Decarbonising the UK's heavy goods vehicles: Lessons from the UK for Australia

D. AINALIS

Senior Technology Leader at the National Transport Research Organisation, Australia, and former Research Manager and Senior Research Associate at the Centre for Sustainable Road Freight, University of Cambridge.

C. DE SAXE

Head of Sustainability at Zeus Labs, London, UK, and former Senior Research Associate at the Centre for Sustainable Road Freight, University of Cambridge.

J. MILES

Professor and Director of Research in Transitional Energy Strategies, University of Cambridge.

D. CEBON

Professor of Mechanical Engineering at the University of Cambridge and Director of the Centre for Sustainable Road Freight.

Abstract

Heavy goods vehicles generate an outsized contribution to national greenhouse gas emissions. They are difficult to decarbonise due to their significant power and range requirements. This paper presents an overview of recent research and developments made in the UK to decarbonise road freight and heavy goods vehicles and the lessons that can be taken and applied to Australia. It focusses on the work undertaken as part of a national feasibility study evaluating the economic and environmental performance of an electric road system for heavy vehicles, specifically the Siemens 'eHighway' overhead catenary solution. The results of the feasibility study show that an electric road system can provide an effective and robust pathway to decarbonise heavy goods vehicles in the UK and Europe. Finally, a discussion is presented on the lessons that can be learned from the UK and how Australia can decarbonise the road freight sector using the UK's approach of 'study, demonstrate, and deploy'.

Keywords: Heavy goods vehicles, Road freight, Decarbonisation, Electric road system.

1. Introduction

Governments around the world have mandated for interim and long-term targets to decarbonise. The UK introduced pioneering legislation under the Climate Change Act 2008 to reduce greenhouse gas (GHG) emissions by 80% from 1990 levels by 2050. This was later amended to deliver net-zero emissions by 2050 (UK Government 2008). One sector requiring comprehensive changes to decarbonise is surface transport. In the UK, surface transport is currently the largest GHG-emitting sector (at around 25%). Emissions from freight vehicles are rising due to demand increases offsetting any system efficiency gains made in recent years.

Recent efforts to decarbonise road freight transport have largely focussed on the electrification of urban logistics. Initial product offerings from vehicle manufacturers were limited to light duty vehicles such as vans and home delivery vehicles, but there is an increasing number of new and larger battery electric vehicles (BEVs) on the market, including rigid delivery vehicles up to 26 t, refuse collection vehicles, and buses. BEVs are ideal for urban logistics for several reasons: (i) the daily mileages of these vehicles are relatively low (typically < 100 km), (ii) they emit no gaseous tailpipe emissions making them attractive for cities, and (iii) the stop-start journey characteristics of urban environments are ideally suited to regenerative braking, which an electric drivetrain typically provides. These factors reduce the battery size, mass, and cost of the vehicles without disrupting operations (Nicolaides, Cebon & Miles 2018). Conversely, long-haul heavy goods vehicles (HGVs) are a far more difficult-to-decarbonise sector due to their high power and range requirements. Despite the relatively small number of HGVs compared to other vehicle types, they carry 90% of the UK's goods lifted (in tonne-km) and are responsible for around 5% of the UK's total GHG emissions (DBEIS 2021). So finding a suitable solution to their decarbonisation is imperative to achieve net zero.

1.1. Net Zero Heavy Goods Vehicle Technologies

Three main zero tailpipe emission powertrain technologies have been proposed to achieve net zero in the long-haul road freight sector in the UK: (i) battery electric vehicles, (ii) battery electric vehicles supported by an electric road system (ERS), and (iii) hydrogen fuel cell electric vehicles. It should be noted that while renewable fuels such as hydrotreated vegetable oil and biomethane offer significant emission reduction potential, they are generally considered to be interim solutions in the UK/Europe due to the production of tailpipe emissions and the challenges associated with supply at national scale (CCC 2019).

All of these three solutions are built on an electric powertrain, differing in battery size, the existence of a pantograph and/or a fuel cell and hydrogen storage tanks, and the required supporting charging/refuelling infrastructure. Battery electric and hydrogen fuel cell HGVs can be more easily deployed at a small-scale, minimising the initial infrastructure investment and can be progressively scaled up over time as demand increases. ERS-based solutions are the most energy efficient and can be the most cost-effective, but require considerable upfront planning and investment to deploy a minimum amount of ERS network before operators will purchase suitable vehicles and utilise the system. Several studies have demonstrated the feasibility and benefits of ERS in countries including Belgium, France, Germany, and Sweden, e.g. (Singh 2016, Jacob 2022, Aronietis & Vanelslander 2021, Boltze 2020).

This paper presents an overview of progress in decarbonising HGVs in the UK, highlighting recent research and development undertaken by the Centre for Sustainable Road Freight (SRF[1]), and supporting initiatives by the UK Government. These learnings are then discussed in the context of Australia and the opportunities for decarbonising heavy vehicles.

2. Development and Progress of Decarbonising Heavy Vehicles in the UK

Since its inception in 2010, the SRF has brought together three leading academic groups specialising in vehicle technology, logistics, and policy, and industry and government partners

[1] www.csrf.ac.uk

to work on fundamental and applied research projects to make road freight environmentally, economically, and socially sustainable. The SRF has played a leading role in identifying decarbonisation pathways for road freight transport and has specifically focussed on HGVs due to their outsized emissions contribution and the scale of the decarbonisation challenge.

Roadmapping research to identify decarbonisation pathways undertaken by the SRF has shown that it is not possible to reduce carbon emissions from the road freight sector by more than 60% without the electrification of long-haul vehicles (Keyes et al. 2016). However, is possible to obtain deep emissions reduction (80-90%) by 2050 if all long-haul vehicles are electrified (Keyes et al. 2016). This conclusion was further supported by a series of early studies investigating road freight electrification pathways for the UK (Nicolaides, Cebon & Miles 2018). In 2020, the SRF published a white paper outlining how the UK could decarbonise HGVs at minimum cost through a national ERS, including build-out plans and rudimentary business cases for: (i) the fleet operators, (ii) ERS infrastructure provider/operator, and (iii) the government's potential to recoup future lost fuel duty revenue (Ainalis, Thorne & Cebon 2020).

Alongside this, the UK government and the Department for Transport have made several announcements aimed at decarbonising heavy vehicles and the broader transport sector. In 2021, a call was issued for a £20 million research programme focussing on of feasibility studies across three streams, including electric road systems, hydrogen fuel cell vehicles, and supply chain technology. Alongside this, the government supported an 18-month trial of 20 battery electric rigid trucks (19 t GVW) for public sector operations, with the vehicles completing a total of more than 285,000 km (CENEX 2023). The government also announced phase out dates for the sale of new non-zero emission HGVs by 2035 (up to 26 t GVW), and all HGVs by 2040 (Logistics UK 2021).

Following the feasibility studies, the UK government announced an intention to fund real-world demonstrations of battery electric, hydrogen fuel cell, and ERS HGVs. The aim of the programme was to kick-start the deployment of long haul zero emission HGVs, with a multi-year demonstration of 40-44 t battery electric trucks and/or hydrogen fuel cell trucks, including the development of the required business models for scalable deployment and a network of dedicated infrastructure. The first trials for battery electric and hydrogen fuel cell HGVs have recently been announced and will be used to gather evidence on the future refuelling and recharging infrastructure needed to ensure a smooth transition to a zero emission freight sector by 2050 (UK Government 2023).

2.1. Research Highlights from the UK Electric Road System Feasibility Study

One of the ERS feasibility studies to be funded in 2021 was carried out by a consortium consisting of Costain (project lead), the SRF, Siemens, Scania, Possible, SPL Powerlines, and Arup. The £2 million project (£1.2 million funded) ran over nine months from July 2021 to March 2022. The project delivered an extensive feasibility study of ERS in the UK, including the design of a system demonstrator programme and national considerations for deploying zero emission heavy-duty road freight. The ERS solution identified as the most promising was the Siemens eHighway catenary technology (Grünjes & Birkner 2012).

2.1.1. Demonstrator programme

The site for the proposed ERS demonstrator was located in the north of England along the M180 motorway was initially identified by (Ainalis, Thorne & Cebon 2020) and further refined in the feasibility study, as shown in Figure 1. The M180 was selected due to the high density of HGV traffic using the motorway and its strategic location between the ports of Grimsby and Immingham, several major warehouses around Doncaster and Armthorpe, and further journeys outwards to major cities such as Manchester, Liverpool, and Leeds (de Saxe et al. 2022).

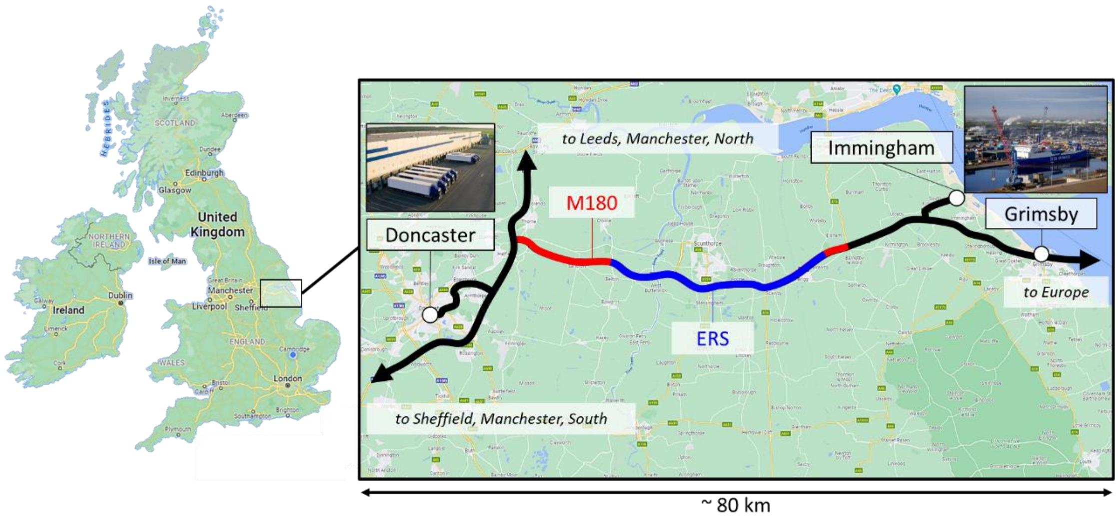

Figure 1 – Overview of the proposed electric road system demonstrator site on the M180 between Doncaster and Immingham

As part of the defining the demonstrator, detailed planning and specification of the ERS infrastructure was undertaken, along with the simulation of vehicle driving cycles to define the vehicle specifications and charging infrastructure requirements (including both ERS and static charging). From the simulation of a range of logistics scenarios, the recommended minimum charging infrastructure and vehicle requirements to meet the research needs of the Electrification demonstrator project were as follows:

- Three pantograph BEV types including: (i) one with a 150 kWh battery, (ii) one with a 500 kWh battery, and (iii) a 300 kWh series hybrid vehicle with a bio-diesel/-gas range extender.
- An ERS length of 50 lane-km (25 km along both directions) with a power supply capacity of at least 300 kW per vehicle.
- Static charging facilities at some warehouses, retailers and rest stops to accommodate vehicle journeys with significant proportions off the 25 km ERS test site. A charging rate of 1.2C would allow for a close to full recharge of the various battery sizes within a 45 minute rest stop, and around a 50% recharge during a 20-minute drop-off stop.

2.1.2. National feasibility study

As part of this work, a framework was developed to assess the feasibility of a national ERS and compare it with alternative solutions (Costain et al. 2022). The framework consists of four steps: (i) evaluation of vehicle technology options, (ii) assessment of operational requirements, particularly difficult edge-cases, (iii) infrastructure system definition (public and private), and

(iv) a triple-bottom-line evaluation of the economic, environmental, and societal benefits. To assess the feasibility of a national ERS, three network topologies of varying sizes were proposed for the UK, as shown in Figure 2.

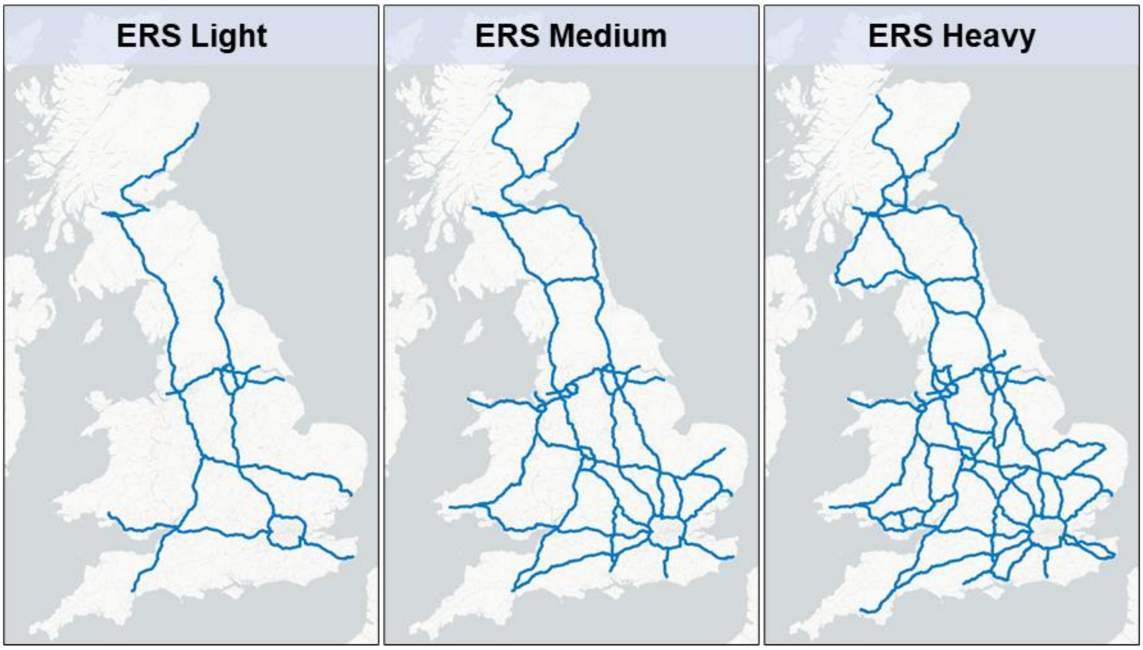

Figure 2 – Proposed ERS topologies for the UK, from left to right: 'Light' (~5,500 lane-km), 'Medium' (~11,000 lane-km), and 'Heavy' (~17,000 lane-km).

Two major research activities were undertaken in this feasibility study. The first focussed on the development of a detailed vehicle-level simulation model to determine the battery capacity requirements across a representative range of real-world UK logistics journeys for different ERS and static charging options. The second focussed on developing an economic and environmental framework to assess the transition to decarbonised HGVs from 2025 to 2050, including perspectives from fleet operators, the ERS infrastructure provider, and the UK Government.

For the battery capacity study, a set of logistics data from UK operators running 44 t HGVs was analysed and it was found that all journeys could be categorised into three distinct groups: (i) warehouse-to-warehouse (i.e., repeatable journeys between two fixed sites), (ii) multi-drop journeys (e.g. deliveries from a distribution centre to various supermarkets), and (iii) tramping journeys (i.e. multiple drop-off journeys over several days). Eight edge-case journeys were selected for simulation, and different ERS networks and static charging opportunities were examined to assess the battery capacities required to complete the journeys. It was assumed that all vehicles would be able to completely charge their batteries overnight, and 'opportunity charge' at high powers during rest stops (45 minutes every 4.5 hours) and drop-off stops (20 minutes) where specified.

The results showed that a BEV with a battery in the region of 600-800 kWh and suitable static charging infrastructure was able to complete all the logistics tasks, without additional stops or time delays. However, this would require expensive supporting static charging infrastructure in private and public locations (with corresponding electricity grid connection upgrades), and also increase the vehicle cost due to the large battery size. The study examined the potential battery capacity reductions through implementation of ERS in addition to static charging and the results are shown in Figure 3. A national ERS could provide significant reductions in the battery size (and mass and cost) required to complete the various journeys, whilst also significantly reducing the high-power charging needs at many fixed logistics locations (de Saxe et al. 2023).

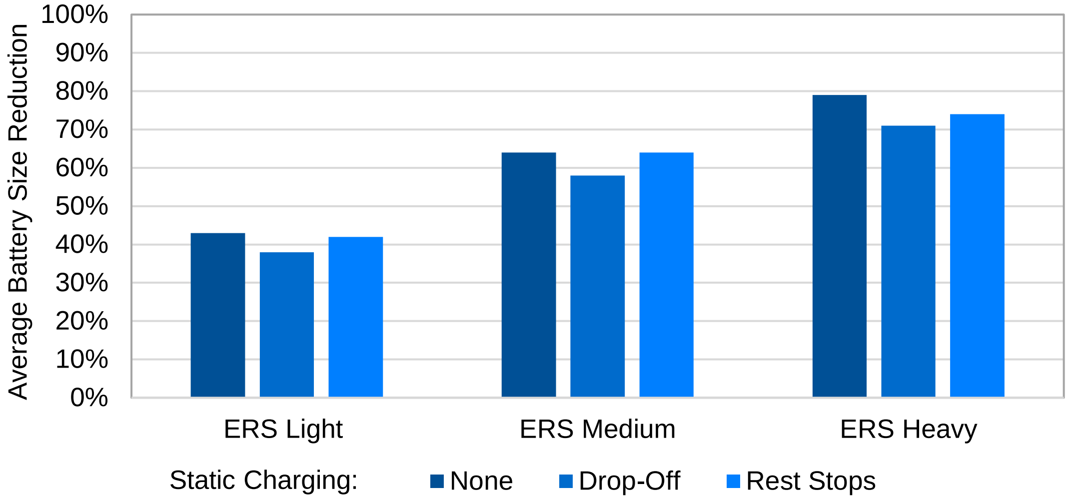

Figure 3 – Average potential battery capacity reductions relative to no electric road system infrastructure for UK heavy vehicles (de Saxe et al. 2023)

The national framework developed in the second part of the study consisted of a technoeconomic model covering the period 2028-2050. The model predicted the uptake rate of zero emission HGVs (> 25 t GVW), and forecasted the vehicle and infrastructure (static and dynamic charging) costs for various powertrains including diesel (baseline), battery electric and green hydrogen fuel cell vehicles. A fleet operator analysis of the Total Cost of Ownership (TCO) investigated the costs of each solution compared to the baseline diesel vehicle and included vehicle purchase and depreciation, depot infrastructure, maintenance, supporting operations, and fuel costs.

The forecasted TCO (for a 6-year 'first life' of the prime mover – i.e., new vehicle to first resale) from 2030 to 2050 is presented in Figure 4 for four different BEVs (150, 300, 500, and 1,200 kWh) and a green hydrogen fuel cell vehicle. From the modelling, it is evident that the fuel cell vehicle is most expensive and will struggle to ever reach parity with existing diesel operations. In addition, the vehicle battery comprises a significant proportion of the vehicle cost, second only to the fuel costs. Consequently, any systematic reductions in the on-board battery capacity and charging infrastructure power will make a substantial difference to overall costs. This demonstrates one advantage of an ERS in that it enables zero emission HGVs to become cost-competitive with current diesel vehicles significantly earlier, by reducing these requirements.

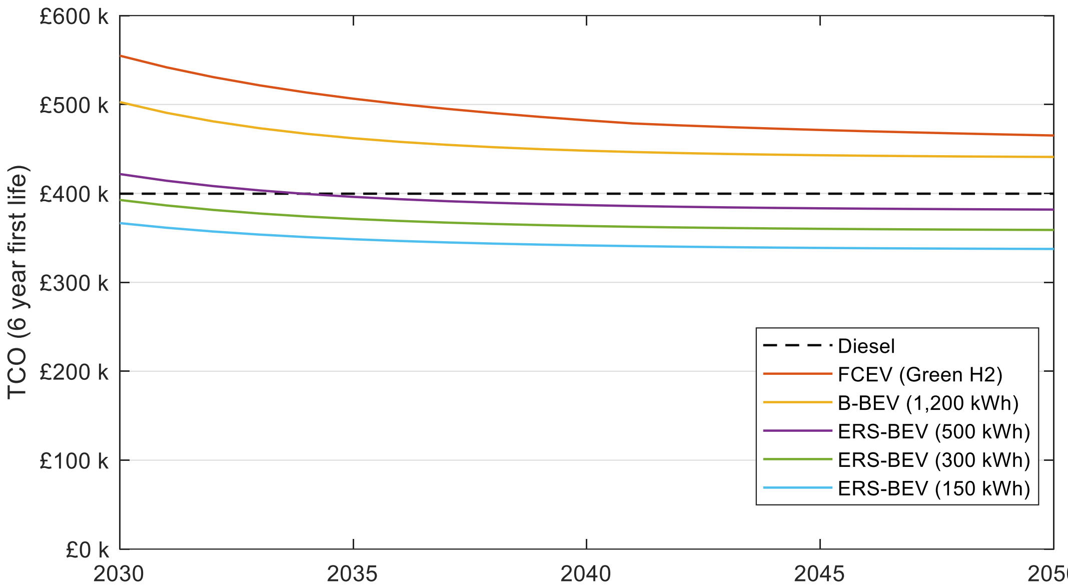

Figure 4 – Comparison of the forecasted total cost of ownership for various future HGVs from 2030 to 2050

The framework was also used to analyse the total national cost to the UK government. This was assessed first by comparing the TCO of each vehicle type to determine the maximum possible fuel levy/subsidy (in p/kWh or p/kg) to achieve parity with the baseline diesel HGV case. It was assumed that if the TCO is more than the diesel TCO, then a subsidy would need to be provided; whereas tax revenue could be collected if the TCO is less than diesel. The national infrastructure costs of an ERS (capital and operating) were also included as part of a coordinated roll-out plan of the infrastructure alongside the uptake of zero emission HGVs, detailed in (Costain et al. 2022).

From the framework, ranges of the total national cost to government were calculated from 2028 to 2050 for green hydrogen HGVs, and an ERS Light network: with BEVs of different average battery capacities, shown in Figure 5. From the results, it is evident that the green hydrogen pathway can be prohibitively expensive unless there is an abundance of cheap renewable electricity available. This would make the cost of fuel cell vehicles to operators (and the government through subsidies to ensure parity with diesel) unfeasible in most scenarios.

The ERS Light pathways examined the total costs including different average fleet battery sizes (150, 300, and 500 kWh), and found that despite the significant initial upfront capital costs, a national ERS can decarbonise HGVs and minimise the total national costs if appropriate battery sizes are selected.

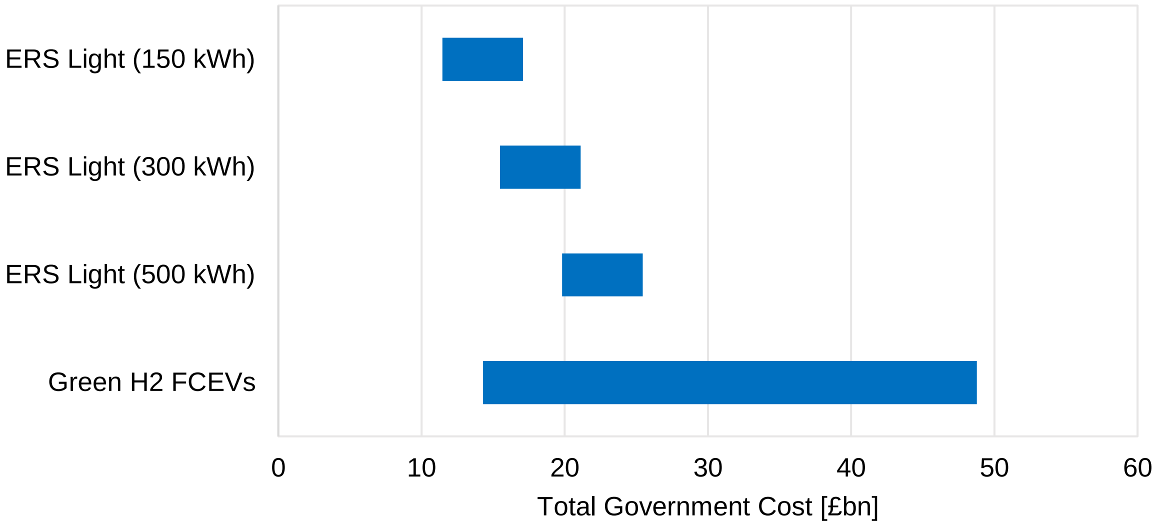

Figure 5 – Comparison of the range of total government discounted costs for decarbonising heavy goods vehicles (2028-2050): battery electric vehicles with an electric road system and fuel cell vehicles using green hydrogen

2.1.3. Next steps

Further research is currently being undertaken to estimate the national infrastructure requirements for static charging infrastructure of battery electric HGVs to provide a comprehensive overview of the economic and environmental feasibility of all three solutions for UK HGVs. With the feasibility studies completed and the results disseminated to the UK Department for Transport, the next steps are focussed on commissioning a series of demonstration programmes to trial and operate zero emission HGVs in the UK to provide insight into real-world operational performance, kick-start the deployment of public recharging/refuelling infrastructure, and assess the actual business case for their operation.

3. What can Australia Learn from the UK?

Considering the developments and progress made thus far in decarbonising HGVs in the UK, it is worthwhile to take stock and assess the difficulties and opportunities facing Australia over the coming years to reach net zero emissions by 2050. Australia has several significant differences to the UK, including different vehicle types and regulations (e.g., longer vehicle combinations, performance-based standards, and the lack of heavy vehicle emissions standards), and vastly different geographies and range requirements. An opportunity exists to take some key learnings from the UK's approach and adapt these to the Australian context. A proposed framework for this based on a (i) study, (ii) demonstrate, and (iii) deploy model.

3.1.1 Study

There is a large and relatively mature body of knowledge that has been produced across the UK (and globally) in assessing the feasibility of alternative fuels and powertrains for HGVs. Many studies have focussed on comparing the economic and environmental aspects of vehicles and infrastructure, and the potential impacts on operations to fleet operators. There is an opportunity to evaluate the data and results from these studies to inform feasible pathways for future solutions. Any new studies in Australia should focus on understanding how to decarbonise current logistics activities the local context, by understanding the similarities and differences to these international studies. They should also assess the potential for alternative opportunities that may provide a feasible route to decarbonisation in Australia (e.g., retrofit, 'pony express', battery swapping, hybrid solutions, etc.). Through engaging with and understanding these studies, a parallel aim should be to develop international collaboration and partnerships to accelerate the transition to a zero emission road freight sector.

3.1.2 Demonstrate

Developing a nationally-coordinated multi-stakeholder demonstrator programme would provide immense value to decarbonising Australian road freight. Such programmes are vital during the early stages of the transition and provide a wealth of benefits. Firstly, they help fleet operators understand the potential changes they will need to make to their operations and develop long-term transition plans. This can reduce many of the barriers to decarbonisation and de-risk the transition. Secondly, they can bring the range of stakeholders on board and engage with them to collaborate and understand the performance and requirements around vehicles and infrastructure in the local and national contexts. Thirdly, they should also bring in new stakeholders that have never previously interacted with the road transport sector (e.g., the energy sector and local governments which have operated separately in the past, but need to be involved extensively in the transition to low emissions heavy road vehicles).

One of the key roles for early-stage demonstrators is to help provide vital early demand signals for vehicle OEMs, refuelling/recharging infrastructure providers, and energy generation, transmission, and storage. They can be used to help kick-start a minimum network of public refuelling/recharging infrastructure, which otherwise may be difficult to set up. Trials also help to build confidence for users of these new technologies as they become commercially available

It is crucial that the demonstration framework and outcomes are clearly defined to ensure consistency, and are independently assessed to establish a robust evidence base. Any Australian demonstrator programme should aim to provide a thorough understanding of:

- The performance of and requirements for low- and zero-emission HGVs and the associated infrastructure and energy – specifically focussed on the Australian context in terms of the vehicle configurations and operational requirements.
- The business case to fleet operators, who will need to make significant capital investments in the coming years to transition.
- The evidence base for necessary policy decisions across all levels of government.
- How interoperability across states and territories will work and the challenges associated with unlocking this. What local lessons can be learnt and adopted from performance-based standards and the national telematics framework?
- New and innovative business models such as freight/vehicles/charging/batteries as a service.
- The impact of automated systems on freight. High levels of automation in vehicles and warehouses may result in continuous operation without rest stops or meaningful loading times during which to charge.
- The environmental case in terms of GHG emissions, and energy and material use.

3.1.3 Deploy

The demonstration programmes will play a crucial role to support the development of a long-term national transition plan to decarbonise the sector. Ensuring the demonstrator results are evaluated by an independent organisation will enable unbiased learnings to be disseminated widely and ensure all stakeholders can make effective transition plans and de-risk the roll-out of zero emission vehicles and infrastructure. Alongside these individual plans, clearly defined emissions standards, targets, and phase-out dates should be defined in consultation with industry to identify local challenges, and potential exemptions for certain applications. This will provide industry with confidence and time to decarbonise their operations.

While the UK can make some decisions about national deployment of solutions, ultimately the choices made by operators and infrastructure providers must be aligned with Europe to ensure interoperability across the continent. Similarly, Australian states and territories cannot go it alone and must work together with international partners to provide operators with the confidence that vehicles are available and can travel around the country, and have access to suitable charging infrastructure. This will be particularly crucial since the increased capital costs associated with producing zero emission HGVs means there will need to be alignment with international markets to enable the widespread deployment of such vehicles.

3.1.4. What will Australia need to do to decarbonise heavy vehicles?

There have been some recent positive announcements in enabling zero emission prime movers to begin operating on Australian roads. The Commonwealth Government has increased the permissible width of new trucks to 2.55 m, ensuring alignment with current offerings available from international OEMs. Several states have also recently announced mass limit exemptions (temporary and permanent) to enable operators to run a variety of low and zero emission trucks. It is vital that, alongside these initiatives, national emissions standards, targets, and phase-out dates are developed and mandated. There is an opportunity to not only deploy the current solutions available internationally, but also for alternatives that may be better suited to the Australian context. For example, considering that the average age of the Australian heavy vehicle fleet is around 15 years (Gjerek, Morgan & Gore-Brown 2021), there may be opportunities around retro-fitting diesel trucks to either fully-electric or hybrid powertrains, using renewable fuels in niche applications outside major urban centres, and battery swapping.

Ultimately, the “deploy” stage towards a decarbonised transport sector requires the participation and buy-in from all stakeholders across industry, academia, the public, and all levels of government: to identify effective policy decisions for viable business cases, operating models, and national infrastructure networks to achieve the necessary environmental outcomes. Significant long-term planning is needed to ensure appropriate access to energy and infrastructure is in place. Consequently, research activities would do well to utilise the model of the UK’s CSRF to establish a baseline to evaluate and trial solutions in Australia.

4. Conclusions and Recommendations

The UK has been playing a leading role in the decarbonisation of HGVs:

- The UK government has made steps towards decarbonisation of HGVs, announcing phase-out dates for the sale of new non-zero tailpipe emission HGVs, and supported national feasibility studies examining the range of decarbonisation solutions from all perspectives (technical, economic, environmental, and operational).
- The SRF was involved in a national feasibility study for a UK ERS and led efforts around modelling the future vehicle and charging requirements (static and dynamic).
- The results of the modelling show that a national ERS has the potential to provide a robust and cost-effective pathway to decarbonise HGVs compared to other solutions.
- The outputs from these feasibility studies have fed into several large-scale demonstrator programmes funded by the government to kick-start and de-risk the transition.

There is a valuable opportunity to learn from the UK to decarbonise the Australian road freight sector. Some of the lessons that Australia can take from the UK include:

- Emissions standards and planned phase-out dates should be implemented to provide interim reductions and allow the industry enough time to plan for the transition.
- Build on the wealth of information from international feasibility studies and demonstrator programmes and identify any differences/gaps to the Australian context.
- Undertake nationally-coordinated demonstrator programmes to provide a robust evidence base and kick-start demand signals to OEMs and infrastructure providers.
- Utilise the results of these demonstrators to develop long-term deployment plans to provide clarity on the transition to a decarbonised road freight sector. It is important that any such plans ensure interoperability across states and territories.

What Australia should do next:

- Australia should aim to develop a nationally-consistent approach based on the study, demonstrate, and deploy model.
- Ensure there is regulatory alignment with Europe for vehicle (and potentially charging) standards to enable these solutions to be made available in Australia.
- Examine the potential to learn from previous successful Australian frameworks (performance-based standards, national telematics framework), and apply it to decarbonising road freight.

5. Acknowledgments

This work was supported by the UK Department for Transport and Innovate UK via the ‘Zero emission road freight strand one: electric road systems’ project and the Engineering and Physical Sciences Research Council grant EP/R035199/1: ‘Centre for Sustainable Road Freight 2018-2023’. Thanks are also extended to the ERS project consortium including Costain, Scania, Siemens Mobility, the Centre for Sustainable Road Freight, Arup, SPL Powerlines, CI Planning, Box Energi, and Possible.

6. References

- Ainalis, DT, Thorne, C & Cebon, D 2020, 'Decarbonising the UK's Long-Haul Road Freight at Minimum Economic Cost', *http://www.csrf.ac.uk/wp-content/uploads/2020/07/SRF-WP-UKEMS-v2.pdf*, , no. CUED/C-SRF/TR17.
- Aronietis, R & Vanelslander, T 2021, *Logibat project: Economic Impacts of the Catenary Electric Road System Implementation in Flanders*, University of Antwerp, Antwerp, Belgium.
- Boltze, M 2020, 'eHighway–An Infrastructure for Sustainable Road Freight Transport', *CIGOS 2019, Innovation for Sustainable Infrastructure: Proceedings of the 5th International Conference on Geotechnics, Civil Engineering Works and Structures*, Springer, pp. 35–44.
- CCC 2019, *Net Zero - Technical Report*, Committee on Climate Change, London, UK.
- CENEX 2023, *BETT Logged Data*, *BETT - Battery Electric Truck Trial*, viewed 1 October 2023, <https://bett.cenex.co.uk/live-data>.
- Costain, Siemens Mobility, Scania, University of Cambridge, Heriot Watt University, SPL-Powerlines, Arup, Centre for Sustainable Road Freight, Box Energi, Possible & CI Planning 2022, *UK Electric Road System: National System Definition and Roll-Out*, DfT, UK.
- DBEIS 2021, *Final UK greenhouse gas emissions national statistics 1990-2019*, London: Department for Business, Energy & Industrial Strategy.
- Gjerek, M, Morgan, A & Gore-Brown, N 2021, *Options for managing the impacts of aged heavy vehicles*.
- Grünjes, H & Birkner, M 2012, 'Electro mobility for heavy duty vehicles (HDV): The Siemens eHighway System', *HVTT12: 12th International Symposium on Heavy Vehicle Transport Technology*.
- Jacob, B 2022, *The electric road: Technical, economic, and environmental study carried out in France, part : Technical aspects*.
- Keyes, A, Greening, P, Palmer, A & Piecyk, M 2016, *Roadmapping Project Report*, CUED/C-SRF/TR10, Centre for Sustainable Road Freight, Edinburgh, Scotland.
- Logistics UK 2021, *COP26: government confirms phase out dates for new diesel HGVs*, viewed 2 October 2023, <https://logistics.org.uk/logistics-magazine-portal/logistics-magazine-features-listing/auto-restrict-folder/18-11-21/cop26-has-government-sounded-the-death-knell-on-ne>.
- Nicolaides, D, Cebon, D & Miles, J 2018, 'Prospects for Electrification of Road Freight', *IEEE Systems Journal*, vol. 12, no. 2, pp. 1838–49, doi: 10.1109/JSYST.2017.2691408.
- de Saxe, C, Ainalis, D, Miles, J, Greening, P, Gripton, A, Thorne, C & Cebon, D 2022, 'Vehicle and charging requirements for an electrified road freight system demonstrator in the UK', *Proceedings of the Transport Research Arena*, pp. 1–8.
- de Saxe, C, Ainalis, D, Miles, J, Greening, P, Gripton, A, Thorne, C & Cebon, D 2023, 'An electric road system or big batteries: Implications for UK road freight', *Transportation Engineering*, p. 100210, doi: 10.1016/j.treng.2023.100210.
- Singh, A 2016, 'Electric road systems: A feasibility study investigating a possible future of road transportation'.
- UK Government 2008, *Climate Change Act 2008*, Statute Law Database, London: The Stationery Office Ltd, viewed 27 October 2023, <https://www.legislation.gov.uk/ukpga/2008/27/contents>.
- UK Government 2023, *£200 million boost to rollout of hundreds more zero-emission HGVs*, *GOV.UK*, viewed 27 October 2023, <https://www.gov.uk/government/news/200-million-boost-to-rollout-of-hundreds-more-zero-emission-hgvs>.