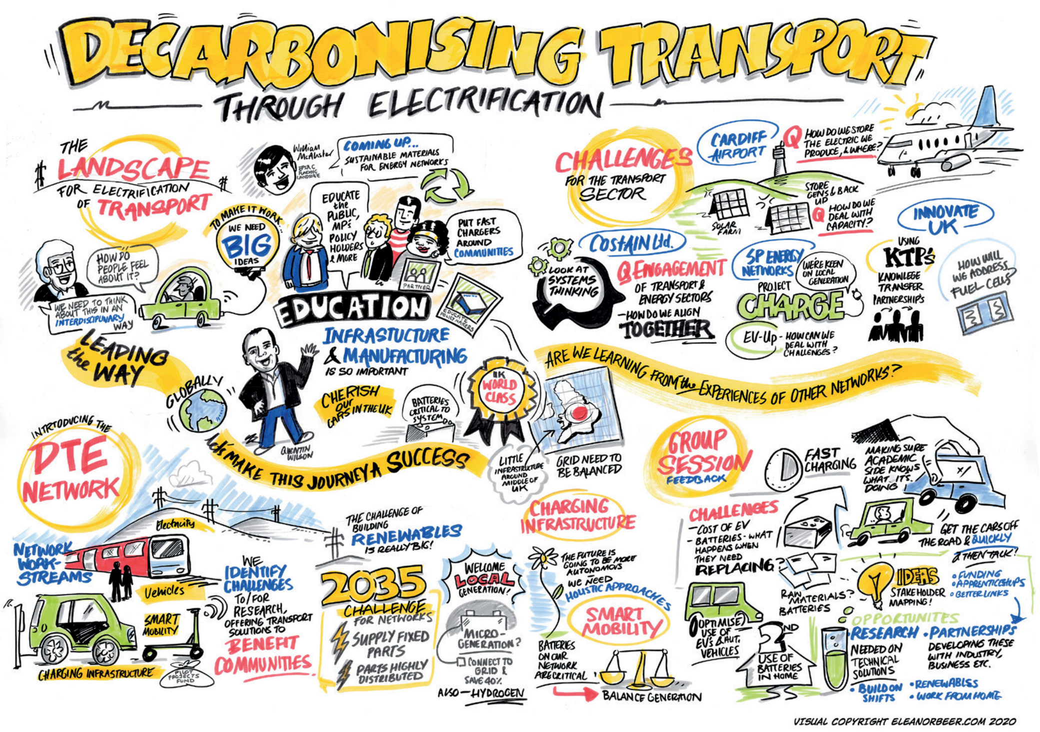
DTE Network

Decarbonising Transport Through Electrification



DTE Network+

Framework and Consultation Document



The Decarbonising Transport through Electrification (DTE) Network+ would like to thank Eleanor Beer for her creation of the Transport Decarbonisation Visual re-purposed in this document.

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DTE Network+

Framework and Consultation Document

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Document design by Dominic Dattero – Snell

Contents

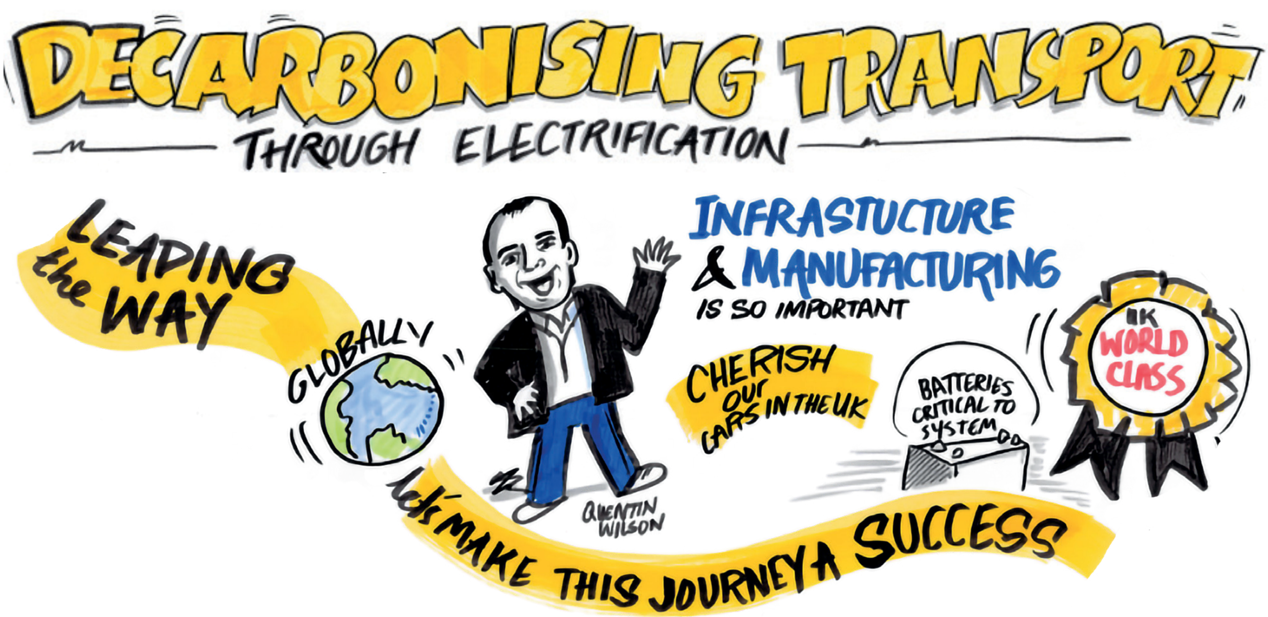
Introduction

About the DTE Network+

The Decarbonising Transport through Electrification (DTE) Network+ is a £1M EPSRC funded multidisciplinary project addressing the challenges of implementing an electrified, cost-effective, and holistically operating transport sector for the UK. Principal Investigator of the DTE Network+ Professor Liana Cipcigan explains the purpose of the network:

“The network will look to prepare the wider industry for decarbonisation commissioning projects addressing short, medium and long-term challenges associated with electric & autonomous vehicles, electric & hybrid aircraft and electrification of rail along with associated infrastructures, developing a wider strategy for decarbonisation of the transport sector through electrification.”

The network brings together academia, industry, and the public sector to work across the major transport divisions of automotive, aerospace, rail and maritime. The integrated, whole system approach of this network will explore drivers for change within the transport system including technological innovation, individual mobility needs and economic requirements for change, alongside environmental and social concerns for sustainability and consider the role, social acceptance and impact of policies and regulations. Multidisciplinary contacts across engineering, psychology, economics, and policy are integrated into the network to facilitate detailed investigation of cross cutting subject matters from the role of social acceptance to the impacts of policy and regulation to maximise emission reduction.



Introduction

Executive Summary

This document has been produced following the recent DTE Network+ launch event and aims to set out a clear structure surrounding the research to be carried out within this consortium. This will be provided through three key sections of material.

The three sections concern:

- The DTE Network+ Structure: this includes a detailed overview of the holistic work stream based approach to DTE Network+ research and a selection of projects based on our current consortium's expertise.
- Launch Event Stakeholder Consultation – a discussion of the methodology surrounding our recent consultation with stakeholders and the subsequent development of key challenges surrounding transport decarbonisation.
- Challenge Frameworks – five visual representations of key challenges developed by our stakeholders and consortium presented over varying time horizons. These aim to highlight the research and innovation interests to be explored over the coming years to aid in removing emissions from transportation.

The motivation behind the information contained within this document is to provide information on this consortium's efforts, and background for individuals interested in participating in our upcoming funding calls and/or network activities. Work within this consortium aims to provide some additional resource to facilitate the cross disciplinary work towards decarbonising transport through electrification.

Introduction

Supporting the TransportDecarbonisation Plan (TDP)

In October 2019,the UK government announced its development of a transport decarbonisation plan (TDP). During March 2020, the Department for Transport (DfT) published **Decarbonising Transport:Setting the Challenge** with six strategic priorities identified to build a structure towards the TDP. The DTE Network+workstreams are aligned with all six. Furthermore, the DTE Network+ has established a presence within the Department for Transport, Transport Research and Innovation Board (TRIB). The report'sstrategic priorities are listed below and how they align with this networks work streams is explained.

Accelerating modal shift to public and active transport

WS1.2 – Connected Autonomous Vehicles

WS4.1– Human Factors

Decarbonisation of road vehicles

WS1.1– Electric Powertrains

WS2.1–Extending/buildingcharginginfrastructure

WS2.2 – Dynamic chargingon the road

WS3 – Supply of electricity as a transport fuel

Decarbonising how we get our goods

WS2.2 – Dynamic chargingon the road

WS2.3 – Railway feeder stations

WS3 – Supply of electricity as a transport fuel

WS4.2 – Big Data, Cybersecurity

Place-based solutions

WS1.3 – Green TaxiingDemonstrator

WS2.3 – Railway feeder stations

WS2.4 – Low carbon generation on the railway electrification network

UK as a hub for green transport technology and innovation

WS3 – Electricity as a transport fuel

WS4.3 – Planning, economics, environmental

Reducing carbon in a global economy

WS4.3 – Planning, economics, environmental

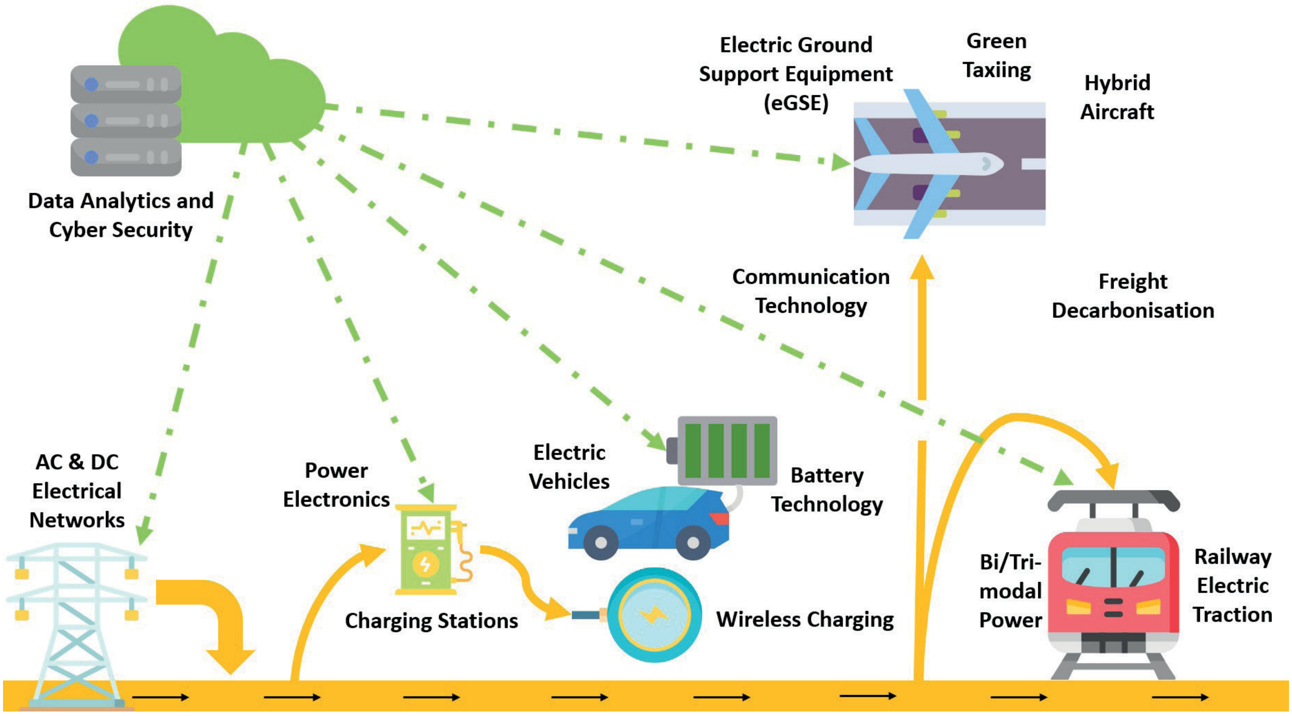
WS4.4 – Policy

Network Structure

The Whole System Approach

The interdisciplinary nature of transport decarbonisation requires a whole system approach to maintain a holistic and systemic viewpoint. Therefore, this Network+ has developed, and will sustain, an interdisciplinary team to help solve the challenges surrounding decarbonising transport and will be able to respond quickly to changes in the transport and energy landscape.

The DTE Network+ will pioneer new ways of engaging and participating with industry, government, regulators, and end users. Through the rigour of academic research and consistent stakeholder involvement, the outputs of this Network+ will be successfully applied to the real problems of decarbonising the transport sector which will be critical to ensuring the future deployment of a flexible, open, and multiservice infrastructure. The DTE Network+ also contains mechanisms to support early career researchers and our work stream approach enables us to widen the dissemination of any results.



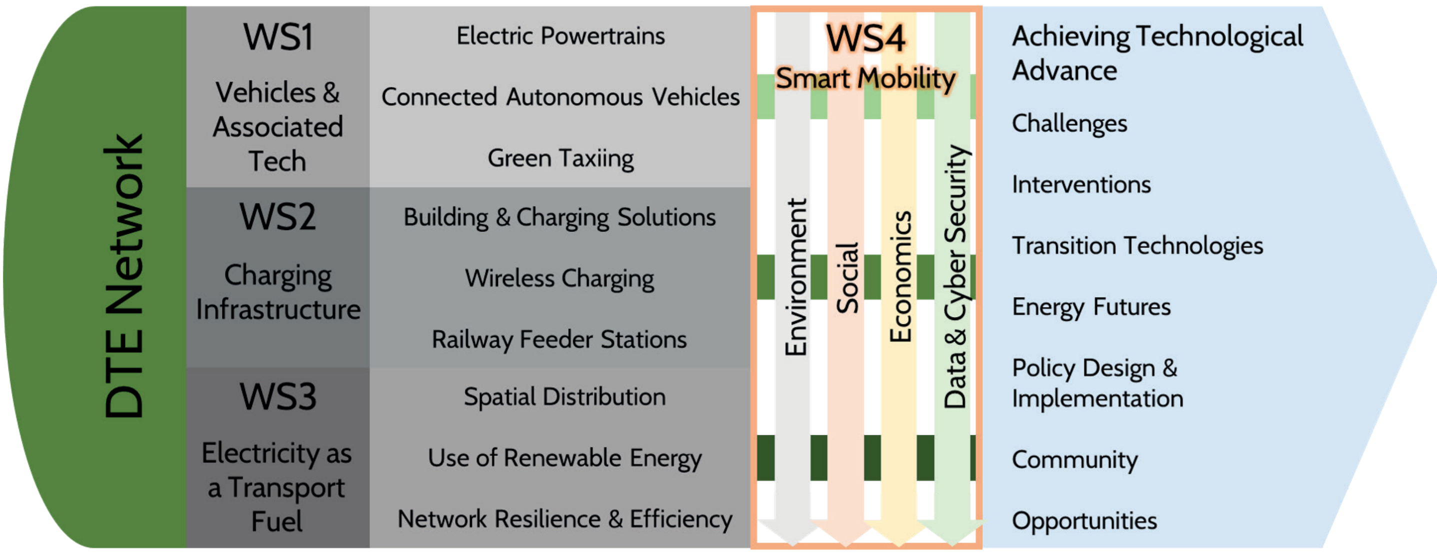
Network Structure

The Work Streams

The activity within the DTE Network+project is distributed across four Work Streams. Using this multidisciplinary work stream approach allows the network to cover a breadth of research topics and spot interdisciplinary synergies where they exist.

The four dedicated work streams are:

Work Stream 1	Vehicles and Associated technologies
Work Stream 2	Charging Infrastructure
Work Stream 3	Supply of electricity as a transport fuel
Work Stream 4	Smart Mobility



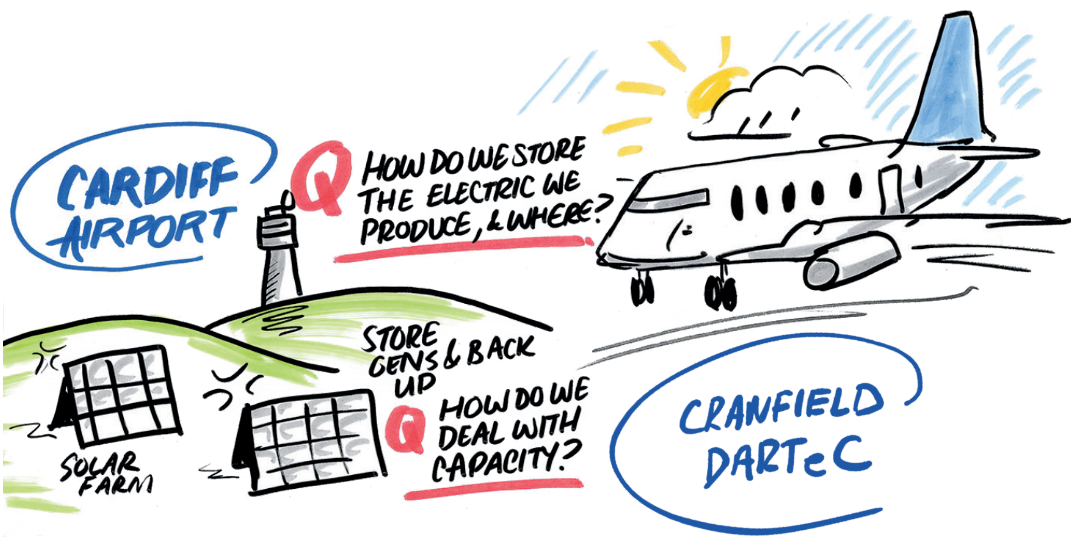
Work Stream 1

Vehicles & Associated Technologies

Leader: Professor Patrick Chi-Kwong Luk
Cranfield University
Contact: p.c.k.luk@cranfield.ac.uk

Under this stream, research efforts are aimed at advancements in specific transport system modal categories (road, rail, aerospace and maritime). The work stream employs a "cradle to grave approach" when evaluating and developing new technologies and innovations for decarbonising the transport sector.

Energy intensity targets can be achieved by the reduction in gross energy consumption; increase in instantaneous powertrain efficiency; and increase in average powertrain efficiency. On the other hand, power density improvement on propulsion systems must be addressed by exploring new frontiers such as in superconductors and novel materials in order to achieve comparable performance with thermal engines, particularly for aerospace applications with hybrid/fullelectric propulsion. Advanced wide-bandgap power electronics technologies and new materials and structures for electric machines will be investigated to provide a high-efficiency and high energy density solution. A strategic plan laying out technology integration targets will be developed through investigation of current and future technology offerings.

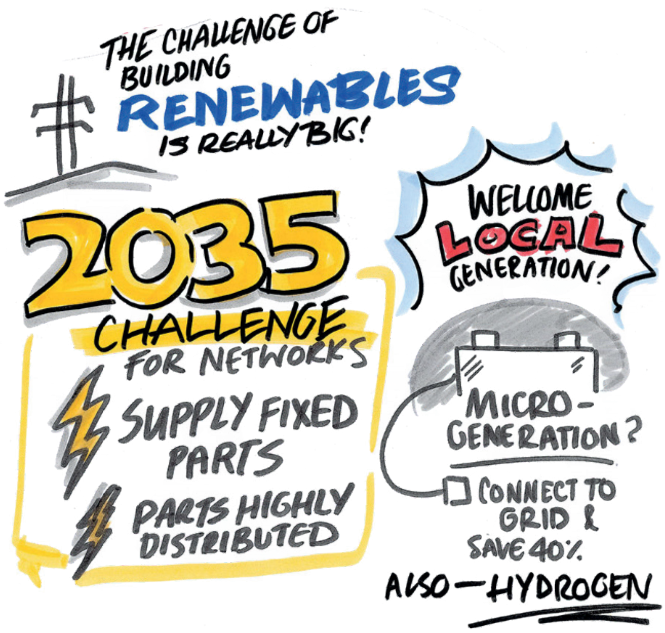


Stream 1.1

Electric Powertrains

The Electric Powertrain stream uses a "cradle to grave" approach to evaluate a suite of electric motors optimised for each of the transport sectors, considering user requirements from design to manufacturing, and from vehicle operation to disposal / reuse with the aim to improve efficiencies, increase performance and reduce costs at each stage. This stream will conduct life cycle analysis of competing electric powertrains and explore modular motor design studies on traction/propulsion motors for road, rail and aircraft applications. Dissemination and competition events on electric powertrains are envisioned as outputs of this work.

The modular motor design studies envision a modular motor with a unique toroidal stator which allows for dynamic and flexible electric drivetrain technologies to be deployed. The modular motor can embody different motor technologies from classical (e.g. permanent magnet) to radical (e.g. superconducting) into an integrated motor. This provides a very robust strategy sufficient to meet the supply chain and technical challenges in the automotive, rail, marine and aerospace sectors.



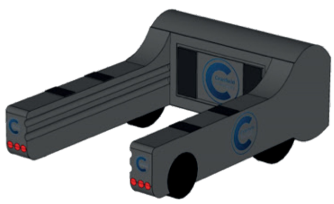
Stream 1.2

Connected Autonomous Vehicles

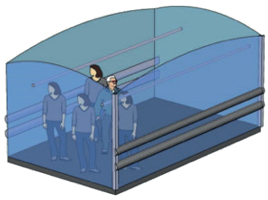
Covers technological (Cranfield) and Human Factors (Cardiff) topics including dynamics & control, guidance & navigation, decision making, sensor fusion, data & information fusion. Since Connected Autonomous Vehicle (CAV) R&D lends itself well to promoting Mobility as a Service (MaaS) and/or shared ownership such that we could see a reduction in road vehicles used for domestic, pleasure and work commute purposes.

Human Factors such as user needs and expectations, attitudes and behaviours associated with MaaS and shared ownership of electric powered CAVs will be developed using Cranfield's Multi-user Environment for Autonomous Vehicle Innovation (MUEAVI) platform, which is a new purpose built experimental facility for developments of on and off highway, ground and airborne autonomous solutions. In addition, questionnaires, interviews and experimental studies (e.g. using driving simulations) will be used to gather data on user needs and experiences. This stream will conduct scenario-based studies on the impacts of technological developments on autonomous & connected vehicles using the MUEAVI platform. It will also investigate the human factors related to the use of CAVs

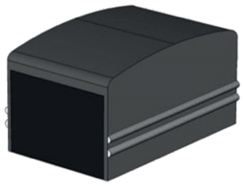
Mobility as a Service (MaaS)



Autonomous and Driven Platform



People Mover Capsule



Cargo Capsule

Stream 1.3

Green Taxiing

By combining the Electric Powertrain and Connected Autonomous Vehicle, this stream proposes Green Taxiing as a technology demonstrator for a decarbonised transport system. The environmental case for zero emissions taxi of short haul airliners has been demonstrated as feasible using on-board systems retrofitted to current aircraft's main landing gear.

Currently, the powered taxi solution is a wheel tug. There are concerns that this nose-wheel driven solution lacks traction for wet runway operations. Safran and Airbus have announced commercialisation of a main-gear-wheel driven solution. However, since it uses aircraft's auxiliary power unit, this is not the long-term zero emission solution required by future targets. TaxiBot is the most advanced and environmentally friendly electric taxiing system, and involves a semi-robotic pilot-controlled electric vehicle for dispatch towing. It has some key drawbacks such as ground operator involvement and potential long delays due to connecting and disconnecting. It also lacks agility and manoeuvrability. This stream will develop a design study of the concept of green taxiing by exploiting the team's expertise on electric drives, autonomous vehicles, airframe design and modular design & manufacture.

This stream will look at:

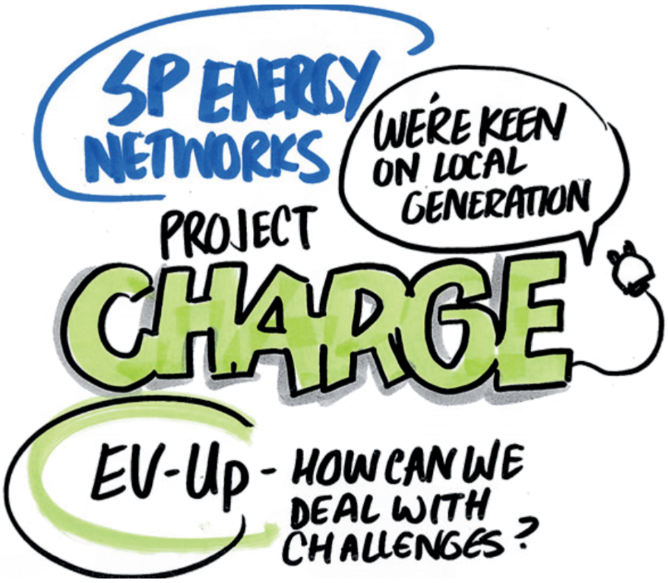
- A design study of the concept of an autonomous modular green taxiing system
- Formulating a simulation of the Green Taxiing within Cranfield's Digital Aviation Research Technology Centre (DARTeC)

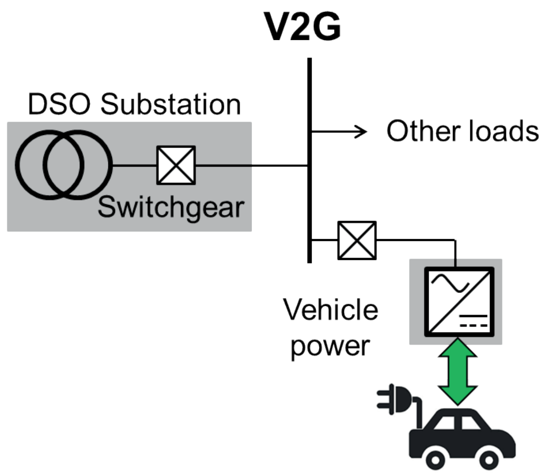
Work Stream 2

Charging Infrastructure

Leader: Dr. Pietro Tricoli
Birmingham University
Contact: p.tricoli@bham.ac.uk

The decarbonisation of transport through electrification relies on the parallel development of charging and electrical infrastructure. The network will consider the current status of various technologies and physical infrastructures as well as the impact of emerging technologies e.g. wireless charging and dynamic charging. It will consider the current status of technologies and physical infrastructures as well as the impact of emergingtechnologies, includingwireless charging. Working with the other work streams, a whole systems approach will be adopted for exploring the implications of radical transformations in energy and transport systems. Close cooperation with cities, regions, road operators, public transport operators and other relevant stakeholders will be established as many of the proposed measures do not need new legislation and can be adopted with local support. Stakeholder involvement will be critical to ensure the deployment of a flexible, open, multi–service infrastructure. Finally, the transitional role of the technologies used to achieve emission reduction goals will be assessed.





Stream 2.1

Extending & Building Charging Infrastructure

This stream will look at the development of charging and/or fuelling infrastructure for EVs, including the development of (smart) integration of these vehicles with grid capacity, flexible demand and energy storage. It will also look at how to enable the integration of autonomous land and air vehicles and the analysis of regional disparity for charging infrastructure (spatial urban planning versus rural, population density).

Stream 2.2

Dynamic Charging on the road and its applicability

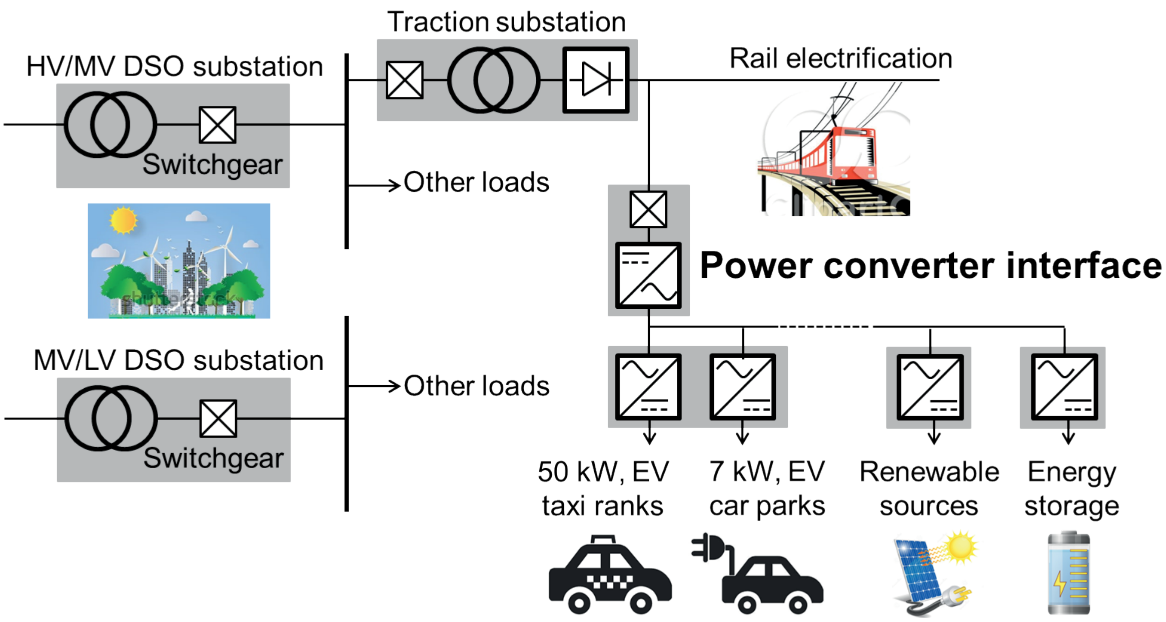
This stream will look at the distribution and transmission network requirements for dynamic charging. The magnetic circuit designs for this application and their relative performances; how demand patterns for dynamic charging would manifest and any installation's impact on the grid; safety issues surrounding successful implementation of high power magnetic field systems. The stream builds on an existing collaboration with National Grid.

Stream 2.3

Railway Feeder Stations

This stream will consider the use of railway feeder stations in an integrated mobility concept (e.g. railway stations fitted with EV charging, combined tickets for rail transport and charging)
Railway feeder stations as a key component of smart grids to aid the storage and optimised use of electricity.

For this objective the Southampton National Infrastructure Systems model for transport can be used. This model can forecast the use of rail stations up to 2100, using a combination of external scenarios and internal strategies, along with energy/electricity requirements. Additional modelling could determine the use of access and egress modes and the resultant energy/electricity requirements. A rolling programme of hub development could then be determined.



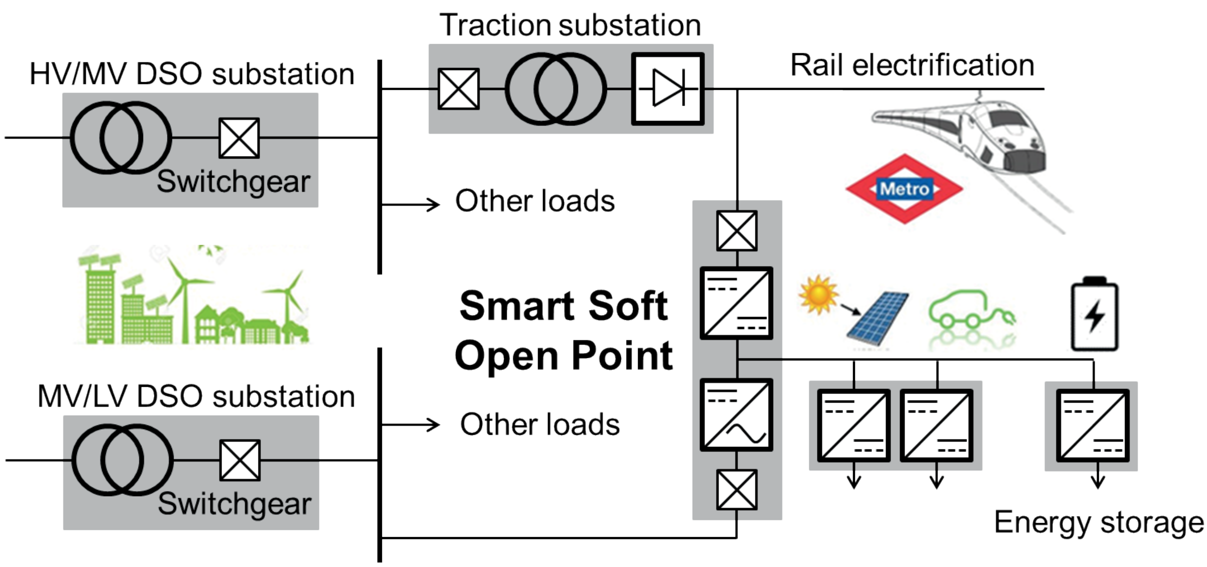
Stream 2.4

Low Carbon Generation on the Railway Network

Attractive opportunities are offered by the integration of low carbon generation on the railway electrification network using the smart grids concept, although this is rather challenging for the railway as off-the-shelf solutions do not currently exist.

This research stream will be focussed on:

- Technologies using Smart Soft Open Points for the reduction of power losses based on a better control of the power flow with energy storage and power distribution grids
- Medium voltage DC traction power supply systems to reduce the cost of the railway electrical infrastructure by increasing the distance between railway substations, eliminating neutral sections and negative phase sequence currents, and allowing connection to the power distribution grid rather than the sub-transmission network



Work Stream 3

Supply of electricity as a TransportFuel

Leader: Professor Manu Haddad
Cardiff University
Contact: Haddad@cardiff.ac.uk

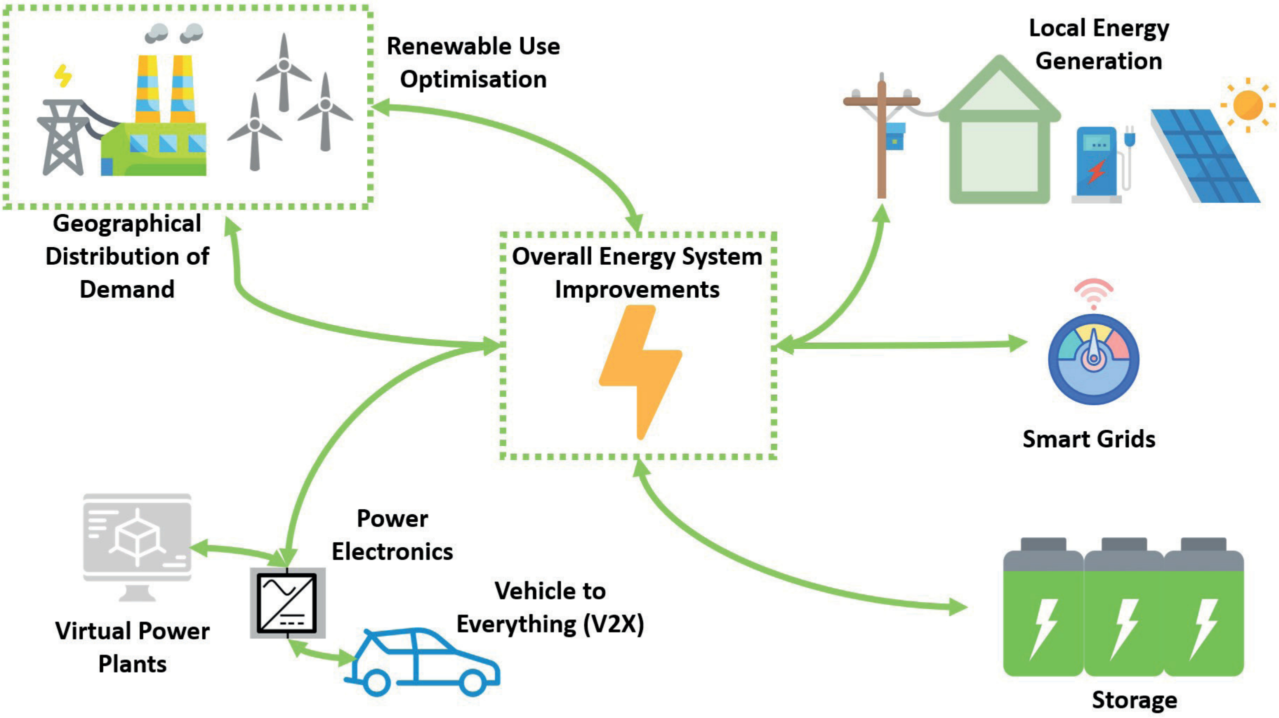
The effectiveness of decarbonising the transport sector is largely dependent on the extent to which the power sector is decarbonised. In order to fully achieve the decarbonisation of transport we need to reinforce both sectors and make these systems smarter. Electricity networks and transport are increasingly interacting in an unprecedented manner with the potential to give rise to a new merged industry.

This research stream will look at the short, medium and long-term challenges associated with electricity as an energy carrier for different low-carbon transport modes and carbon intensive services (cars, trains and electric aircraft). Mapping this with planned electricity generation mixes in the UK up to 2040 is key to future proofing supply.

This work stream will closely collaborate with WS1 and WS2 to identify the technological, infrastructural, and regulatory changes needed to deliver energy demand reduction. In addition to modelling the supply of electricity as a transport fuel, the electricity demand for transport will also be taken into account, and made dependent on different market / business scenarios, resulting from different levels of demand-side and supply-side incentives to accelerate the market take-up of low carbon transport modes. The whole-system framework across sectors will allow the cost-effectiveness of decarbonisation to be assessed more holistically.

Areas of focus for this work stream are:

- Analysis of geographical distribution of demand as a result of low-carbon transport modes
- Optimising the use of renewables
- Studying the cost of, and interaction between demand-side and supply-side measures.
- Investigating the carbon footprint reduction of low-carbon transport modes by considering synergies and interaction with renewable energy sources, local energy generation, storage and management systems
- Exploring synergies between power grids and rail electrification lines with power electronics technologies
- Analysing charging infrastructure deployment in combination with grid edge technologies (decentralized generation, microgrids, storage, and smart buildings) & integration with smart grids
- Increased reliability, resilience, efficiency, and asset utilization of the overall system using grid edge devices
- EVs as a source of flexibility, vehicle-to-everything (V2X)



Work Stream 4

Smart Mobility

Leader: Professor Carol Featherston
Cardiff University
Contact: FeatherstonCA@cardiff.ac.uk

Smart Mobility is based around delivering a system which is:

- Flexible: multiple transportation modes allow travellers to choose which works best for a given situation
- Efficient: the traveller gets to their destination with minimal disruption and in as little time as possible
- Integrated: the full route is planned door-to-door, regardless of modes of transport used.
- Clean: transportation moves away from pollution-causing vehicles to zero-emission ones.
- Safe: fatalities and injuries are drastically reduced

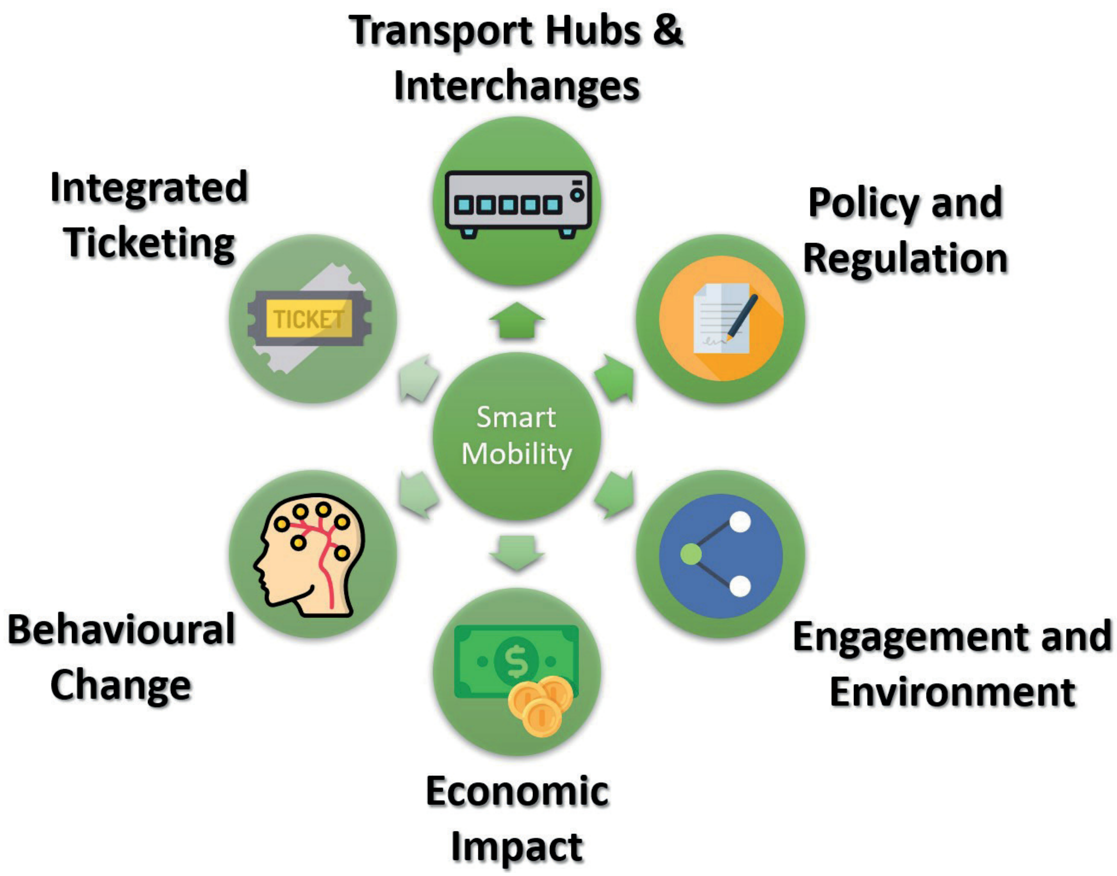
To deliver this we need to make significant changes, but this shift has already begun. New business models inspired by the sharing economy and disruptive technologies are ushering in an exciting new age in transportation: the era of smart mobility. The arrival of on-demand ride services like Uber, real-time ride-sharing services, car-sharing and bike sharing programs, and thousands of miles of urban bike lanes are all changing how people get around. Commuters no longer need to own a car to have one at their disposal. They don't have to pre-arrange carpools to share a ride with others headed in the same direction. They needn't wait for a ride home when it's pouring down rain and there's not an empty cab in sight.

Automakers increasingly see themselves as both product manufacturers and mobility services companies. In addition to developing next-generation connected and autonomous vehicles that will improve traffic flows and safety, automakers are investing in a wide swath of new mobility services—everything from car-sharing and rental services to multi-modal trip-planning applications.

There's no question that consumers have been the primary beneficiaries of new mobility services. The question facing urban planners is how today's expanded mobility ecosystem can help advance public policy goals such as encouraging higher productivity and reducing congestion, while bringing related benefits such as fewer traffic accidents, better air quality, and a smaller urban footprint for parking.

We need to look at the feasibility of using alternative transportation modes to help metropolitan areas reduce traffic congestion without spending tens of billions of pounds on new roads, tunnels, and light rail. What are the most promising strategies? Which approaches work best in which cities? How can automakers and transportation officials work together to address changing mobility needs?

In this workstream we look at how four cross cutting themes can be used to deliver this vision:



Stream 4.1

Human Factors

How we change our relationship with the use of vehicles?

The move to this autonomous, shared transport systems will require a transition in how we view our relationship and use of vehicles. Factors such as handover and handback of manual controls within highly automated vehicles, designing human-machine interfaces for fully autonomous vehicles and trust in automated vehicles when negotiating junctions, other traffic, pedestrians and cyclists. Issues related to shared travel, exploring the human motivations and decision-making considering physical mobility, in relation to the ability to use a mode of transport, user perceptions, expectations, knowledge and social factors, including perceptions of trust, communication and collaboration.

Stream 4.2

Big Data and Cyber Security

How do we foster balanced development of all transport modes?

One of the frustrations of urban transport systems is the lack of co-ordination between different transport providers. We want to know how to get from A to B as easily as possible, whether that's on foot, by bicycle, electric scooter, metro, bus, train, hire car or taxi - or a mixture. In the past we didn't have enough data to know. Now we do, and we have the connected smartphones to help us visualise it all.

Stream 4.3

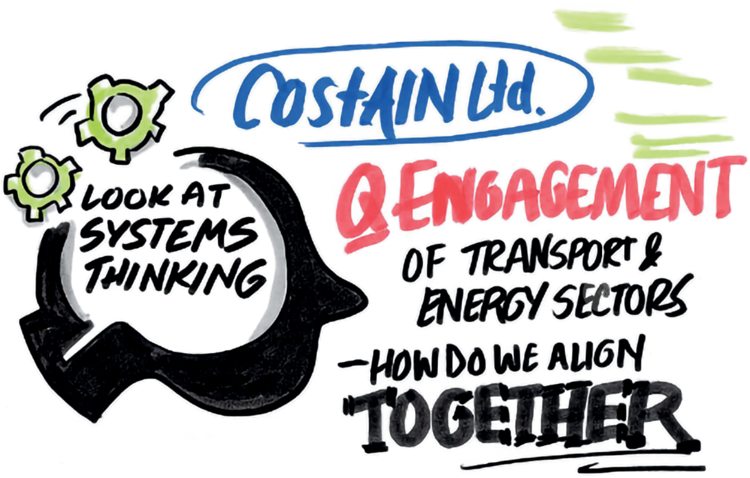
Planning, Economics and the Environment

How do we get from A to B as easily as possible?

A Sustainable Urban Mobility Plan fosters a balanced development of all relevant transport modes, while encouraging a shift towards more sustainable modes.

Considering:

- Public transport: provide a strategy to enhance the quality, security, integration and accessibility of public transport services
- Non-motorised transport: raising the attractiveness, safety and security of walking and cycling
- Inter-modality: contributing to a better integration of the different modes
- Urban road safety: improving road safety based on an analysis of the main road safety problems and risk areas in the concerned urban area
- Road transport: optimising the use of existing road infrastructure considering reallocating road space to other modes of transport
- Urban logistics: including urban freight delivery, while reducing related externalities like emissions of GHG, pollutants and noise
- Mobility management: fostering change towards more sustainable mobility patterns

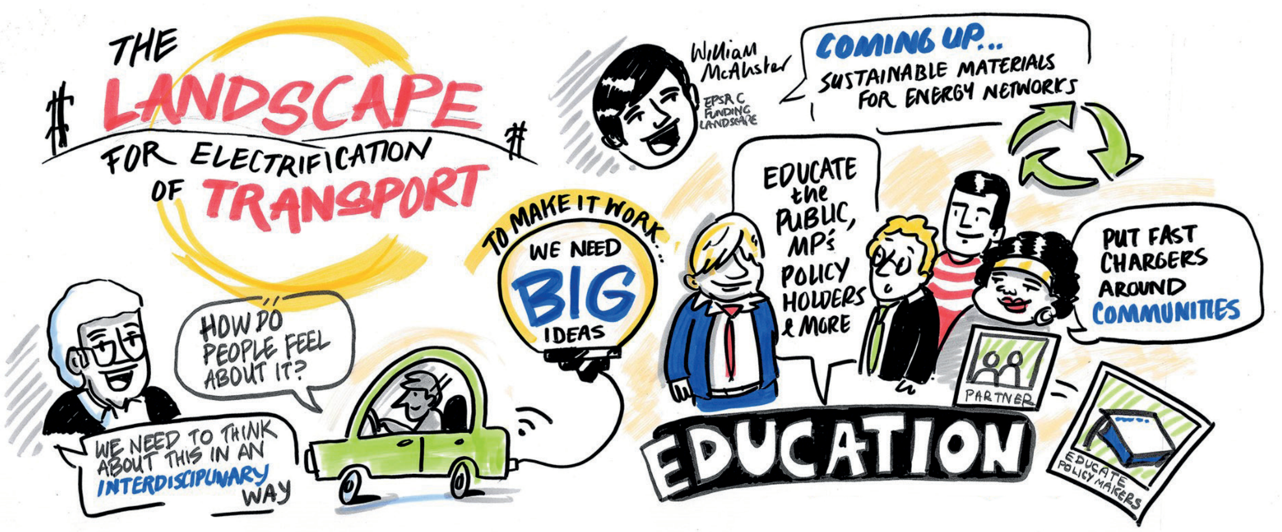


Stream 4.4

Policy

How do we implement sustainable governance?

This stream aims to explore fully the role of transport policy, infrastructure planning, energy infrastructure deployment and policy making at national, regional and local level on transport decarbonisation. Sustainable governance and regulatory appraisal of the interdependencies between infrastructure plans (road, rail and airborne) is essential for effective carbon reduction.



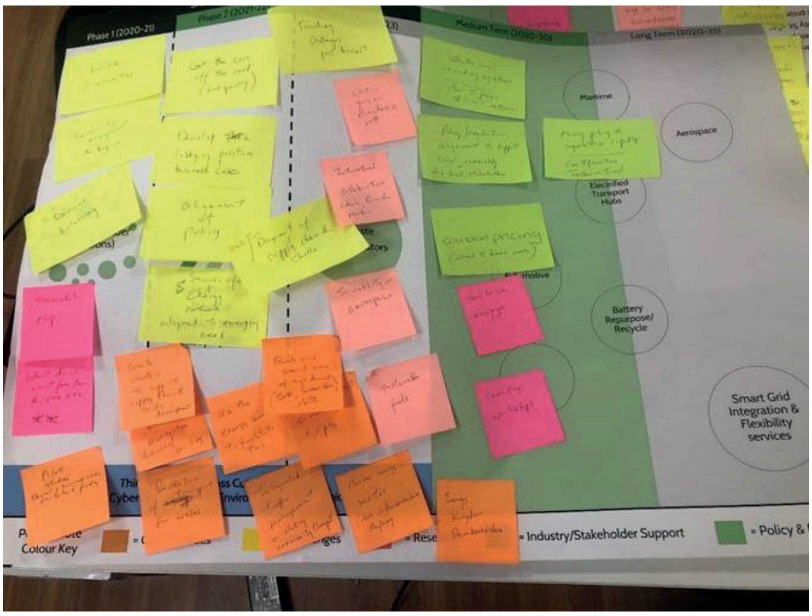
Stakeholder Consult

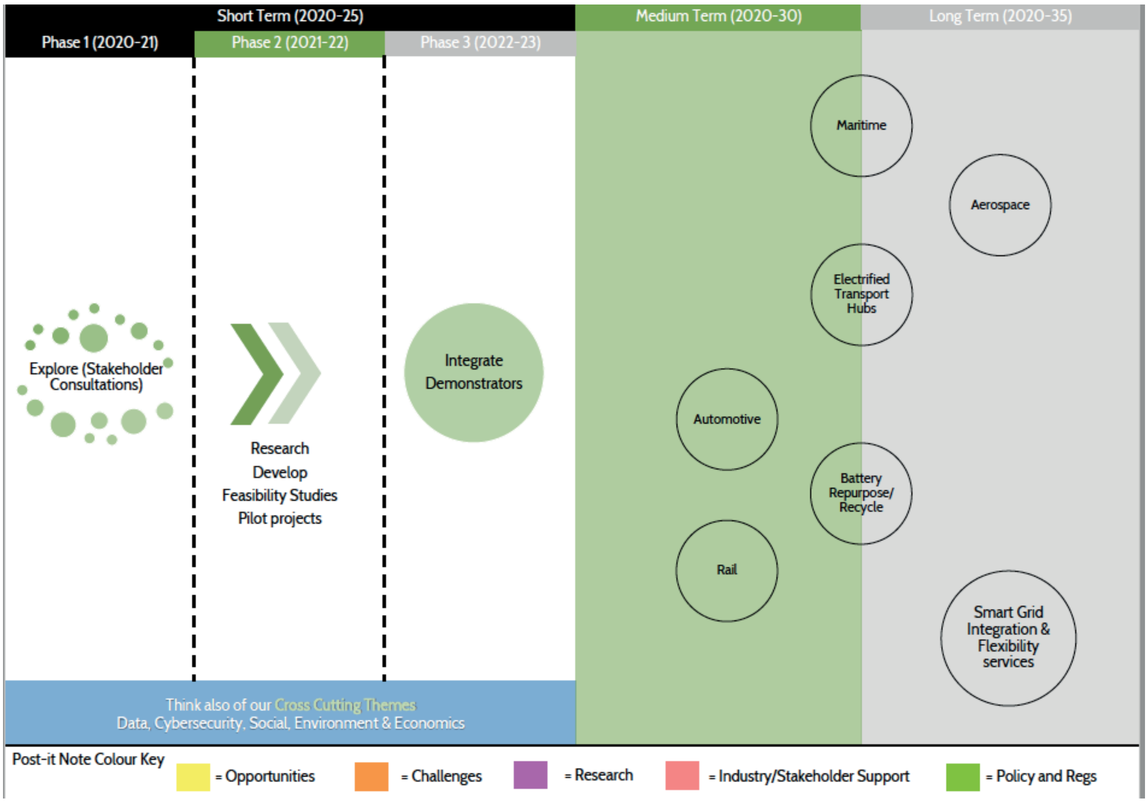
Consultation Methodology

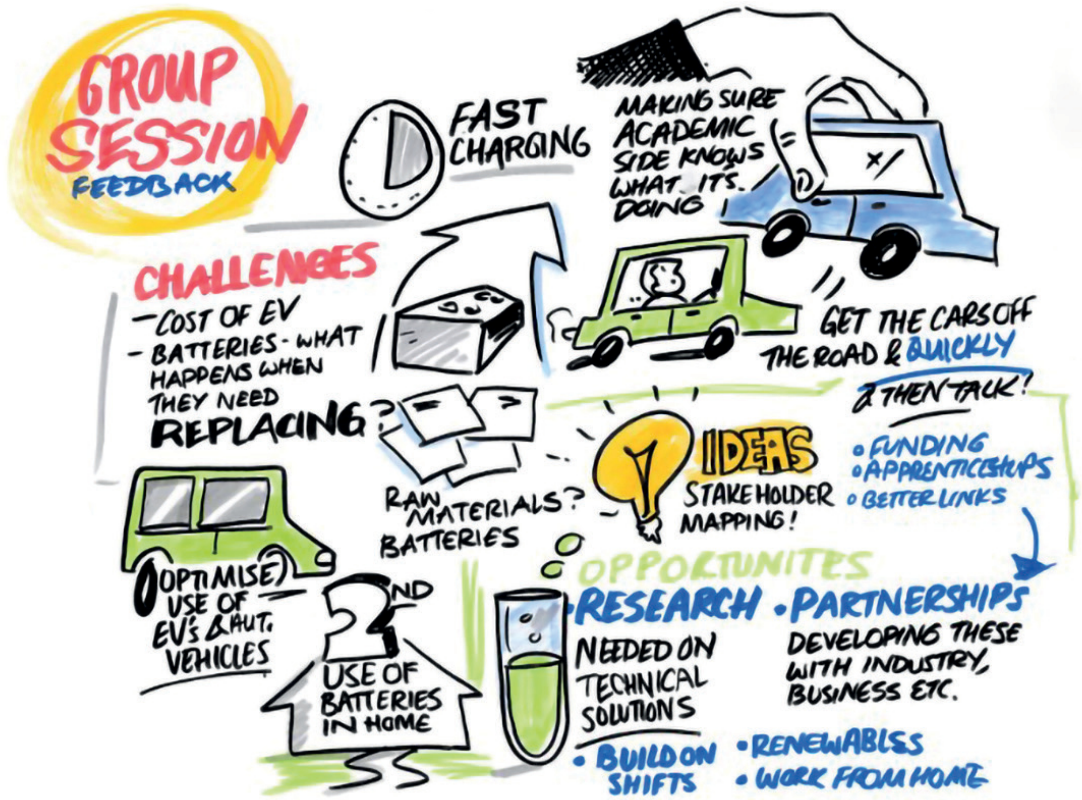
During the DTE Network+ launch event a consultation was conducted to identify the key challenges and priorities for this consortium's efforts as well as to identify the medium and long term challenges surrounding transport decarbonisation.

Over 200 individuals participated in the consultation activity and many unique ideas and challenges were identified. Participants represented many different industries and thus formed a very diverse group. Ideas were categorised and fitted to the appropriate work streams and key opportunities were identified. These will be considered in the feasibility and pilot projects within this network over the medium to long-term. It is our intention to organise workshops and sandpit events that will focus entirely on medium and long term goals. The questions asked in the roadmap exercise were:

- What are the challenges to be addressed by the network?
- What are the short-term, medium term and long-term priority issues?
- How the industry could engage with the researchers?
- How the DTE Network+ research could benefit your industry/sector?
- What are the other sectors / themes to be addressed to achieve the whole system approach and integration?



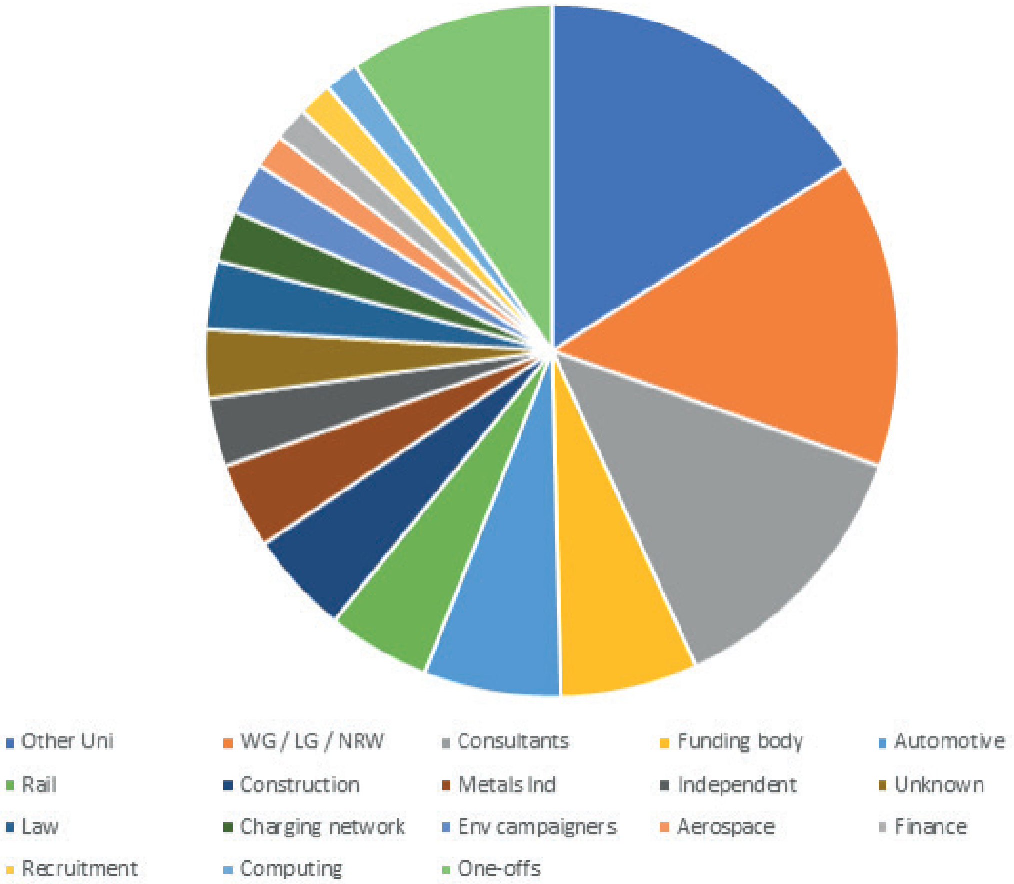

Short Term (2020-25)
Medium Term (2020-30)
Long Term (2020-35)
Phase 1 (2020-21)
Phase 2 (2021-22)
Phase 3 (2022-23)
Explore (Stakeholder Consultations)
Research
Develop
Feasibility Studies
Pilot projects
Integrate Demonstrators
Maritime
Aerospace
Electrified Transport Hubs
Automotive
Battery Repurpose/ Recycle
Rail
Smart Grid Integration & Flexibility services
Think also of our Cross Cutting Themes
Data, Cybersecurity, Social, Environment & Economics
Post-it Note Colour Key
= Opportunities
= Challenges
= Research
= Industry/Stakeholder Support
= Policy and Regs


GROUP SESSION
FEEDBACK
FAST CHARGING
MAKING SURE ACADEMIC SIDE KNOWS WHAT ITS DOING
CHALLENGES
- COST OF EV
- BATTERIES - WHAT HAPPENS WHEN THEY NEED REPLACING?
GET THE CARS OFF THE ROAD & QUICKLY
& THEN TALK!
RAW MATERIALS? BATTERIES
IDEAS
STAKEHOLDER MAPPING!
• FUNDING
• APPRENTICESHIPS
• BETTER LINKS
OPTIMISE USE OF EV'S & AUT. VEHICLES
2ND USE OF BATTERIES IN HOME
OPPORTUNITIES
• RESEARCH NEEDED ON TECHNICAL SOLUTIONS
• PARTNERSHIPS DEVELOPING THESE WITH INDUSTRY, BUSINESS ETC.
• BUILD ON SHIFTS
• RENEWABLES
• WORK FROM HOME

Stakeholder Consult

Participants

During our launch event we were delighted to see 200+participants covering a wide range of stakeholders from various sectors.

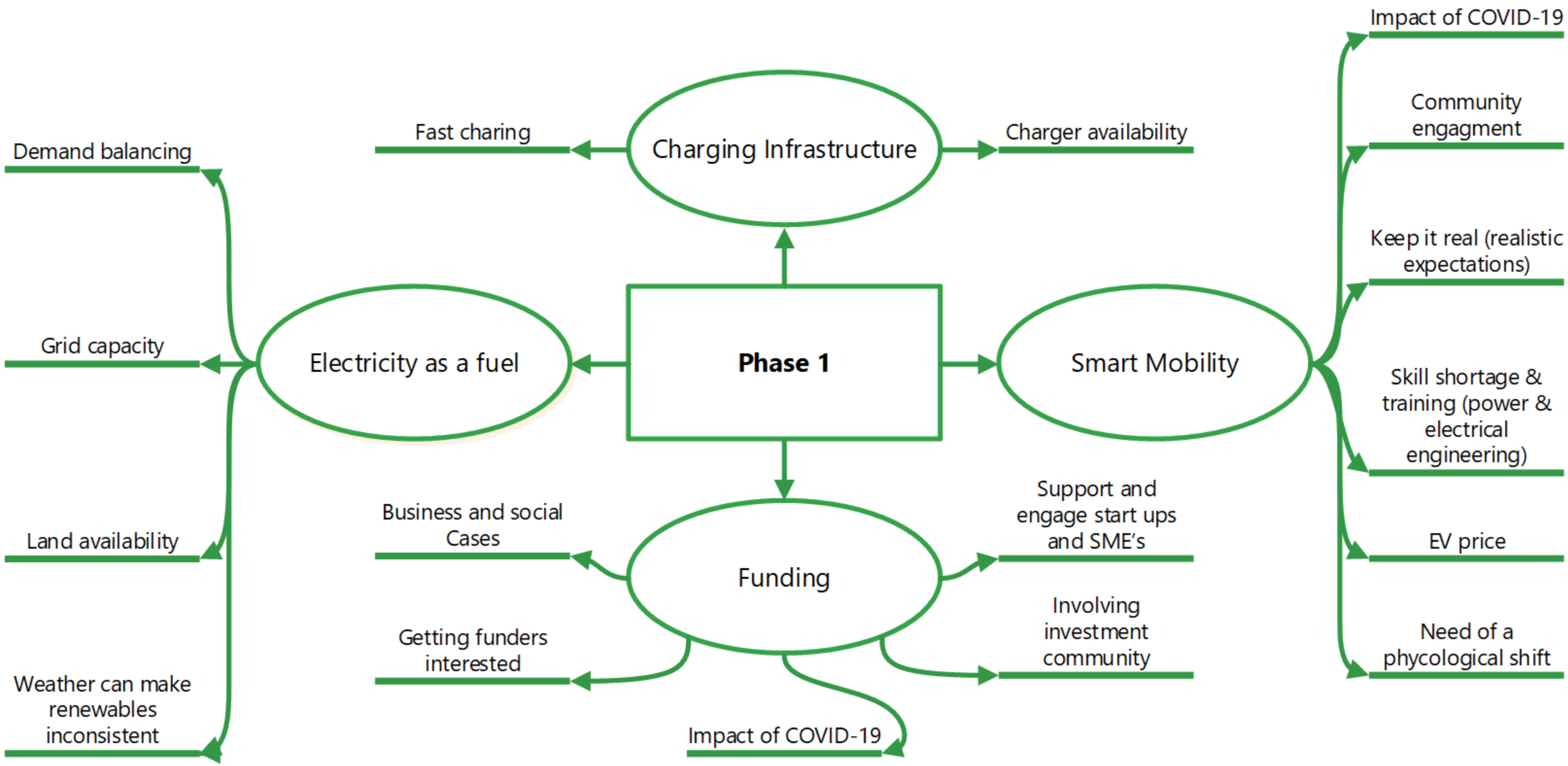


We would like to thank those listed for their contribution to the report. We welcome all feedback and encourage you to communicate any ideas you may have with us. We would like you to be part of the DTE Network+ as an enourmous amount of effort is required to tackle decarbonisation of transport through electrification.

Admiral Group
Aerospace Wales
Amey Consulting
Apex Transport Planning Ltd
B J Seals Limited
Birmingham University
Cardiff City Council
Carmarthenshire Energy
Cardiff University
Celtic Innovation Solutions Limited
Cenin Renewables Ltd.
Costain
Cranfield University
CSA Catapult
Deregallera
Dragon Executive Management Ltd
Energy Service Wales
Engenie
EPSRC
European Recycling Platform
FSEW – International Freight
Geldards LLP
Industry Wales
Innovate UK
IPFT
Maple Consulting
Meritor
Microchip
Mott McDonald
National Grid
Natural Resources Wales
Neath Port Talbort Council
NPL
Quercus Investment Partners
Renewable UK
Ricardo
River Simple
Riding Sunbeams
Safran
Set Squared
SP Energy Networks
Spectrum Technologies Brigend
Swansea University
TATA
Transport for Wales
TurboPower Systems
UDL Intellectual Property
United Plastics Group
University of Derby
University of Exeter
University of South Wales
Vibe Recruit
Welsh Government

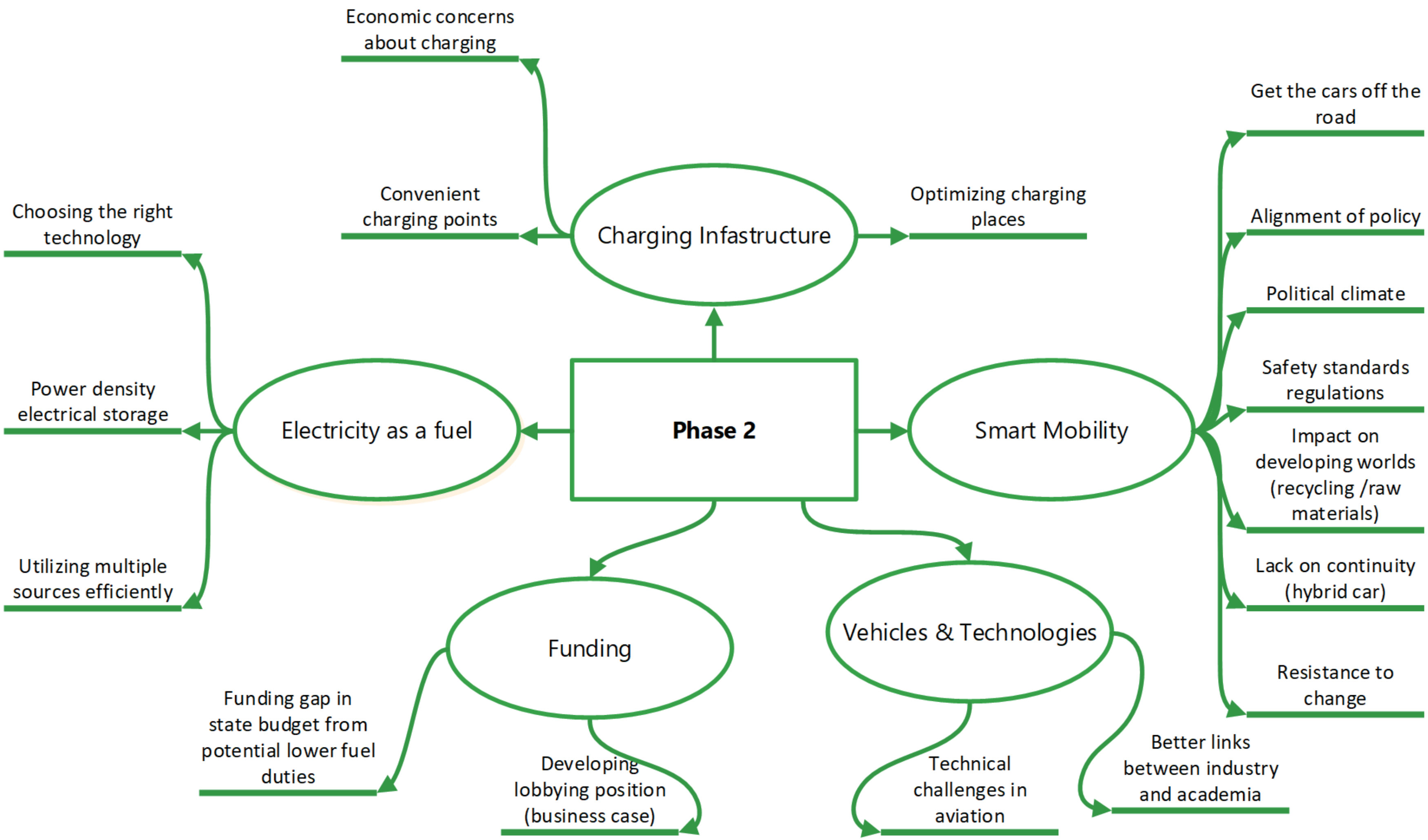
Frameworks

DTE Network+Phase 1(2020–2021)



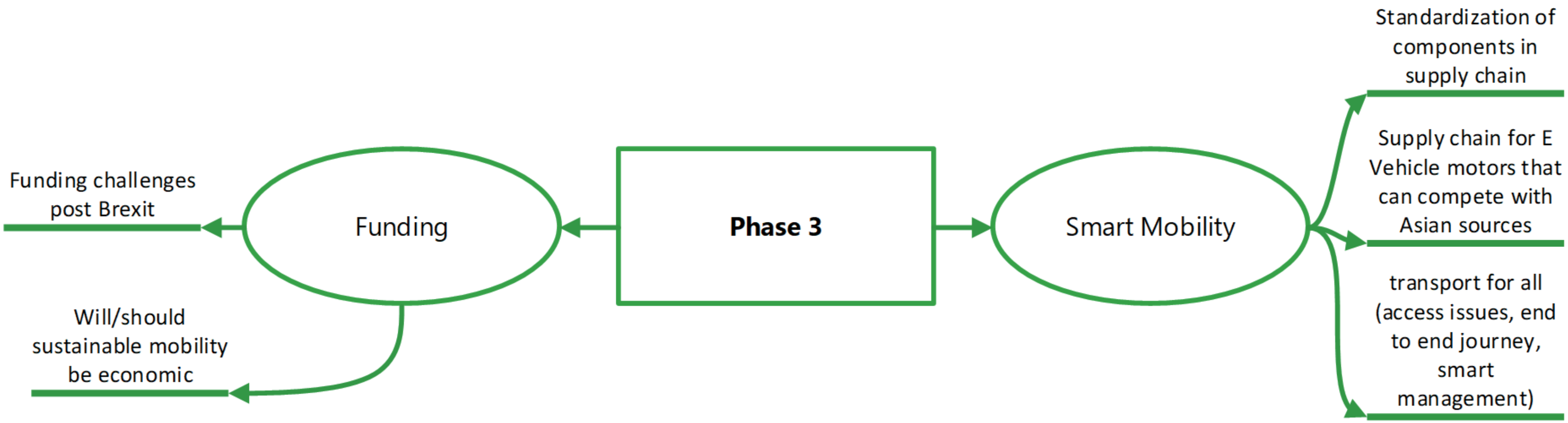
Frameworks

DTE Network+Phase 2 (2021–2022)



Frameworks

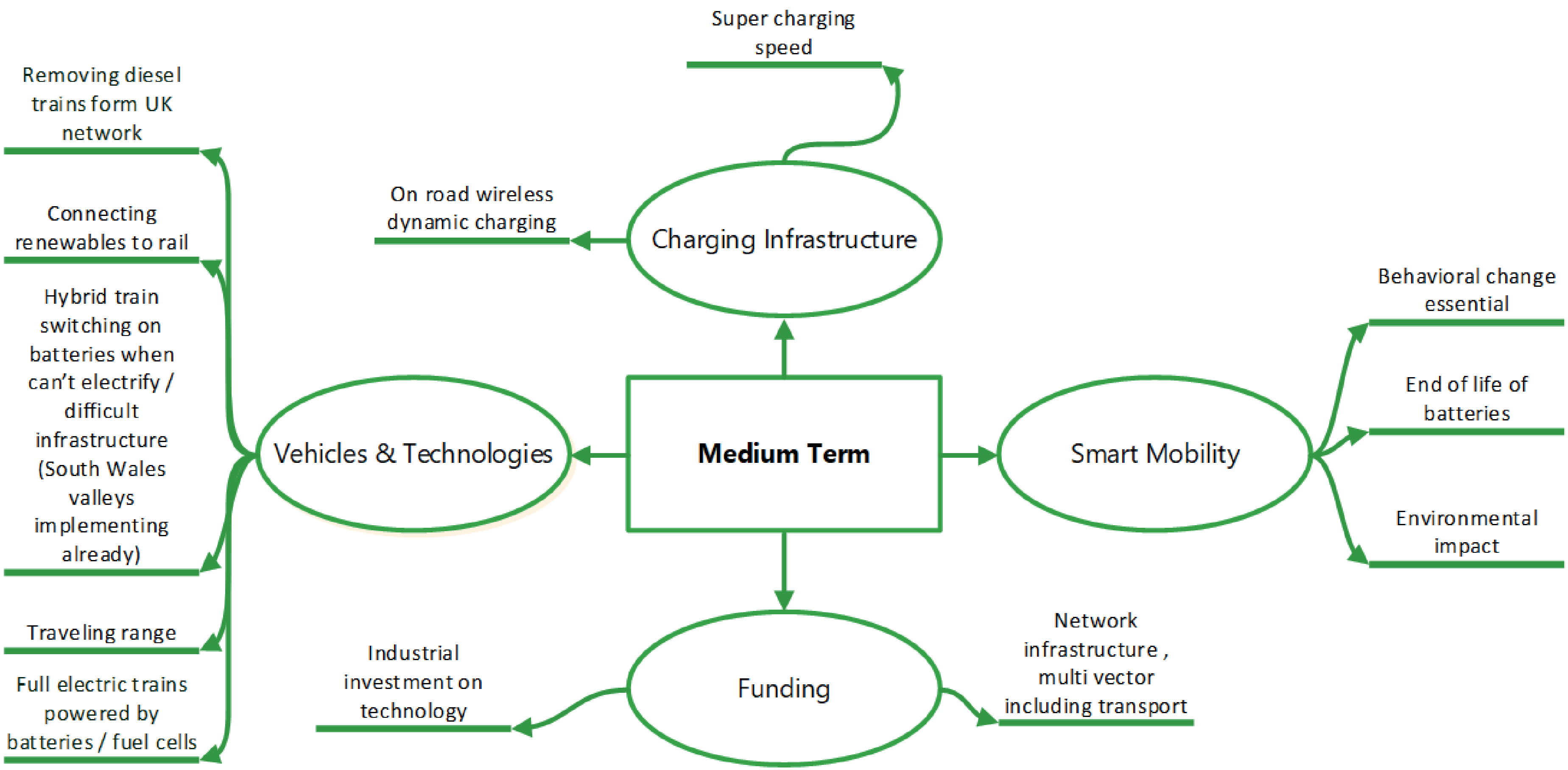
DTE Network+Phase 3 (2022–2023)



Frameworks

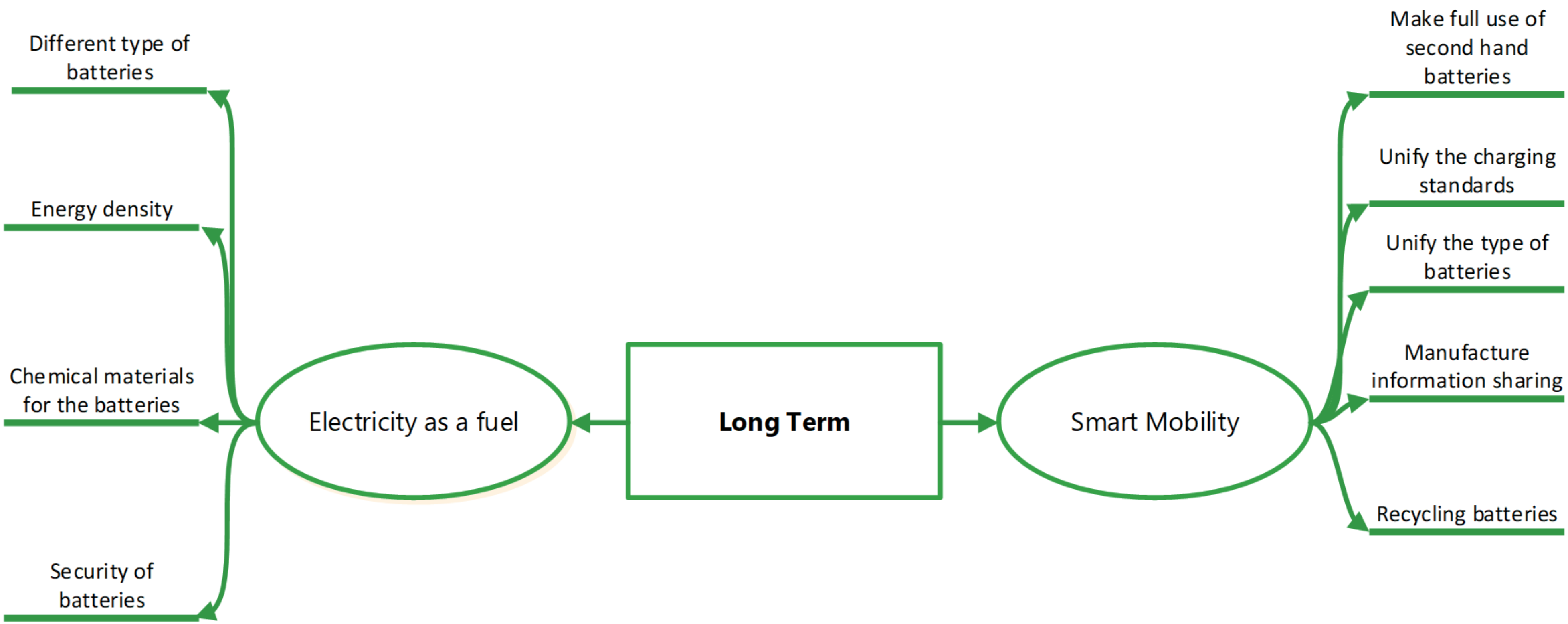
DTE Network+ Medium Term (2020–2030)

Medium and long term challenges can be harder to identify but there were several interesting ideas received. It is important to note that there will be further development of the medium and long term challenges as the DTE Network+ project progresses.



Frameworks

DTE Network+Long Term (2030–2040)



Optimisation of Intermittent Electrification of Rail Transport for Near-Term Decarbonisation

Dr Will Midgley, Dr Bilal Abdurahman, Dr Chris Ward, and Dr Tim Harrison Loughborough University

Introduction

The UK rail network must be decarbonised to meet the UK Government's 2050 net zero commitment [1]. Electrifying incrementally/continuously has operational benefits but is expensive, costing around £2M–£3M per single-track kilometre [2]. Electrifying intermittently (i.e., leaving unelectrified gaps) might allow the UK to cut its greenhouse gas emissions faster and more cheaply in the short term than electrifying incrementally. This work investigated the feasibility of intermittent electrification and developed a method for finding the optimal intermittent electrification strategy for cutting emissions the fastest.

Modelling

An initial model developed by the team presented a high-fidelity model of a 5-car electric-diesel bi-mode rail vehicle that allowed detailed modelling of the CO2 emissions of these trains when meeting a given timetable [3]. This project built on that model by improving the speed control and the modelling of individual components such as the electric motors. A battery pack based on a high-charge/discharge lithium-titanite oxide (LTO) battery module has been modelled and installed on the train. This was used to investigate the battery-electric hybrid train's traction performance, and the feasibility and energy benefits of replacing diesel engines with batteries on trains running on intermittently electrified tracks. Optimal battery sizes were also identified for given percentages of optimal intermittent electrification. The optimal electrification strategy devised in [4] was improved to include the energy consumption for both directions of travel, as opposed to a single travel direction. The Newbury-Plymouth route was divided into 50 5.6-km sections and the maximum energy consumption for each direction of travel was selected as the energy footprint for each section. The optimal intermittent electrification method was then found using the strategy in [4].

Results

Optimal intermittent electrification can reduce operational CO2 emissions by up to 54% when compared to the same length of continuous electrification [4]. This happens at 50% of route electrification as shown in Figure 1. At full electrification, both intermittent and continuous electrification provide the same operational CO2 saving.

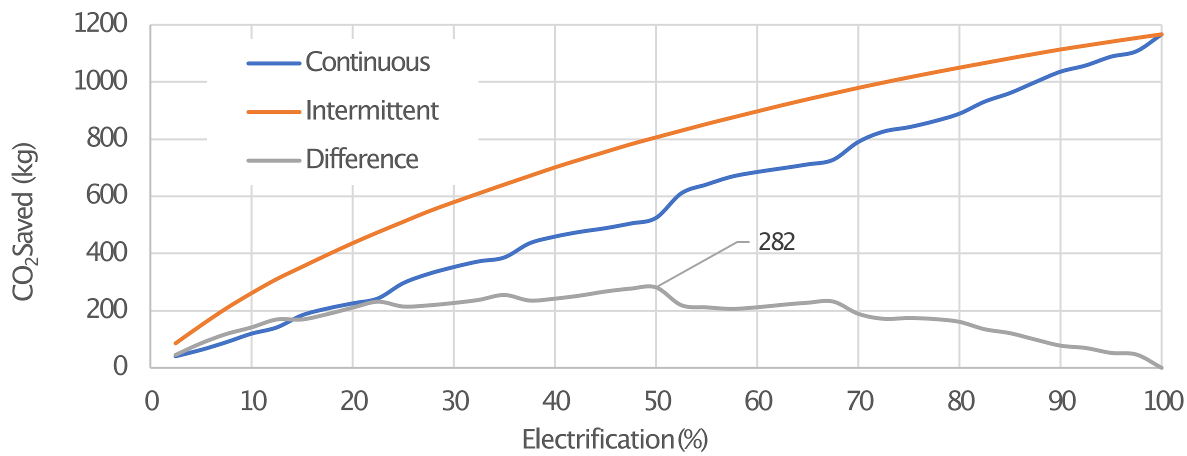


Figure 1: CO2 saved from discontinuous (intermittent) and continuous electrification [4]

Replacing a diesel engine with a battery can allow energy savings as the battery-electric train can recover energy during braking through regenerative braking. Of the 2.5MWh required to move a fully laden 5-car Class 80x train with the weight diesel engines from Plymouth to Newbury, approximately 1.2MWh of this energy is available for recuperation through regenerative braking.

Modelling was used to determine the required battery capacity for the train at different extents of intermittent electrification (see Figure 2), where the battery was sized to ensure its state of charge (SOC) never dropped below 20%, and an additional 25% capacity was added to account for battery wear over its lifetime. (This, taken with the high-power requirements, explains the higher-than-expected battery capacities for low amounts of electrification.)

The amount of energy saved (recuperated) by the battery is also included in Figure 2. Also included in Figure 2 is the results of a 'common sense manual approach' to optimization that consists of longer 10-km stretches of electrification centred on stations and the hilly section connecting Totnes and Ivybridge (the triangle and square at 36% electrification). This produced a much lower battery size (around half the size) as these sections include much of the high-power demand for the route. In contrast, the discretised method is constrained to using 5.6-km sections which can result in different choices for electrification.

At 36% of optimal electrification, the battery would undergo an average of 5475 cycles per year at 5 trips per day (approximately 15 cycles per day), a standard LTO datasheet [5] suggests that the batteries would be able to operate for about 1.1 year (at 550C) before their capacity is reduced to 80%. At this point they may need to be replaced and the old batteries could be used for lineside storage or recycled.

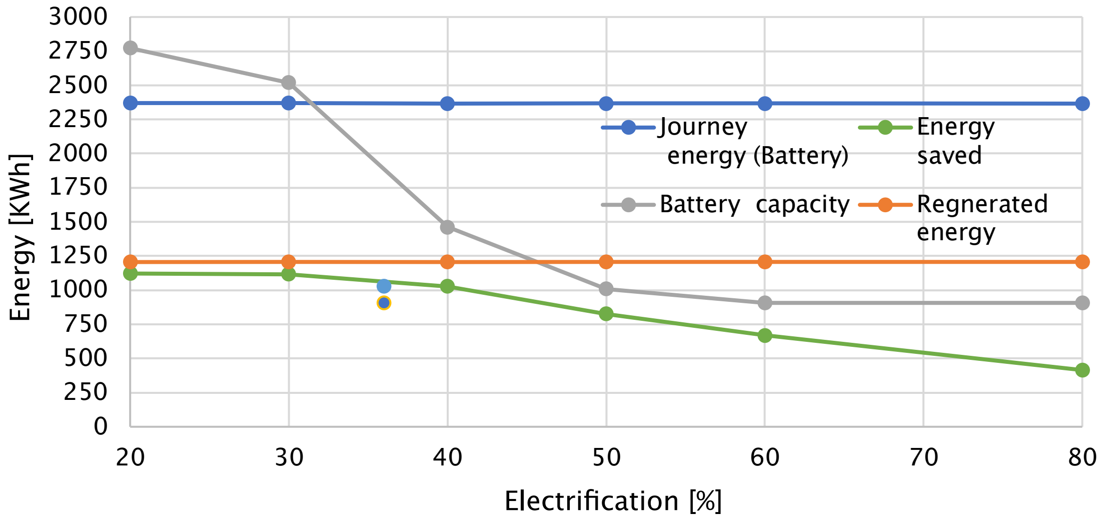


Figure 2: Effect of intermittent electrification on battery size and energy saved

Conclusion

This study has shown that intermittent electrification would provide the fastest means of decarbonising the UK railway, saving up to 50% more CO2 than continuous electrification. It also shows that battery infill for electrified sections is feasible, to allow complete decarbonisation of the rail network whilst electrification progresses. However, practical considerations for intermittent electrification and battery infill remain, including raising and lowering of pantographs at speed, the connection of two adjacent electrified sections and end-of-use considerations for traction batteries.

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3. T. J. Harrison, W. J. B. Midgley, R. M. Goodall, and C. P. Ward, "Development and control of a rail vehicle model to reduce energy consumption and carbon dioxide emissions," Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit, vol. Online Fir, Feb. 2021 doi: 10.1177/0954409721993632.
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A data-driven approach for optimal distribution network operation with rapid charging infrastructure and large-scale battery storage

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Project Description and Methodology

This project develops an innovative toolkit to enable the active management of distribution networks to maximise the large-scale battery profit and to maintain distribution networks' voltage limits. The toolkit will support energy storage investments in distribution networks. The power dispatch strategy for large-scale batteries aims to enhance the performance of distribution networks and considers EVs charging demand, photovoltaic power generation and electricity arbitrage. The Twin Delayed Deep Deterministic Policy Gradient (TD3), a reinforcement learning method which works in environments with continuous action space, is used to perform the power dispatch of large-scale battery.

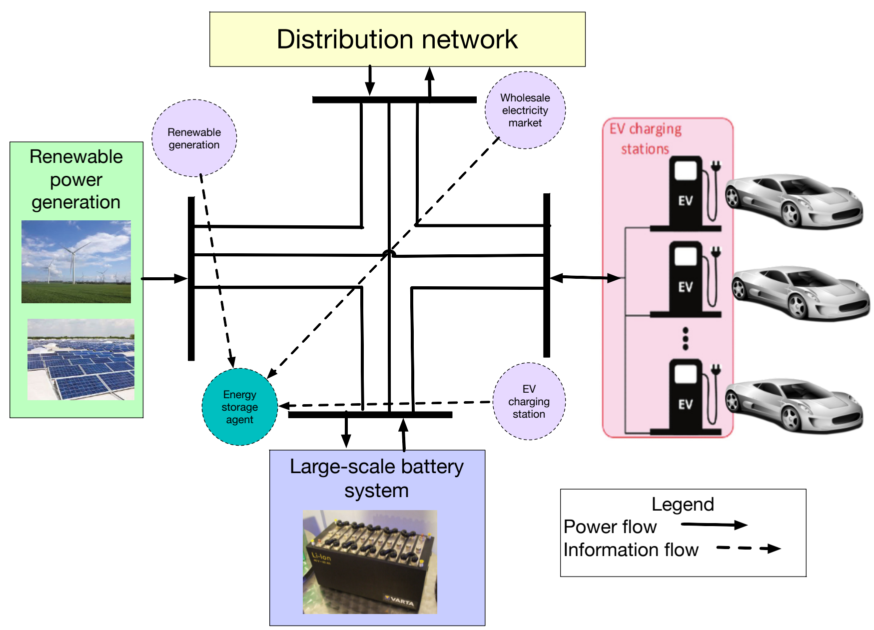

Figure 1: System Context

Fig. 1 presents the basic components of a distribution network with EV charging stations, renewable power generation including solar, and large-scale batteries. The project employs the following methodology: consider that the distribution network operator has access to large-scale batteries owned by a third-party company, the objective for the energy management system is to maximise the profit of the large-scale battery. The voltage constraints are considered and to maintain a healthy voltage level of the distribution network.

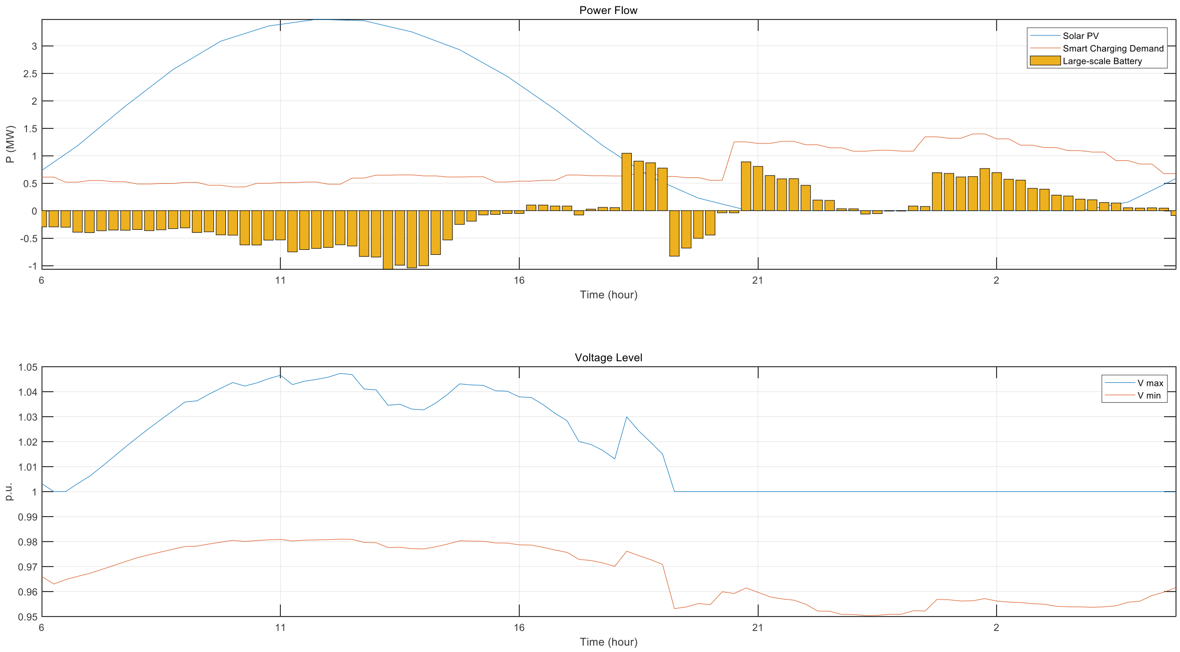

Fig. 2. Power flow and voltage level of the distribution network.

Preliminary Results and Collaboration

This project utilises smart EV charging (SMC) data from **UK Power Network's** recent project, Project Shift, and photovoltaic data of Great Britain for case studies. After TD3 is trained with the forecast data, the dispatch strategy can work effectively with real-time data or environment as shown in Fig. 2. The distribution network can charge the large-scale batteries during off-peak hours and provide electricity to charging stations during high and rapid charging demand. Local renewable power generation such as solar can be used to meet the local charging demand, to be stored in battery storage, or to export to the grid. Fig. 3 presents the Levelized Cost of Storage (LCOS) results which provides the economic comparisons between different types of energy storage operating methods and consideration of charging demand.

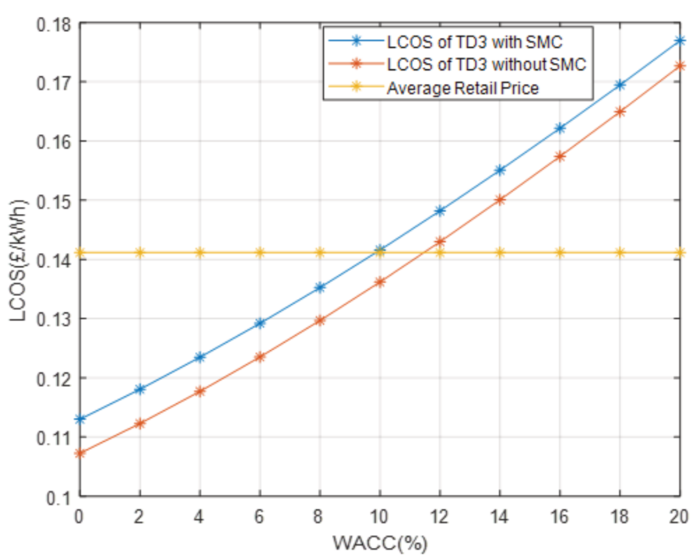

Fig. 3. Levelized Cost of Storage analysis.

As the LCOS is lower than the average retail electricity price when below 10% Weighted Average Cost of Capital (WACC), the use of large-scale battery can be a viable option. The ongoing research includes a detailed financial analysis of the large-scale battery investment. A journal article is under preparation to report the novel power dispatch methodology. International collaboration has been formed with **Guangdong University of Technology, China** and one conference article has been published. The work has paved ideas for developing a research proposal with the DTE consortium members on wireless charging technology.

Design of Wireless Charging Lane Infrastructure

Petrina Constantinou, Jose Escribano Macias, Panagiotis Angeloudis
Imperial College London

The transport industry represented 27% of all UK greenhouse gas emissions in 2017, with 90% of which being attributed to road transportation. Despite improvements in technology over the last three decades, emissions only decreased by 4%, compared to a 47% decrease in the industrial sector. These increases took place despite improvements in automotive technologies, motor efficiency and policy efforts, and are attributed to increased road traffic.

Extensive efforts are currently underway in the UK to promote the electrification of transport. In terms of public transport, buses constitute about 60% of all trips and particularly in London, where about half of bus trips take place, the number of journeys has increased by 20% since 2005, illustrating that electrifying the bus network offers a significant opportunity to reduce emissions.

Even though the implementation of electric buses is a promising solution, there are some aspects that confine their usage, such as the limited driving range and the long recharging times which translates into a requirement for larger fleets to compensate for the downtime due to charging. An alternative solution is the adoption of wireless charging lane (WCL) technology. This technology allows the bus to charge while on the move, increasing the driving range and reducing the downtime for recharging. This results in a reduction in demand for fixed charging infrastructure as well as fleet sizes.

Network optimisation, combined with reduced battery size, can also reduce bus procurement and battery renewal costs through increased utilisation and other cost-savings. To date, the studies carried out to estimate the infrastructure requirements to implement WCL have severe limitations that preclude their realistic application. As an example, energy consumption is generally assumed constant and independent of traffic congestion, which simplifies the relationships between velocity, emissions, and start-and-go traffic. Several studies do consider some of these aspects, but seldom incorporate them simultaneously.

Neglecting these relationships may lead to serious operational consequences, such as buses running out of electricity, or requiring shutting down on-board services such as heating and air conditioning.

The aim of this study is to optimize the deployment of wireless charging infrastructure for the electric bus system. The main contribution of this study is the formulation of a stochastic model where variations in traffic, temperature, and passenger loading are considered. A two-stage stochastic programming model has been established to identify the best location of the WCL along with the optimal on-board battery size for every bus route while also considering all the possible energy consumption scenarios. The objective of the model is to minimize the total cost requirements of the WCL set up.

The total cost is the summation of the following three major components:

- The cost of building the WCL,
- The cost of on-board battery for the entire bus fleet
- A penalty attributed when the battery level falls below the designated threshold.

Associated with the said objective function, there are three main constraints:

- The buses are assumed to be fully charged at the beginning of the route,
- The buses will never run out of power while in operation,
- The battery is only charged when the bus is using a WCL lane,
- Energy consumption continuity is maintained throughout the bus route.

The battery discharge rate is calculated considering five sources of energy loss, namely: energy loss due to friction or rolling resistance, aerodynamic resistance, road gradient, vehicle acceleration, and energy loss due to auxiliary systems usage. The developed two stage-stochastic programming model was used to carry out an analysis using public domain data for the area of London. At an initial stage, 22 London central bus routes have been considered. To determine the benefits of WCL, two different scenarios have been studied: one with WCL-base recharge and another with only stationary charging facilities installed at the two ends of each bus route. The scenario where WCL has been used resulted on average in 36% reduction of battery size requirements, and over £300,000 savings in procurement costs in comparison to the scenario where WCL have been neglected.

A more extensive sensitivity analysis is carried out with additional considerations to the model. This instance incorporates the bus fleet size as a decision variable and can be used to jointly determine the optimal operational requirements in terms of battery size, WCL infrastructure, and bus fleet size. Due to the larger size of the problem caused by the greater number of decision variables, the analysis is carried out to optimize a single route in central London (line 43). An optimal battery capacity of 348.8 kWh is required, reducing annual costs for the operation of this route by 24% during the 10-year period considered.

Further modifications to the model have taken place to improve speed prediction of the bus, as speed is one of the main sources of uncertainty in our model. Machine learning framework has been used for the development of vehicular speed prediction in an urban context with heterogeneous traffic states. For this study, London bus route 9 has been used as a case study. From the studied models, the best accuracy was obtained by the random forest classifier, correctly predicting the speed class in 53.3% of occasions, while in 86.6% of the occasions the model predicts the correct speed class or only misses it by one class (either the immediately faster or slower class). The random forest classifier resulted in the lowest mean average error (MAE) of 1.94 mph.

Future work will focus in applying the improved model to the full London bus network. Such an endeavour will require the development of bespoke heuristic algorithms to overcome the dimensionality problem caused by several non-linearities, stochastic components, and large number of decision variables that describe the system.

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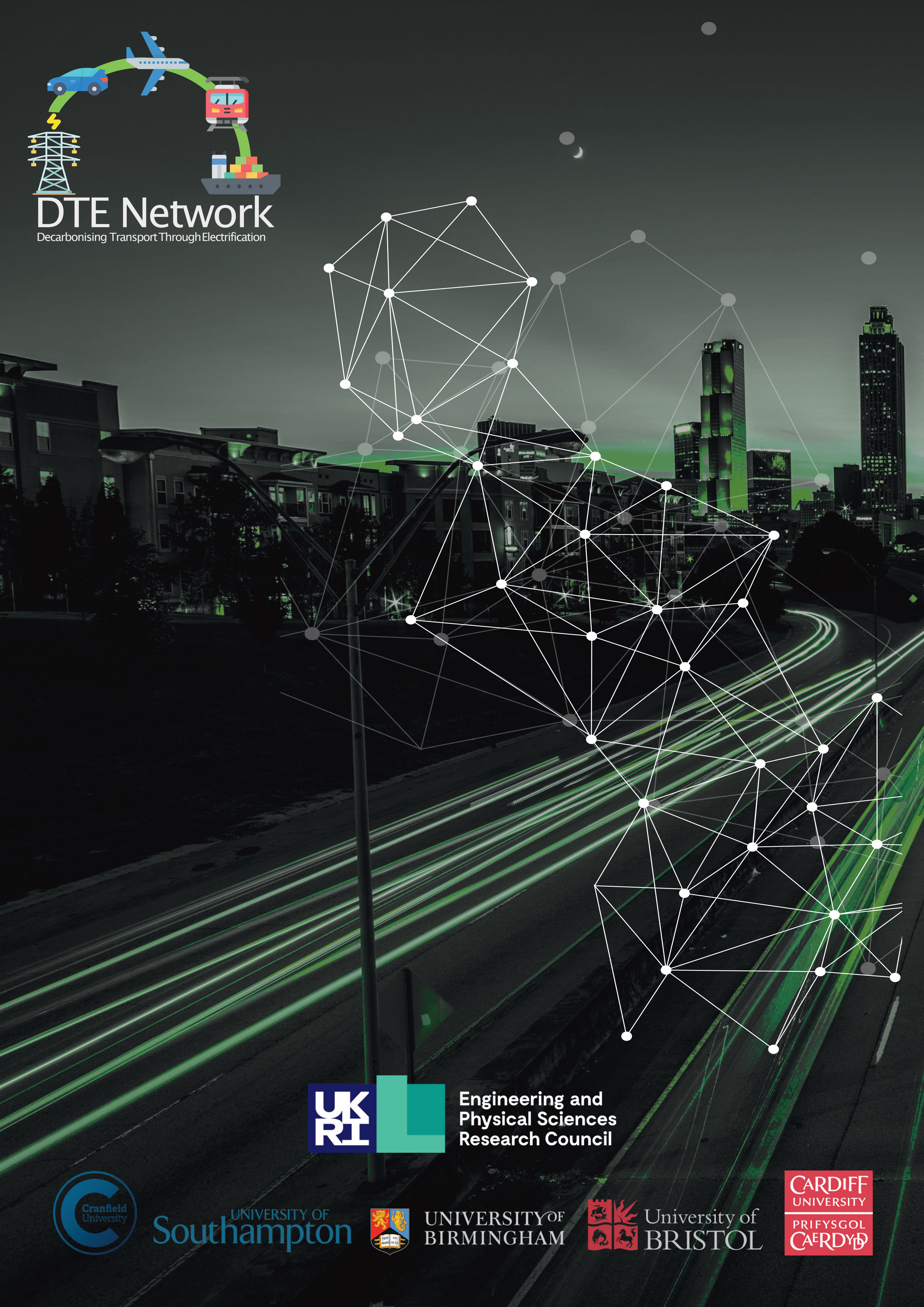
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