Scotland Zero Emission Bus (ScotZEB) Market Transition Scheme 2022/23

Stream 3

Final Report by Houston's Coaches

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with contributions from Houston's Coaches and Kleanbus

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Contents

1 Introduction

1.1 Scope

This report explores the potential role of repowering existing diesel buses with an electric powertrain to support the transition to a zero-emission bus fleet. This report is based on the experience of Houston's Coaches with electric buses and the repowering solution from Kleanbus as applied to an Optare Solo bus. Because this is the only funded project in Phase 1 Stream 3 of the Scottish Zero Emission Bus Challenge Fund (ScotZEB)[1], the report also tries to capture the general feasibility of repowering used buses for small to medium-sized (SME) bus operators. Further detail on the scope can be found in Section 7: Appendix B: Project Context.

The report focuses on three key topics.

- The first is an analysis of the repowering process, both from the perspective of the operator and from a technical point of view.
- The second topic is a model of the impact of repowering when compared to alternative solutions. This includes a model for vehicle economy, environmental impact, and the business case of repowering.
- The last topic covers the challenges and opportunities for the industry and the social impact. A rapid change in skills and infrastructure will be required, but there is also a window of opportunity to build up a UK-based or Scottish supply chain.

All three topics feed into the conclusions.

1.2 Summary for Bus Operators

Repowering means the diesel engine is removed from an existing bus, and an electric powertrain is installed. This converts a bus from running on diesel to a zero-emission bus (ZEB) running on electric energy, with most of the advantages of a new ZEB. It is similar to an engine swap but slightly more involved due to updates in the vehicle software, air conditioning and driver displays.

The main advantage of repowering is that it is considerably cheaper than purchasing a new bus, at about half or a third of the cost. It may also extend the lifetime of existing buses.

However, many factors need to come together to make repowering worthwhile. Like a ZEB, it will require charging infrastructure at the depot at night and charging time and infrastructure for a top-up (opportunity charging) during breaks in the day. If the electricity supply needs to be strengthened, this is a job for the Distribution System Operator (DSO), previously the Distribution Network Operator (DNO), not the electricity company. The work still must be paid for by the operator. Training for bus drivers and technicians is necessary.

Repowering adds a few further requirements for the operation of a new ZEB. It needs a suitable donor vehicle that is not too old and for which a repowering solution has been developed. The solution is specific to the exact model and model year, so it is typically only commercially viable if tens of buses of an identical model are being repowered. The bus needs to accommodate the additional space and weight of the powertrain. For most models, these

[1] Energy Saving Trust: Zero Emission Bus Market Transition Scheme, accessed 2023-08-21.

constraints will lead to a shorter range after repowering than a new ZEB could achieve. So, a repowered bus is most suitable for low energy duties (such as low-speed stop-and-go traffic in town) or if opportunity charging is available during the day. Finally, depending on the available capital, a suitable finance model has to be selected, and the contractual relationship with a repower partner needs to be specified.

For bus operators, Section 2: Process and Section 3: Impact further down in this report are relevant. Particular attention should be paid to the process in Figure 1, the indications for and against repowering in Figure 5, and the business case in Figure 12. Section 4.1: Managing Change and Section 4.8: Up-Skilling may also be of interest.

1.3 Summary of Public Policy Implications

Transport emissions significantly affect health and climate, and public policy aims to reduce these adverse effects while providing inclusive and accessible transport for everybody. Electrifying buses is an obvious way to reduce emissions, but finding the most suitable electrification model is a difficult choice with many factors to consider.

Repowering offers an exciting opportunity to achieve rapid and affordable impact. This is because conventional buses already exist, and repowering comes a third to half the capital investment of a new zero-emission bus (ZEB). At the same time, repowering is only worthwhile under specific circumstances, mainly because a repowered bus will have a smaller battery capacity than a new ZEB. Repowering offers the opportunity to build up an industry in Scotland because the logistics make it preferable to install the powertrain close to the location of the operator.

The repowering process from Kleanbus is based on pre-assembling an electric powertrain, which means the bus only has to be taken out of service for a few days for the installation of the pre-assembled powertrain. This is an advantage over conventional approaches, where the assembly happens in situ. However, the up-front engineering effort means that Kleanbus needs economies of scale: the process needs at least tens, and ideally, a hundred identical buses to repower to reach commercial viability. Public policy could help to find these identical models, and public funding could support the upfront engineering cost.

Repowering is also an opportunity to improve equality. Cities benefit from great public transport and rapid electrification of buses, but rural areas often rely on fleets of older used buses. It could take a decade until the ZEBs from the cities filter through to rural areas while repowering is viable now. It is worth noting that the time window of opportunity for repowering is limited by the availability of suitable donor vehicles. This industry will naturally end ten years after the last diesel bus has been put into service, so for the UK, this will be in the late 2030s.

Overall, repowering will only be feasible in a minority of cases. But where possible, it should be given priority over alternative routes to net zero because it offers significant benefits in terms of capital demand, carbon footprint, and industry impact.

From a policy perspective, the model in Section 3: Impact and the discussion in Section 4: Industry are most relevant. The appendix goes into further detail. Section 6 – Appendix A: Background covers the situation in the UK and Scotland, and Section 9 – Appendix D: Feasibility

Analysis provides more evidence on Environmental, Social, and Governance (ESG) considerations.

1.4 Acknowledgements

We thank the Energy Savings Trust Scotland for part-funding the repowering of a bus via the Stream 3 activity and providing guidance and feedback on the report.

The report is a collaborative exercise written by Dr Thomas Steffen, Loughborough University, Dr Yiji Lu, and Nan Zang, both at the University of Glasgow. Technical contributions from Kleanbus and Houston's are included as appropriate.

The partners in this project are:

Houston's Coaches: Houston's Coaches is a family-run business that operates scheduled service, school bus service, and private hire in and around the Lockerbie and Castle Douglas area. Currently, they operate a fleet of diesel vehicles. They received their first two electric buses in February 2023, with more to follow. Houston's is the key contractor of the project grant funding.

Kleanbus: A business seeking to eliminate diesel emissions from our streets rapidly. Diesel bus emissions seriously threaten the health of urban residents, particularly children. Kleanbus provides a fast, innovative, and cost-effective solution to remove diesel engines from our bus transport network by repowering diesel vehicles to electric.

Dr Yiji Lu: Yiji is an Assistant Professor (UK Lecturer) of Energy Conversion and Storage Systems at the James Watt School of Engineering at the University of Glasgow. His research is focused on the technological development of Low-Carbon Technologies, including Renewable and Clean Energy Conversion, Energy Storage, and Cleaner/Alternative Fuels to tackle the Climate Change challenges.

Nan Zang: Nan is a doctoral researcher at the James Watt School of Engineering at the University of Glasgow. This work is focused on energy-efficient heating and cooling systems for electric vehicles.

Dr Thomas Steffen: Thomas is an electrical and control engineer and Reader for the Control of Energy Systems at the Department of Automotive and Aeronautical Engineering of Loughborough University, where he joined 15 years ago. He teaches electrification and electric vehicles, while his research is focused on the control of energy systems, especially in automotive and heavy-duty applications. He chairs the Loughborough University Net Zero (LUNZ) committee for staff transport emissions, and he is a member of the Society of Automotive Engineers (SAE) and the Institute of Electrical and Electronics Engineers (IEEE).

1.5 Structure of the Report

This report is written for specific audiences and according to the report requirements. The report addresses both bus operators who may be looking into a repowering opportunity and the Energy Savings Trust Scotland as the funder of this project.

This report aims to provide the most significant amount of transparency while considering the commercial sensitivities of some of the detail. The underlying models have been published on GitHub[2]. It can be manipulated in Excel online to test different assumptions and scenarios.

The remainder of the document is structured as follows. Section 2 covers the process of repowering and the different factors to consider. It will reference Section 3, which talks about the impact of repowering because a prediction of the impact and the business case presented in Section 3 is essential to make the right decisions. Finally, Section 4 discusses the broad effects on the industry in Scotland and the UK. Section 5 presents a short conclusion. Further details are in the appendix, such as an extended literature review and more background information about the project.

[2] T. Steffen: ScotZEB, tsteffenlboro/scotzeb.

2 Process

2.1 Houston's Case

This section is based on the experience of Houston's in moving towards electric buses, and it is focused on the scheduled routes that Houston's is running for the local authorities. Houston's has ca 30 buses, 4 of which are electric. It operates 19 routes, usually using 26 buses with 26 drivers on any day to cover them. Houston's is a typical small bus operating company in many ways, running both local routes in and between small towns and overland connections to a tier 1 centre.

A list of duties and routes is shown in Table 1. The table notes how many times each duty includes a certain route – so, for example, Duty 1 consists of 11 cycles on Route 111 plus one cycle on Route 381.

Table 1: Route Cycles by Duty

Duty	School	6	6a	103	104	111	113	115	117	202	236	372	373	379	380	381	382	383	385	825
1						11										1				
2												8				2				
3		2						2			4					2			1	
4	1																			1
5			1			1		4			4			3						
6										7	3									
7																		14		
8					5									2	2		4			
9	4									4						2				
10					1				3											
11			1			1					2	4	4							
12		2	2								4	2	2							
14					1									1	6		2	2		
15				2			2	1	4								1			
16	2																			
17	2																			
18	2																			
20					4										7					
21														3			8			
22					1													2		
23	1																			
24	2																			
25			1			3						4								
26						5										7				
Σ	**14**	**4**	**5**	**2**	**12**	**21**	**2**	**7**	**7**	**11**	**17**	**18**	**6**	**9**	**15**	**14**	**15**	**18**	**1**	**1**

After analysing the available duties, the decision was made to purchase four electric vehicles (based on a Mercedes eSprinter) and repower one existing bus (an Optare Solo from 2013). This is the first repowering of a bus of this specific type, and according to the process shown below, this requires extensive engineering and takes about 12 months to complete. Consequently, no operational experience with a repowered bus can be presented here. Instead, this report draws on the analysis performed in Stream 2 and on the operational experience with the new BEV buses.

2.2 Perspective of the Bus Operator

The process from the perspective of the bus operator is shown in Figure 1.

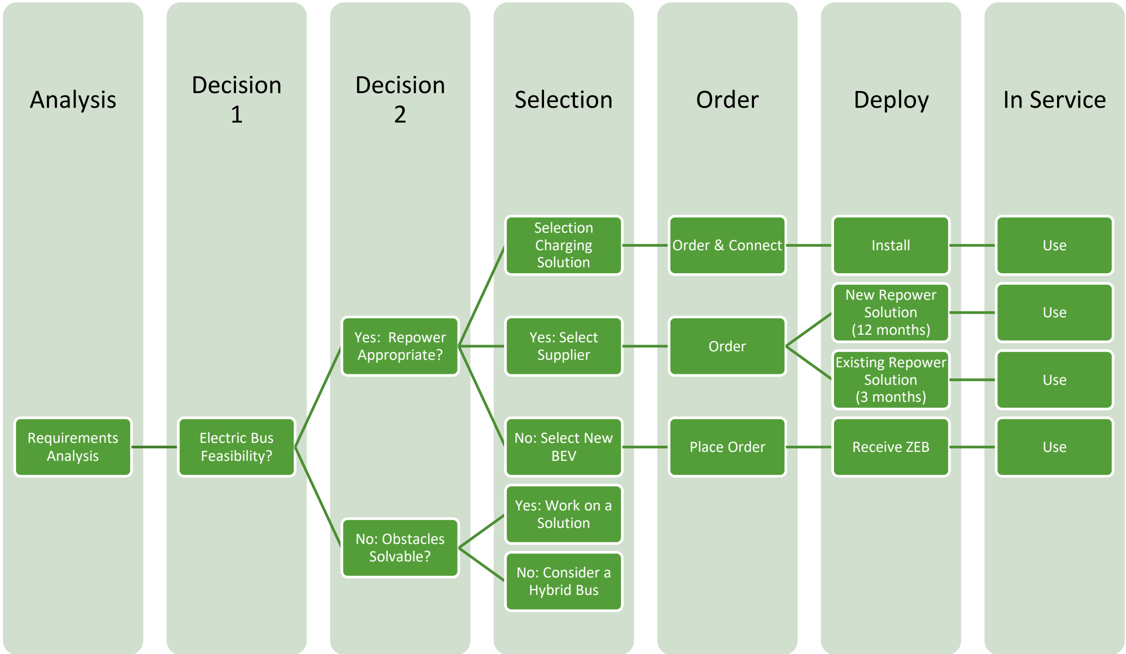

Figure 1: Process for the Bus Operator

It starts with analysing the existing vehicle, the existing route commitments and duty assignments, the availability or suitability of locations for charging, and the availability of public funding to support electrification. Not all routes may be suitable for electric vehicles. There are several ways to analyse the route:

1. Using map data and prediction tools such as ABPR[3]. These tools are designed for light-duty vehicles, so they do not include frequent stopping and air conditioning power, so they are bound to underestimate the energy demand.
2. Kleanbus used a purpose-made tool to analyse the existing duties, which takes representative values of the bus economy based on the available map information.
3. Ideally, live data could be recorded from existing buses using the diagnostic port of the vehicle and/or GPS and IMU data. Using either a model-based or a signal-based analysis, the economy of both conventional and electric buses can be established from the recorded data. This approach is typical for passenger vehicles, but no such solution exists for buses.

[3] ABRP (abetterrouteplanner.com)

4. Finally, the fuel consumption of a Diesel bus can be used to estimate vehicle energy usage and somewhat indicate the required battery size for electrification. More research is needed to confirm this correlation.

A clear set of requirement specifications should emerge based on the duty and operational analysis parameters. The requirements here originate from a Stream 2 project and are replicated in Table 2. These have been developed and reviewed together with Houston's, and they represent their core business interests.

Table 2: Requirements and Priorities

Fleet Operator Requirements	Description	Key Performance Indicator (KPI)
1. Vehicles must be able to deliver the daily duty cycle	*The worst thing for a fleet operator is the need for a "swap out vehicle"; an afternoon bus, deployed to replace a vehicle with insufficient charge to continue.*	# of vehicles per duty cycle Target = 1
2. Lowest cost per mile / km.	*It is typical for a public transport vehicle to drive over 200 miles / 321 km per day. Marginal improvements per mile have significant impact*	Mpg (diesel) or kWh per km (electric) converted to **Cost per km (£ GBP)**
3. Vehicles must be assignable to any duty cycle / route	*Breakdowns, vehicle off road (VOR) etc, create the need for interchangeability between individual vehicles and duty cycles or routes*	"*Route Bound**" city fleet (*meaning vehicle assigned to a single route) or... Interchangeability of vehicle to duty (typically SMEs)
4. Minimise schedule and route disruption	*Buses / coaches are only making money when they are moving people. Time in bus stands / stops and the route taken must be preservce in the shift to electric*	# of changes to stop times # of changes to route schedule
5. Vehicles may be assigned unplanned additional duty	*If unplanned events (e.g. breakdown) create the need for emergency adjustments, other vehicles must be available to respond.* *Diesel vehicles can be filled with fuel in minutes, with electric vehicle it requires a minimum state of charge at any time.*	# of vehicles available for dispatch at any time
6. Lowest overall cost of ownership	*Considerations such as the cost of vehicle checks, maintenance and spare parts etc.*	Cost of operations

These requirements feed into the first decision: whether an electric bus is feasible for the different duties. This decision may rest on operational constraints, such as the availability of chargers or suitable locations to install them and a way of providing additional top-up charging if necessary.

The second decision is whether to purchase a new electric bus or retrofit an existing one. New buses can have large batteries that allow a range compatible with most typical uses, but they come at a significantly higher cost than conventional buses. A retrofit usually means a smaller battery capacity at a much-reduced cost. Technical, operational, and commercial viability must be tested at this point. The financial model presented in Impact Section can be used to build a business case.

Finally, a provider and a financing option must be selected for the retrofit operation. This is much easier if a retrofit solution exists for the specific bus model. If a new solution has to be engineered, this adds additional cost and time to the project. For a small operator alone, this may not be commercially viable. It can be made viable either by public funding, by bringing several operators together to reach critical mass or by the repowering partner making an investment that will pay back in future sales.

Once a decision to retrofit has been made, a repowering partner must be chosen. Several repowering companies exist[4], indicating a healthy industry, including Equipmake[5] in Norfolk, Kleanbus[6] in Essex, and Lunaz[7] in Northampton. There are also international partners, such as Pepper Motion[8] in Germany, but the logistics would be more complicated. Then, the project must be contractually arranged and technically prepared (design and preassembly).

The duration of the actual retrofit depends on the provider chosen and whether parts are available or custom-made. An approach like Kleanbus relies on a preassembled module powertrain installed like an engine swap, which means the actual repowering takes very little time. The industry standard is still to assemble the powertrain in situ, which takes several weeks.

Parallel with the preparations for the retrofit, the business can also perform required training for key staff and install a charger if necessary. The charger needs ordering and may require coordination with the Distribution Systems Operator (DSO) to reinforce the electricity connection.

2.3 Technical Process of Repowering

The technical process happens at the repowering partner and works in parallel with the process at the bus operator. It depends significantly on whether this is the first model for which a repowering solution is being developed because that adds significant engineering time to the process.

The process for developing a new repowering solution is shown in Figure 2. The steps unique to the first repowering of a new model are highlighted in bold. Overall, this process takes about 12 months to complete, and any engineering setback (such as incorrect components or difficulties with system integration) could set it back by another 3 to 6 months.

Critically, this engineering can only fully start once the bus has been received and tested, and the conventional powertrain must be stripped to find the geometry of the engine bay. The bus must be out of service for 6 to 9 months to develop a repowering solution. This affects the bus operator and adds additional costs on all sides. Public funding or stipulations that the original manufacturer must provide engineering documentation could help overcome this obstacle.

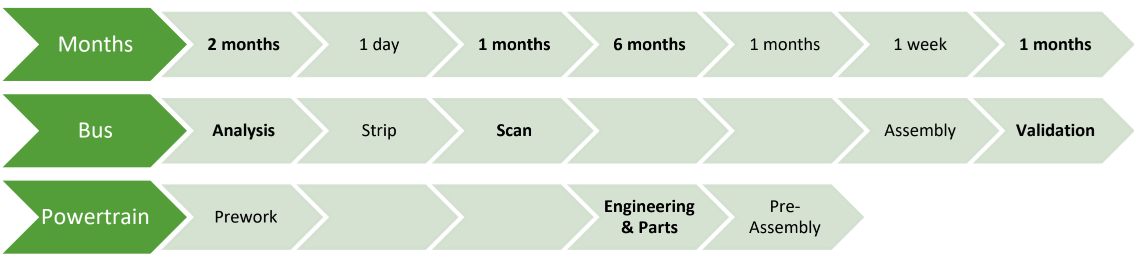

Figure 2: Developing a New Repowering Solution

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[4] SMMT: Repower to the people: Converting vehicles from diesel to electric, 2023-05-11, accessed 2023-08-17.
[5] Equipmake: Home, accessed 2023-08-17.
[6] Kleanbus: Diesel Bus Conversion | Bus Fleet Electrification | Bus Electric Retrofit, accessed 2023-08-17.
[7] Lunaz: Home, accessed 2023-08-17.
[8] Pepper Motion: pepper - electrifying transportation!, accessed 2023-08-17.

Once a repowering solution has been developed, some engineering steps are no longer required. Notably, the order of parts and the preassembly of the electric powertrain can happen while the bus is still in service. This means the time the bus is out of service has been reduced significantly, as shown in the process in Figure 3.

For this project, Kleanbus promises to complete the engine swap for a preassembled battery electric powertrain within one week, a timeframe similar to an engine replacement. This could not be tested on the selected bus because the first model requires a significantly longer time out of service to complete the engineering. The stripping of the conventional diesel powertrain took about two days, which adds credibility to the claim. Assuming the preassembled powertrain fits without issues, there is no reason to question the given timeframe. Preassembly certainly reduces the time that the bus is out of service significantly.

To avoid additional transport delays, the powertrain could eventually be fitted under license by a qualified workshop in Scotland close to the operator.

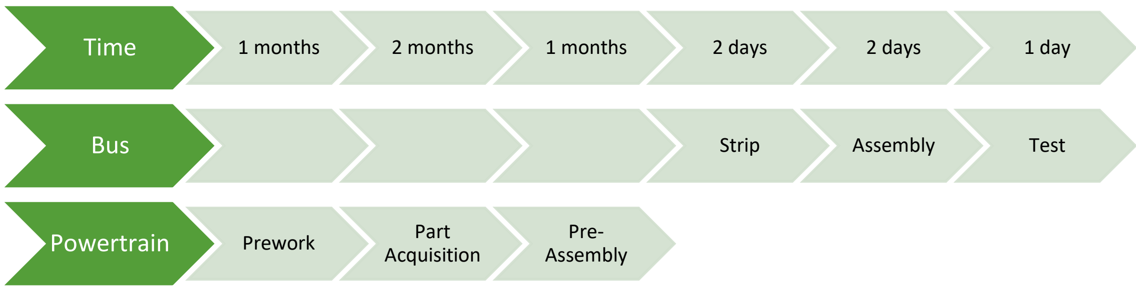

Figure 3: Implementing an Existing Repowering Solution

2.4 Technical Challenges

The technical challenges of repowering are significant. Compared to a new design, a repowering solution is limited by existing design decisions made in a different context. This will always lead to slightly lower performance compared to a bus designed as electric from the start. This is balanced by a significant reduction in cost and embedded carbon emissions.

Three key challenges must be overcome for a successful retrofit, and every single one has the potential to cause a project failure:

1. Vehicle Network integration: Modern buses have several communication networks (typically CAN bus and sometimes other networks based on older standards or on Ethernet) that are essential for bus operation. The engine, and especially the engine control unit (ECU), is an integral part of this network, and removing the engine can render the bus dysfunctional. Since documentation is typically unavailable or incomplete, a dedicated analysis is necessary to understand the communication (the "language" used by the existing ECU) and replicate the essential elements in the repowering solution. It is not clear that this is even possible because there is no limit to the complexity of the communication. Theoretically, the network can also be encrypted, making repowering impossible without knowledge of the correct cryptographic keys.

2. Packaging: The batteries take up a significant amount of space, and the preassembly approach requires that all this space is continuous and available from the back of the bus. This is mitigated because the electric powertrain components can be arranged in a flexible manner because they are only connected by cables.
3. Weight: An electric powertrain is typically significantly heavier than a conventional powertrain. The difference is often similar to the weight of the battery. Assuming a typical energy density of a pack of 120 Wh/kg[9], even a relatively small 180 kWh battery would add 1.5t to the weight of the vehicle. This may require changes to the suspension to restore the original suspension geometry, and it may, in the worst case, lead to a reduction of the available payload.

The Optare Solo from 2013 is being repowered in the Kleanbus workshop. Challenges 1 and 3 have been addressed, which means that the bus is sitting without an engine in the workshop, and the engineering of the electric powertrain is nearly compleed. Challenge 2 remains the only open concern. Other Optare Solo have been retrofitted successfully, but this specific model has a smaller space available for the powertrain, and the intended number of battery packs for a capacity of 180 kWh does not fit the given space. One solution may be to place battery packs in the passenger space under the seats, but this is a last resort that reduces the flexibility of the bus and requires additional measures to ensure the safety of the passengers in case of a battery malfunction. The repowering effort is continuing and will finish early in 2024.

All three challenges will become easier as the technology progresses. Network communication processing is increasingly automated, and with more experience, it can understand the approaches of different original manufacturers. The packaging and the weight penalty will become easier as battery chemistries and packaging technology improve. Solid-state lithium-ion batteries may lead to significant gains in this area and make repowering possible in cases where otherwise not feasible.

The engineering effort to develop a repowering solution is significant, and it is only worthwhile if a good number of identical bus models can be repowered. Ideally, this would be 100 or more, and at the very least, tens of buses. According to the DVLA[10], there are 1569 Optare Solo registered in the UK, with about 10% SORNED. So, an economical solution would require repowering most of the Optare Solo of a specific model year still on the road to reach the necessary economies of scale.

More technical information on the repowering can be found in Section 8: Appendix C: Technical Evaluation.

2.5 Charging Infrastructure

One of the requirements for operating electric buses is access to reliable charging infrastructure.

There are five primary charging connections to consider, as shown in Table 3. The first two standards are finalised, mandated across the EU, and widely available. MCS is still being finalised, to be released in 2024. WPT exists up to 11 kW according to J2954, which is not

[9] Volvo: Why Electric trucks? Check our FAQ, accessed 2023-08-12.
[10] DVLA: Vehicle licensing statistics data tables, accessed 2023-08-18.

enough for a bus, but it is updated for HDVs with powers up to 500 kW in J2945/2. In addition, pantograph solutions are being tested, but so far, no standard is being prepared.

Table 3: Relevant Charging Connectors

Name	Standard	Connection	Power Range	Aimed at
Type 2	IEC 62196	3 phase AC	22 kW untethered (“fast”) 43 kW tethered (“semi-rapid”)	LDV
CCS 2 (FF)	IEC 62196	DC	50 kW – 350 kW (“rapid”)	LDV / HDV
MCS	Chargin BV	DC	up to 3.75 MW (“megawatt”)	Large HDV
WPT	J2954/2	Wireless	11 kW (J2954) up to 500 kW (J2954/2)	Opportunity charging at stops
Pantograph	proprietary, ABB	DC	ca 300 kW	HDV opportunity charging at stops

The second question is whether to charge at the bus depot or on the route. The advantage of charging at the depot is that it is a controlled environment, and the electricity is usually cheaper (around 10p/kWh for Houston’s, based on a legacy tariff). Electricity prices have been highly volatile since 2021, which makes it challenging to present a prediction for the future, and hedging this risk may be appropriate. “Normal” prices are around 15p to 20p/kWh. Charging on the route using publicly available chargers is not under the control of the operator; there may be contention, and the electricity is often more expensive (often around 30p to 50p/kWh). But for some routes, returning to the depot is not feasible, and on-route charging is the only option. The combination of both categories leads to a quadrant model of charging opportunities shown in Figure 4.

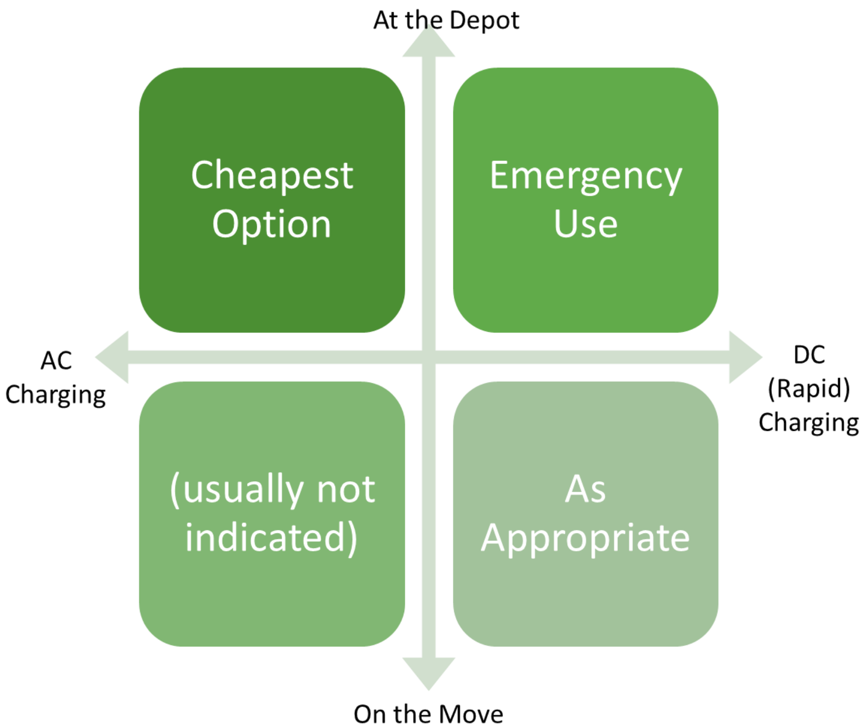

Figure 4: Charging Opportunities

The installation of charge points can be complicated. While the availability of chargers and parts has improved, the existing grid connection (substation) may be a constraint if it does not have enough power capacity. Installing a new substation is in the remit of the Distribution Network Operator (DNO) or Distribution System Operator (DSO). Still, it may need to be paid for by the electricity customer.

There can be a shortage of skills and parts, and there may be a planning process to complete if the supply needs reinforcing, which can delay substation work significantly. The DSO of Houston's is SP Energy Network,[11] a division of Scottish Power. For this project, no reinforcement work was required. Sometimes, smart charging and load management can work within the power provisions available from the existing substation. This depends on enough energy being available at night to recharge all-electric vehicles. One advantage of smart charging is that it increases the utilisation of the existing substation, which means it can operate at higher efficiency with reduced losses.

In the future, high-power chargers may interface directly with the 11kV "medium voltage" distribution layer, eliminating the need for a substation.[12] This has significant impacts on the way that power is provided and how the contracts are structured.

Houston's opted for AC and DC charging (using the Configuration EE), like their existing BEV buses. This allows AC charging at 22 kW overnight and top-ups during breaks over the day using DC charging with 50 to 100 kW. This combination may work for many operators if there

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[11] SP Energy Network: https://www.spenergynetworks.co.uk/, accessed 2023-08-12.
[12] A. Ahmad et al: An Overview on Medium Voltage Grid Integration of Ultra-Fast Charging Stations: Current Status and Future Trends, in IEEE Open Journal of the Industrial Electronics Society, vol. 3, pp. 420-447, 2022, doi:10.1109/OJIES.2022.3179743.

are breaks in the service. The top-up means the bus can have a moderate-size battery, reducing the capital, weight, and space demand.

The availability of on-route chargers also limits the routes that can be electrified. The lack of chargers in and around Edinburgh Bus Station means that electric buses to Edinburgh (Routes 101, 101A, 102)[13] are not feasible. This is an opportunity for councils to provide better charging infrastructure.

2.6 Logistics

There are several logistical challenges when repowering a bus.

This project has uncovered that developing a new repowering solution is a significant challenge. It must happen at the repowering partner, and it takes a lot of time during which the bus is not available for use because the engine has been removed. Reinstalling the engine and putting the bus into service may be possible. At the same time, the repowering solution is engineered and assembled, which may further delay the process and require more bus movements, which tends to be expensive. It is vital that this phase is lined out and agreed upon between the project partners. It may be helpful for the repowering partner to acquire ownership of the first bus to turn it into a prototype vehicle (as the cost of the used bus is small compared to the cost of the repowering solution). This is how Kleanbus is planning to proceed with this project.

Once a repowering solution has been developed, the logistics become much more manageable. The electric powertrain is assembled separately, without any operation impact. Then, the conventional powertrain is switched to the electric powertrain, which only takes a day or a few days. This could happen at the repowering partner, which means transporting the bus there and back, or in a workshop close to the bus operator (or even the workshop of the bus operator), with support from the repowering partner. This way, transport costs can be minimised.

The components of the electric powertrain come from global sources. Many electronics can be sourced within Europe, so they arrive by road transport. However, most batteries are made in China, so they are the most likely supplier for the cells or the complete battery modules. This adds a significant lead time to the project, which must be considered.

Keeping a spare stock of batteries is not usually a viable solution. Safe storage is complicated; the batteries need to be charged every few months, and they will still deteriorate slowly (calendar ageing) while in storage. Together with the high capital investment, this makes storing batteries undesirable from a commercial perspective. A local battery manufacturer in Scotland would help, and this is discussed in more detail in the Industry Section.

2.7 Risk

A live risk register was maintained throughout the project. The final version, sanitised for commercially sensitive information, is shown in Table 4. It turns out that the most significant risks in hindsight were the lack of space for the batteries and the commercial funding for the engineering of the repowering solution, which took slightly longer than planned.

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[13] Houston's Coaches: New Routes - Dumfries to Edinburgh, 2023-04-01, accessed 2023-08-17.

Table 4: Risk Register

Options: 1 - low, 2 - medium, 4 - high, 8 - very high

Type	Name	Owner	Likelihood	Impact	Exposure	Risk	Mitigation	L	I	E	New Risk
Technical Risk											
	Analysing the Vehicle Network	KB	2	8	4	**64**	This is mitigated through experience and planning enough time, but it remains a high-impact risk.	1	8	4	**32**
	Software Errors	KB	2	4	4	**32**	The software is subjected to rigorous testing before and after assembly.	1	4	2	**8**
	Battery Space	KB	4	4	4	**64**	Flexible placement of the batteries reduces the risk of space constraints	1	4	2	
	Donor Vehicle	HC	2	4	4	**32**	A well-known vehicle is used, which reduces the risk of hidden flaws.	1	4	4	**16**
	Lack of range	HC	2	2	4	**16**	Opportunity charging is available, so a range reduction can be managed due to weather.	2	2	1	**4**
Project											
	Poor Communication	All	2	2	2	**8**	Regular meetings are held, both technical and management.	1	2	2	**4**
	Lead Times	KB	2	4	4	**32**	Battery modules have a lead time of up to six months, which will delay the project.	2	4	4	**32**
	Charging Infrastructure	HC	2	2	4	**16**	Charging infrastructure already exists from a previous project.	0	2	4	**0**
	Diverging Interests	KB	2	2	4	**16**	The collaboration contract will spell out rights and responsibilities in line with business interests.	1	2	2	**4**
Health and Safety											
	Malfunction	KB	1	8	4	**32**	ISO 26262 is used to ensure functional safety	1	1	2	**2**
	Maintenance	HC	2	4	4	**32**	Existing technicians must be upskilled to work safely	1	2	2	**4**
Operation											
	Reduction in Flexibility	HC	1	4	4	**16**	This requires more careful scheduling to reduce exposure.	1	4	1	**4**
	Charging Failure	HC	2	4	4	**32**	Maintenance, monitoring, and opportunity charging can mitigate	1	4	1	**4**
Commercial Environment											
	Lack of Funding for Repowering	KB	2	2	4	**16**	This is mitigated through public funding.	2	2	1	**4**
	Electricity Cost Increases	HC	2	4	2	**16**	This can be mitigated via forward trading or energy diversity.	2	4	1	**8**

2.8 Factors to Consider

Based on the experience at Houston's, several factors must be considered to repower an existing bus or buy a new electric bus. The list in Figure 5 includes the lessons learned during this project.

Reasons for an Electric Retrofit

- The bus needs a new engine anyway
- The bus has at least 10 years of lifetime left.
- The range is moderate or opportunity charging is available
- The bus operates a regular schedule
- A retrofit solution exists for the specific model
- Electrification with budget constraints.

Reasons for a New Electric Bus

- A regular route requires more range than a retrofit can provide
- Opportunity charging is not available or too expensive
- A new bus is required anyway
- Clean air zones require electrification.

Reasons Against a ZEB

- The bus is used rarely or irregularly
- The bus is very old or a rare model
- The bus has a new engine used on a long route.
- Lack of charging facilities or capital
- There is not enough space to fit sufficient battery capacity

Figure 5: Factors For and Against Repowering and Electric Buses

Especially consideration should be given to operational constraints and the contractual relationship to the requirement. Developing a repowering solution is not a simple process, and the bus is unavailable for use over a significant period. The opportunity cost and the engineering need to be appropriately funded, and the balance between both partners must be carefully considered.

3 Impact

This section presents an impact model for the electrification of buses at Houston's. It aims to include a wide range of impact, covering operational, financial, environmental, social and governance considerations. A wider review of the available literature can be found in Section 9.1: Economic Analysis.

3.1 Consumption Model

The industry standard for measuring fuel consumption is over distance, but that is not always the most helpful way of looking at it because different routes and drivers will lead to different consumption figures. For research and development purposes, drive cycles such as the Millbrook London Transport Bus (MLTB) cycle[14] or the World Harmonised Transient Cycle (WHTC)[15] are used together with detailed technical models such as QSS[16], Elvio[17], Advisor[18], AVL Cruise[19], MOVES,[20] etc. are used. However, these models are expensive to create and too detailed to provide easy and generalisable results.

Instead, the "Moments of Power" approach[21] is used as a compromise between complexity and accuracy. The consumption can be broken down into four key components:

1. A distance-based component covers tyre friction and some of the aerodynamic drag. This component dominates on longer (overland) routes. Before powertrain efficiency, typical friction and drag forces are around 1 kN for a 10 t bus or 0.3 kWh per km.
2. A time-based component accounts for auxiliary devices, including engine idle consumption, heating, cooling, ventilation, lighting, A/C, etc. This component is significant in a bus and can depend on temperature and occupancy. Typical values are in single-digit kW.
3. A deceleration-based component accounts for the loss of kinetic energy during braking. This component dominates for city and town bus routes. Typical values are around 0.25 kWh per stop, significant deceleration, or steep slope. Recuperation (on the electric powertrain) and fuel shut-off (Diesel) can help to recover some of the

[14] Transport for London: london-exhaust-emissions-study-drive-cycle-development, 2016-01-22, accessed 2023-08-18.
[15] UN ECE: Development of a World-wide Harmonised Heavy-duty Engine Emissions Test Cycle, TRANS-WP29-GRPE-41-inf01, 2001-01-09, accessed 2023-08-18.
[16] G. Rizzoni, L. Guzzella, B. M. Baumann: "Unified modeling of hybrid electric vehicle drivetrains," in IEEE/ASME Transactions on Mechatronics, vol. 4, no. 3, pp. 246-257, Sept. 1999, doi:10.1109/3516.789683.
[17] T. Steffen: ELectrified Vehicle lIbrary for simulation and Optimisation, tsteffenlboro/elvio: Electrified Vehicle Library for Simulation and Optimisation, accessed 2023-08-18.
[18] K.B. Wipke, M.R. Cuddy, S.D. Burch, S.D.: ADVISOR 2.1: A user-friendly advanced powertrain simulation using a combined backward/forward approach, IEEE transactions on vehicular technology, 48(6), pp.1751-1761, 1999, doi:10.1109/25.806767.
[19] AVL: AVL CRUISE™ M, accessed 2023-08-18.
[20] EPA: Overview of EPA's MOtor Vehicle Emission Simulator (MOVES3), 420r21004.pdf (epa.gov), March 2021, accessed 2023-08-18.
[21] T. Steffen, T. Jegede, J. Knowles: Moments of Power: Statistical Analysis of the Primary Energy Consumption of a Vehicle, SAE Technical Paper 2023-01-0541, doi:10.4271/2023-01-0541.

kinetic energy, but this is highly dependent on the regeneration power limit of the bus, the driving style ("lift and coast"[22]), and battery condition.

4. A velocity-based component, which accounts for the increasing aerodynamic drag at higher speed. This component only becomes important at highway speed (above 40mph), so it is not considered here.

All four components must be scaled using the differential powertrain efficiency, which can be assumed to be roughly constant. It tends to be around 40% for ICE powertrains and 80% for electric powertrains. This four-component model is significantly more accurate than the previous module used in the Stream 2 project. The model parameters based on standard industry assumptions are shown in Table 5:

Table 5: Vehicle Model

Vehicle Model								
	Label	Text		ICE	Repower120	Repower180	eSprinter	Enviro200
	Manufacturer	Text	Default	Optare	Optare	Optare	Mercedes	AD
	Model	Text	Default	Solo	Solo	Solo	eSprinter	Enviro200
	Base Mass	t	10	10	10	10	6	10
	Rolling Friction	%	0.75	0.75	0.75	0.75	0.75	0.75
	Drag Force	N	350	350	350	350	350	350
Powertrain Model								
	Name	Text	Default	Default	Small EV	Med EV	Med EV	Big EV
	Efficiency	%	45	45	80	80	80	80
	Idle Power	kW	3	3	3	3	3	3
	Recuperation	%	10	10	60	60	60	60
	Energy Density	kWh/kg	0.12	0.12	0.12	0.12	0.12	0.12
	Battery Size	kWh	0	0	120	180	113	350

3.2 Route Model

Route 111 is chosen for this model because it is short, typical for town routes, and easy to reproduce. The input data has been collected from bustimes.org[23], based on data from the Traveline Scotland repository[24]. A map of the route is shown in Figure 6. With the help of Google Maps[25], the route has been reconstructed, leading to the following statistics for the model as shown in Table 6.

[22] FIA: Energy Management 101: The importance of energy in Formula E, 2020-03-16, accessed 2023-08-17.

[23] Bustimes: 111 - Dumfries - Royal Infirmary – Houston's Minicoaches, accessed 2023-08-05.

[24] Traveline Scotland: Traveline Scotland, accessed 2023-08-05.

[25] Google: Google Maps, accessed 2023-08-05.

Figure 6: Route 111

The model calculates a fuel consumption of 2.35 kW/km, which equates to 0.223 l/km for the Optare Solo. Houston's report a typical fuel consumption of 0.221 l/km, so this model is within the expected accuracy of a few % and more flexible than a constant economy (mpg) assumption.

Table 6: Route Model

Inputs								
	Label	Text		ICE	Repower120	Repower180	eSprinter	Enviro200
	Length	km	9.5	9.5	9.5	9.5	9.5	9.5
	Duration	h	0.5	0.5	0.5	0.5	0.5	0.5
	Stops	1	13	13	13	13	13	13
	Turns	1	18	18	18	18	18	18
	Traffic Lights	1	5	5	5	5	5	5
	Default Speed	mph	25	25	25	25	25	25

A check against the experience with the new ZEB shows that the model calculates a consumption of 0.724 kWh/km, and the experience records 0.736 kWh/km. Again, this shows that the model is within the expected accuracy.

For the repowered bus, the model calculates a demand of 0.991 kWh/km or 113 kWh per day. This is just within the battery capacity, 30 kW of which are expected to be met by opportunity charging to maintain an operating reserve (Repower120).

The distribution across the components for the different vehicles is shown in Figure 7. Note that these values are before the powertrain efficiency is applied, so powertrain losses have to be added to get the full picture.

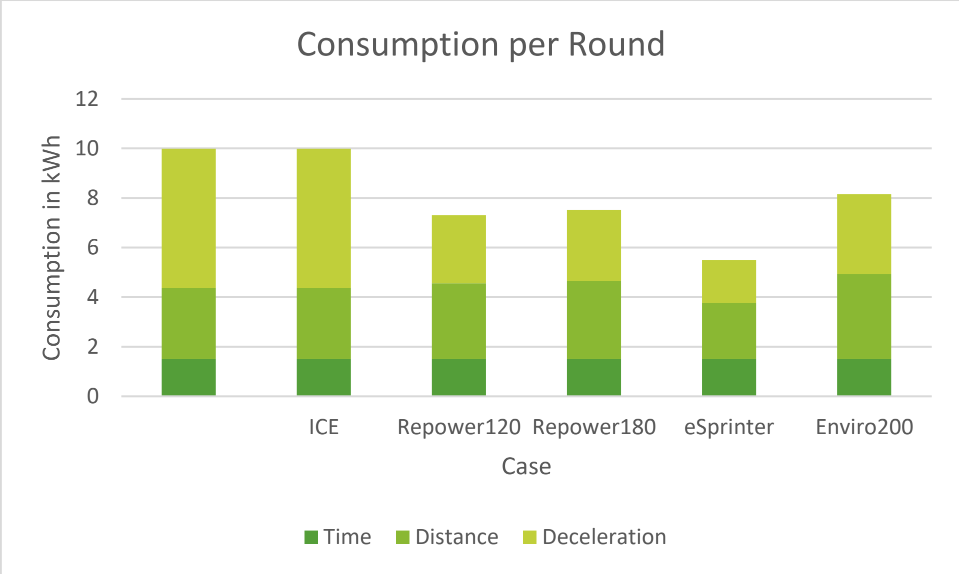

Figure 7: Consumption Components

The resulting SoC prediction at the end of the day is shown in Figure 8. All cases easily satisfy the requirement of 20% operational reserve.

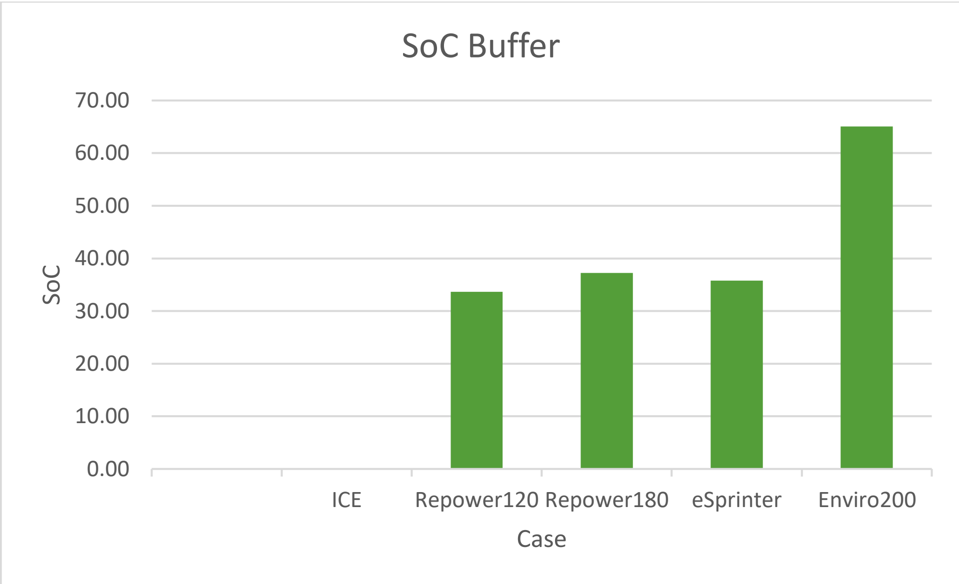

Figure 8: Remaining SoC Buffer

3.3 Subsidies

Public subsidies for bus operators are complex and variable, and operators will have varying opportunities to benefit from them. This is a devolved matter, and Scotland operates its policies as set up by Transport Scotland.

BSOG has been replaced by the Network Support Grant (NSG)[26] since 31 March 2023, and NSG no longer differentiates by emissions for new vehicles. However, subsidies for low-carbon vehicles (LCVs) or low-emission vehicles (LEVs) can be grandfathered from previous schemes.

[26] Transport Scotland: Network Support Grant, accessed 2023-08-18.

This means there is no difference in subsidies between a used bus with an ICE powertrain and a repowered bus with an electric powertrain or a new BEV bus.

The core NSG rate is 14.4 p/km, which Houston's receive for conventional and electric buses. Because there is no difference, including the subsidy element in the cost model is unnecessary, but it is stated for completeness.

Subsidies are subject to subsidy controls, which aim to ensure fair competition within and across markets. The WTO and trade agreements stipulate these controls, codified in UK law[27]. The main consequence of subsidy controls is that while subsidies for bus operators can be limited to provisions in Scotland, they cannot stipulate that the work is performed in Scotland or by Scottish companies. The same applies, to a lesser degree, to the UK and UK companies.

However, there are physical reasons, such as proximity and transport costs, that will give companies in Scotland a natural advantage. These are especially pronounced for repowering because the price is lower than a new bus and must be transported twice. In this sense, repowering is an excellent opportunity to support a Scottish industry for electric powertrain assembly and possibly for its components.

3.4 Operating Cost Model

Once the consumption has been established, the fuel cost of a vehicle is easy to calculate. Most operators will have their fuelling station, paying only wholesale prices. Some small operators may not have this advantage and may pay retail prices at regular filling stations. Houston's has their own fuel distribution at a cost of about £1.40/l.

AdBlue™ is a branded variant of an ammonia-based agent used in the DeNOx system of most modern Diesel engines (Euro 6). The amount is typically around 5% of the fuel consumption, costing around 50p to 60p per litre in large quantities. This means it adds about 3p/l over the fuel cost to the operating cost. For simplicity reasons, it is included in the fuel cost calculation, using a value of £1.43/l.

Servicing cost is more difficult to establish. For a medium-age bus, Houston's estimate service costs of about £22 000/year. This figure should be significantly lower for an electric powertrain because the powertrain requires a lot less service. This meanly leaves work related to the interior and the mechanics of the bus. This is estimated to amount to about £12 000/year. See Section 9.1.3 for a more detailed background on Maintenance.

3.5 Repowering Cost Model

The base vehicle considered is a used Optare Solo with a value of approximately £35k. Houston's has significant experience with this vehicle, and it was chosen as the basis for the repowering exercise.

Based on the cost of the parts presented in the Industry Section, and in line with the Stream 1[28] report for Telford Coaches[29] by Kleanbus and the Stream 2 report for Houston's Coaches

[27] UK Parliament: Subsidy Control Act 2022, 2022, accessed 2023-08-16.
[28] Energy Saving Trust: Zero Emission Bus Market Transition Scheme, accessed 2023-08-14.
[29] Telford's Coaches: Scotland Zero Emission Bus (ScotZEB) Market Transition Scheme 2023/23 – STREAM 1 Report – Telford's Coaches, 2023-03-14, accessed 2023-08-14.

(unpublished), the cost of a repowering solution for the Optare Solo is expected to cost £110k per bus at reasonable numbers, and once the engineering costs are covered. The battery will cost an extra £200/kWh to £250/kWh, and the upper end is used here.

A key competitor is a slightly smaller vehicle with 15 seats based on a bus conversion of a Mercedes eSprinter[30]. According to the Stream 1 report, this vehicle costs £227k. The listed economy is excellent, explained partly by the smaller size of the vehicle and partly by the fact that it is probably based on the WLTP cycle, which does not include frequent stops and air-conditioning, so it will predict a much longer range than is realistic in service.

A second competitor is a full-sized electric bus like the Alexander Dennis Enviro200EV[31] or a Yutong E10[32]. Both offer excellent range due to the large battery, which comes at a higher weight and purchase price, although the exact cost remains a well-guarded trade secret. For this model, a purchase price of £350k is assumed, which aligns with the reports from ScotZEB and the previous Scottish Ultra-Low Emission Bus Scheme[33]. These buses are not expected to be competitive for the use case at Houston's, who have usually operated with smaller and used buses, as it is standard for rural bus operators. New buses always command a premium and are generally only purchased if the tender for the bus route stipulates this or if it is a very busy route that can justify the cost. More detail on the underlying data can be found in Section 9.1.

3.6 Environmental Impact

The environmental impact is calculated for the CO2 emissions of production and operation. The embedded CO2 emissions of a new bus are assumed to be 100t, distributed over the lifetime of the bus.[34] The exact figure is not too important because this is a reasonably small model component. A wide range of values can be found in the literature for the battery,[35] and 50 kgCO2/kWh is used here. This is probably the factor with the highest uncertainty in the model, but it is a small share of overall emissions.

In all cases, the CO2 impact is dominated by operating emissions. These are assumed to be 2.54 kg per litre of Diesel[36]. Note that this source ignores production and distribution losses, but it is the official figure typically used in the UK. A difference must be considered for electricity between night-time charging in the depot and opportunity charging during the day. Data from the National Grid[37] was used and averaged over 2022, resulting in the results shown in Figure 9.

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[30] EVM: EVM e-Cityline Minibus 15 Seater Low Floor, accessed 2023-08-14.
[31] Alexander Dennis: BYD AD Enviro200EV, accessed 2023-08-14.
[32] Yutong: E10_E-vehicles_YUTONG, accessed 2023-08-16.
[33] Transport Scotland: Scottish Ultra-Low Emission Bus Scheme, accessed 2023-08-16.
[34] K.W. Lie et al: The Carbon Footprint of Electrified City Buses: A Case Study in Trondheim, Norway. *Energies* **2021**, *14*, 770. doi:10.3390/en14030770.
[35] X. Lai, et al: Critical review of life cycle assessment of lithium-ion batteries for electric vehicles: A lifespan perspective, eTransportation (12), 2022. doi:10.1016/j.etran.2022.100169.
[36] UK gov: Greenhouse gas reporting: conversion factors, 2023-06-28, accessed 2023-08-14.
[37] National Grid ESO: Carbon Intensity, accessed 2023-08-14.

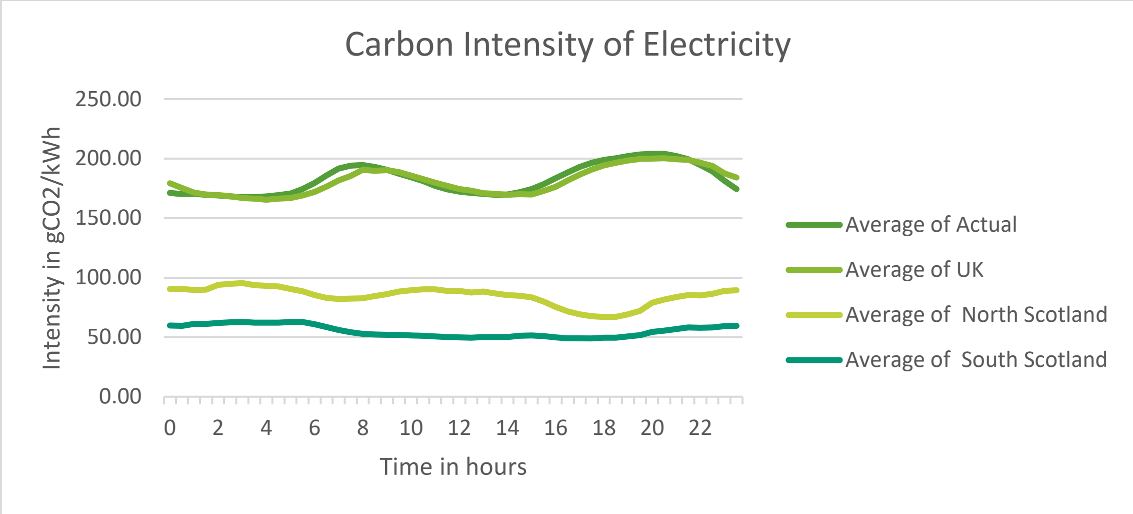

Figure 9: Average Carbon Intensity of Electricity by Time of Day

While it is tempting to use the better for Scotland, the UK has a common electricity grid, so it seems more appropriate to use the average for the whole grid (although this may change if the management of the electricity grid is devolved). The analysis uses a figure of 180g/kWh for night-time charging (between midnight and 6 am) and 200g/kWh for day-time charging (assuming it does not usually fall into the evening peak). These figures include conversion losses of around 5%.

The CO2 estimated impact is shown in Figure 10. Of course, CO2 is a global pollutant, so this data must be considered globally. It is obvious that the operating impact dominates over the embedded CO2, and electric buses of any kind have around three times lower CO2 emissions than conventional buses.

The figures show that repowering has amongst the lowest overall CO2 impact. Only the eSprinter receives a lower figure, and it is a much smaller vehicle. This good result for repowering is not surprising because repowering fits into the 7 Rs of sustainability: Reduce, Reuse, Respect, Rethink, Reflect, Recycle, Redistribute.

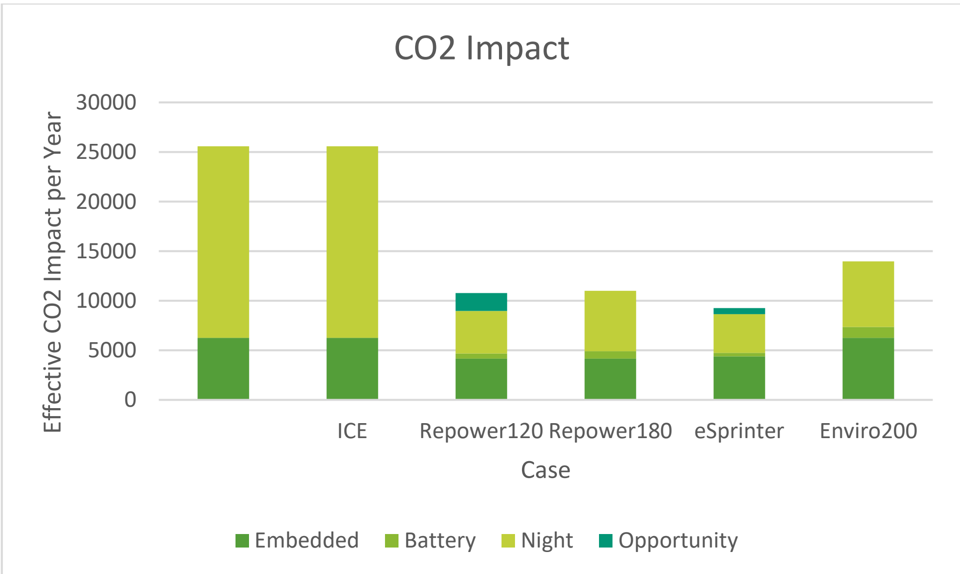

Figure 10: CO2 Impact of Different Solutions

Local pollutants such as nitrous oxide (NOx), particulate matter (PM) and, to a lesser degree, hydrocarbons (HCs) are more critical for the local air quality, especially in towns and around bus stops, traffic lights, etc. Since electric vehicles have zero tailpipe emissions, they contribute a lot less to these emissions. A precise model does not seem appropriate here because it would only investigate conventional vehicles. On the other hand, EVs still produce tyre and brake dust, and this is subject to ongoing research.[38] Noise emissions from EVs are much lower, especially around stops, which can improve local well-being and quality of life.

3.7 Vehicle Utility Model

The value of a repowered bus is hard to determine because it is subject to supply and demand considerations outside of the scope of a technical report. The argument here will be based on the utility question: how much does the bus save the operator annually and over its lifetime? Based on the model, the repowering Repower120 offers operational savings of £14 500 per year.

The expected lifetime of the repowered bus is 12 years. This is based on the battery warranty of 8 years. As the most expensive part of the powertrain, a battery failure outside of warranty often means that it is not economical to fix it, and the bus is written off. This could happen at any point after eight years, but on average, we expect the battery to outlast the warranty by some margin.

Over twelve years of operation, this generation has an overall added utility value for the repowered bus of £174k. Compared to a repower cost of £140k, this is a small but clear benefit. The figures are sensitive to many assumptions, mostly the operating life, the operating cost, and the comparison to a conventional bus. Whether the utility value can be realised by selling the bus is another question because, as stated, the market is tiny.

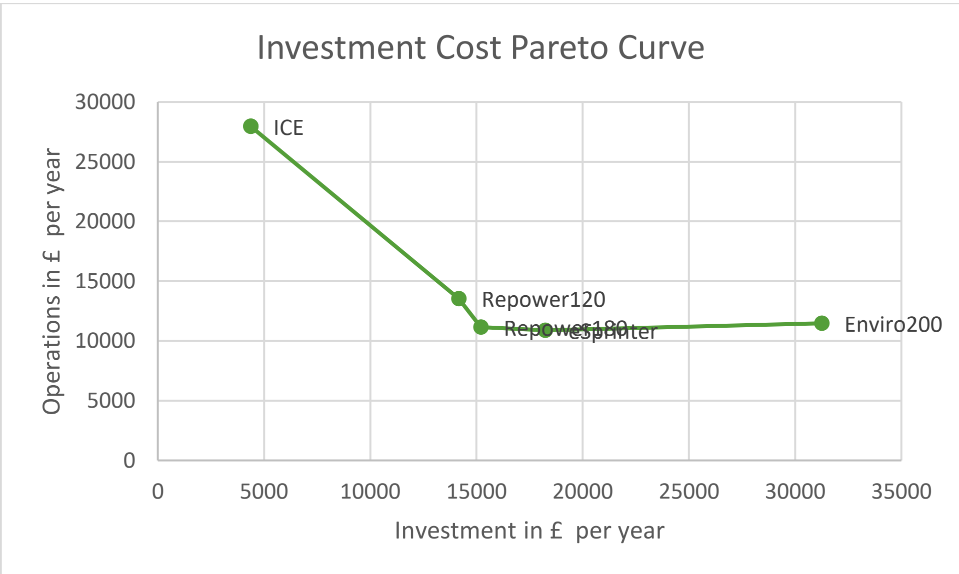

Figure 11: Pareto Curve of Solutions

[38] C.S. David et al: PM_{10} and $PM_{2.5}$ emission factors for non-exhaust particles from road vehicles: dependence upon vehicle mass and implications for battery electric vehicles, Atmospheric Environment, Volume 244, 2021, doi:10.1016/j.atmosenv.2020.117886.

3.8 Overall Business Case

From this data, an overall business case is supported. The resulting business case is interesting. All five considered solutions are shown as a Pareto Curve in Figure 11. Lower cost is better, so the lower left corner is the direction to aim in.

The total cost, comprising operations and capital cost, is shown in Figure 12.

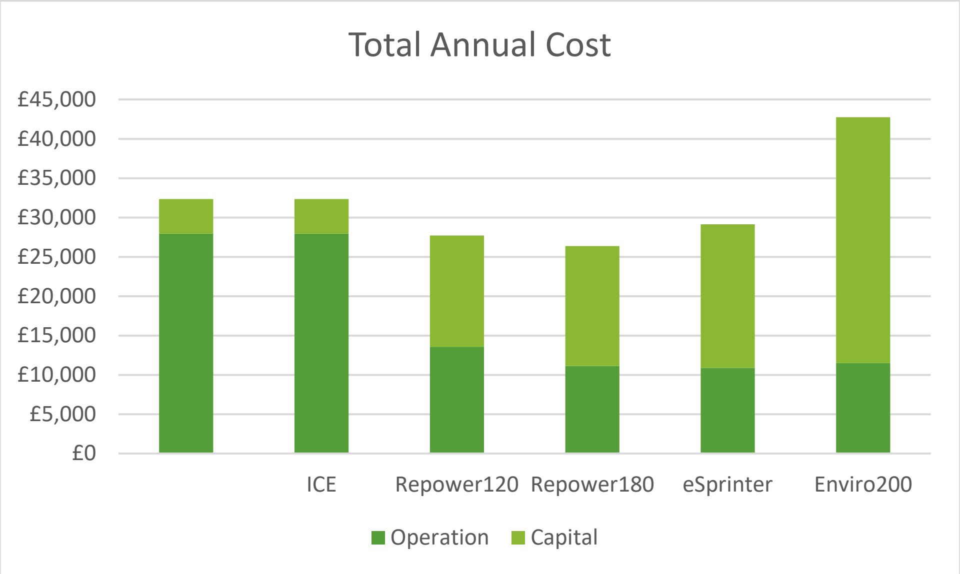

Figure 12: Operation and Capital Cost

A simple finance model is used here to consider the return on investment, assuming today's prices throughout and no significant interest rate relative to inflation. It is assumed that small companies will get financing offers that can be added to the model, and larger companies have their depreciation model that can be inserted. The return on investment ratio is shown in Figure 13.

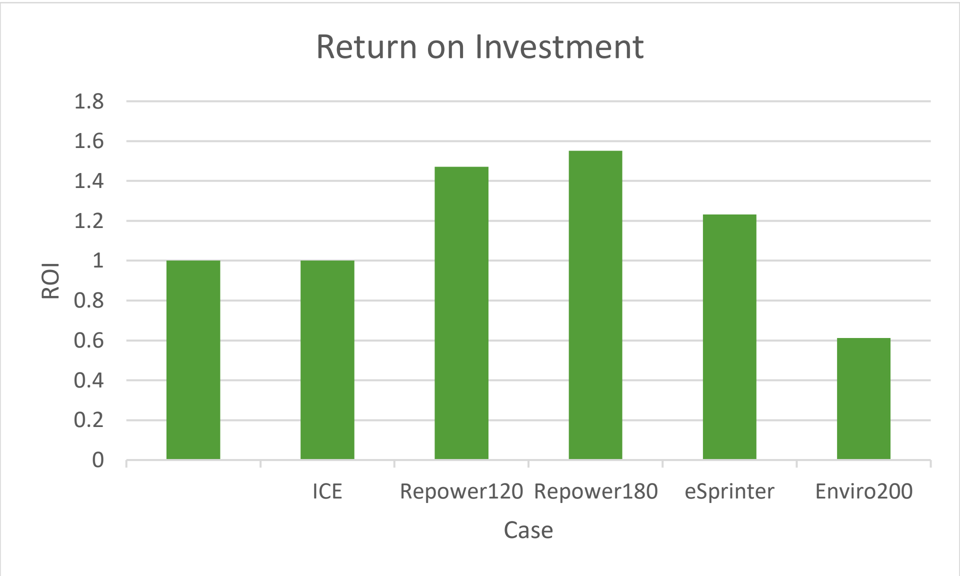

Figure 13: Return on Investment

The results are in line with expectations: it demonstrates that there is a clear case for all electrification solutions except for the full-price, full-scale new bus, which is too big (and expensive) for this route. The financially most beneficial case is Repower180 – a repowering solution with a large battery capacity. This is partially due to the cheap legacy electricity tariff at Houston's, which makes depot charging much cheaper than opportunity charging. Unfortunately, this solution is technically difficult to realise because the space is not sufficient for this battery capacity. The next best solutions are a retrofit with a smaller battery or a new ZEB. It is worth pointing out that the new ZEB has a reduced passenger capacity, and it may not be suitable for all routes.

A sensitivity analysis of the model shows that while the exact results depend heavily on the input values, the overall picture is remarkably stable over a wide range of assumptions. The reader is encouraged to play with the model to experience this.

4 Industry

This section covers the potential impact of repowering on the industry in Scotland. Section 9.2: Social Contribution contains further background information and literature.

4.1 Managing Change

A structured interview was conducted with William Houston to establish the change that the introduction of electric vehicles at Houston's had on the operation of the business, the skills requirements, and the business-to-business needs. The following main questions were asked. We hope that this experience can help others on the same journey towards net zero.

What is your experience with electric buses?

The buses are very impressive, even if we experience some initial teething problems with both the buses and the chargers. There were some software problems with the buses and some voltage issues with the chargers. The chargers cannot handle both Level 3 (AC) and Level 4 (DC) charging at the same time, which is unusual for modern chargers. Our charging partner SWARCO and our electricity supplier Scottish Power have been very responsible and were able to resolve most issues to our satisfaction. Gaining experience helps, as does training on electric vehicles.

How did you finance the purchase of new vehicles?

We used a combination of the ScotZEB Phase 1 capital funding and a commercial business loan to finance the purchase. This is new territory for us since we usually buy used buses at a much lower value.

How did you organise the charging during the night?

This is part of the locking down procedure. The last in the yard, whether it is a driver or a service person, has to make sure that all buses are connected and charging. This is generally not too difficult, especially if the buses are parked appropriately.

How did you organise the charging during the day if necessary?

This is the responsibility of the driver during the day. We do provide on-the-job training at the location for each driver if necessary. We did not have any significant problems with contention, but this could change as more electric buses operate in the area.

How did the drivers respond to the new buses?

Generally, the response from the drivers was positive and sometimes even enthusiastic. They are comfortable, accessible, and easy to drive. However, they are quite small, and they provide limited space for luggage, wheelchairs, prams or bicycles. This can occasionally be contentious, and the driver has to try to resolve the conflict.

Interestingly enough, we do see significant differences in consumption between drivers. On the whole, it seems that female drivers tend to adjust to the required driving style more easily than male drivers, although more experience is needed to present a full picture. (Note: The general trend has been confirmed in the scientific literature as one of the most important factors.[39])

How do the passengers respond to the new buses?

The passengers are generally excited about being on an electric, although the novelty will soon wear off. They consider the bus to be comfortable and very accessible. (Arguably, the same may be true for any new bus, independent of the powertrain.)

What kind of training was required for your employees?

We provide training for charging and an induction for the first use of the vehicle, as we do for any new bus model. Generally, this is sufficient, although more training on economical driving may be required.

What do you think is the main barrier to adopting electric buses?

Our primary concern is the charging infrastructure in the area. We cannot afford a bus with the battery size to last a full day, so opportunity charging is part of our usage pattern. Returning to the depot is usually not an option, and there is only one rapid charger anyway. This is only possible if the bus is near a public charger during the lunch break, and that eliminates several routes and duties from electrification.

We also found that the range of the electric buses depends on the weather, so while an electric bus may work fine in the summer, there could still be problems in winter. This makes scheduling more complicated.

4.2 Parts

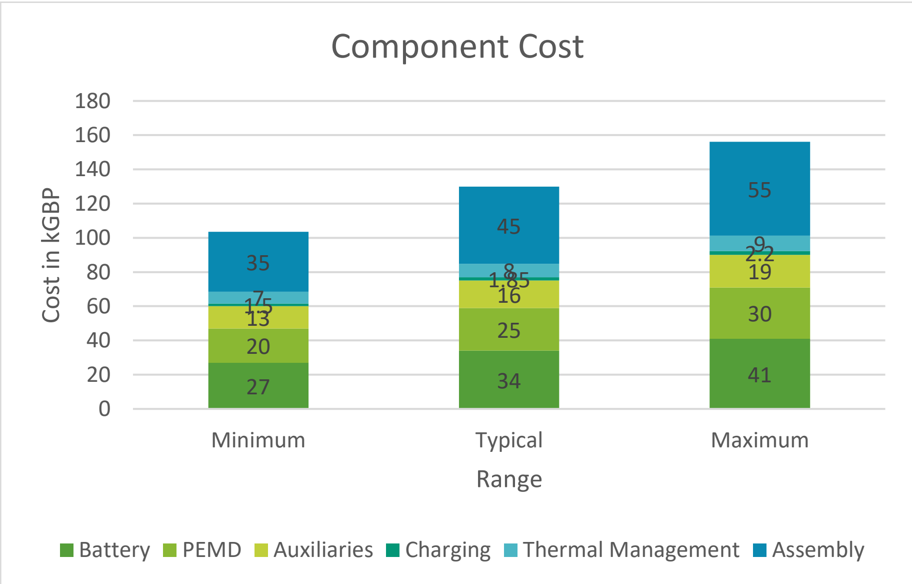

Figure 14: Component Cost of Key Parts of the Powertrain

[39] H. Zhang, J. Sun, Y. Tian: The impact of socio-demographic characteristics and driving behaviors on fuel efficiency, Transportation Research Part D: Transport and Environment (88), 2020, doi:10.1016/j.trd.2020.102565.

To establish the technical side of the impact, intensive discussions with Kleanbus have been conducted. They lead to an overview of parts and labour's technical and financial value in the repowering project. A list of the main constituent parts of the powertrain is listed in Figure 14, with an approximate cost range and typical origin countries. This graph excludes the one-off engineering cost for a new bus type.

A list of origin regions for these parts is shown in Table 7. It shows that there is apparent diversity in supply for most parts at the system level. However, this diversity may disappear, for example, when all magnets are sourced indirectly from production in China. More detail will be explicitly presented on Batteries and PEMD.

Table 7: Origin of Powertrain Parts

Part	Typical Origin	Lead Time in Months
Battery	China, South Korea, EU	2-3
PEMD	USA, EU, UK	2
Auxiliaries	USA, EU, UK	2
Charging	China, USA	1
Thermal Management	UK, China	1-2
Assembly	UK	1
Engineering	UK	ca 6 (first bus only)

These results inform the opportunities for setting up manufacturing of automotive parts within a supply chain for electric heavy-duty vehicles in Scotland. The chance of reshoring some of the production back to the UK certainly exists.

4.3 History of Scottish Industry

History has shown how vital mindshare is for investment decisions: is there general awareness of the opportunities in Scotland? One way to measure this is to look at the frequency of key phrases to describe these opportunities. The Google Books Ngram Viewer[40] is the most popular tool, even if the database lags slightly behind. The result for some key terms is shown in Figure 15. It highlights the demise of Silicon Glen due to the market competition from Eastern Europe, but also the rise of Alexander Dennis.

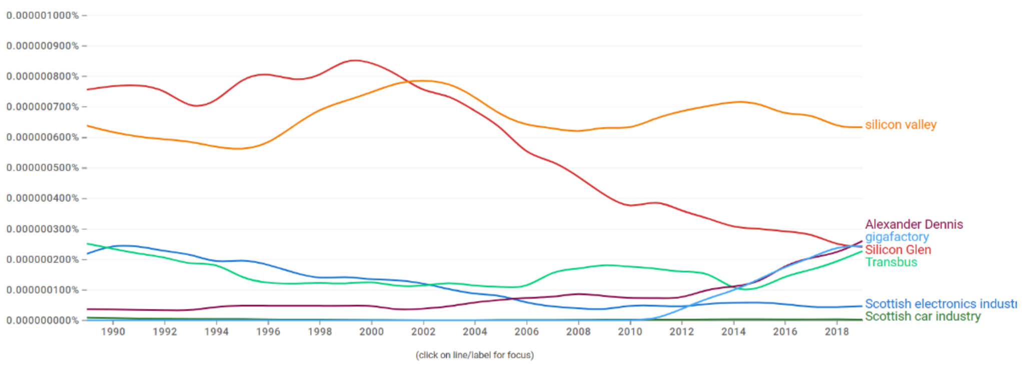

Figure 15: Mindshare according to the Ngram Viewer

[40] Google: Google Books Ngram Viewer, data up to 2019, accessed 2023-08-11.

A decade ago, there was still optimism to reinvent the electronics industry with an environmental focus.[41] But the transition was more difficult than expected, and there has only been a noticeable upward trend in the last few years.[42]

4.4 Technology Transition

The technology transition from one energy source to another can be highly dynamic, but even the best technology is subject to constraints regarding feasible growth rate. History shows that a new technology tends to grow exponentially (upscaling) until it reaches a limit or market saturation.

This model has been replicated in Excel based on the data presented in an industry report[43]. Similar figures are used in most publications, so they are uncontentious. More problematic is the assumption about market saturation. Based on an automotive market of 100 million vehicles per year, a battery size of 50 kWh, and a market penetration of 100%, a limit of 5 000 GWh per year can be calculated. But this is only for the light-duty sector; heavy-duty and stationary energy applications may create a higher demand, so limits of 10 000 GWh and 20 000 GWh are also tried in the simulation.

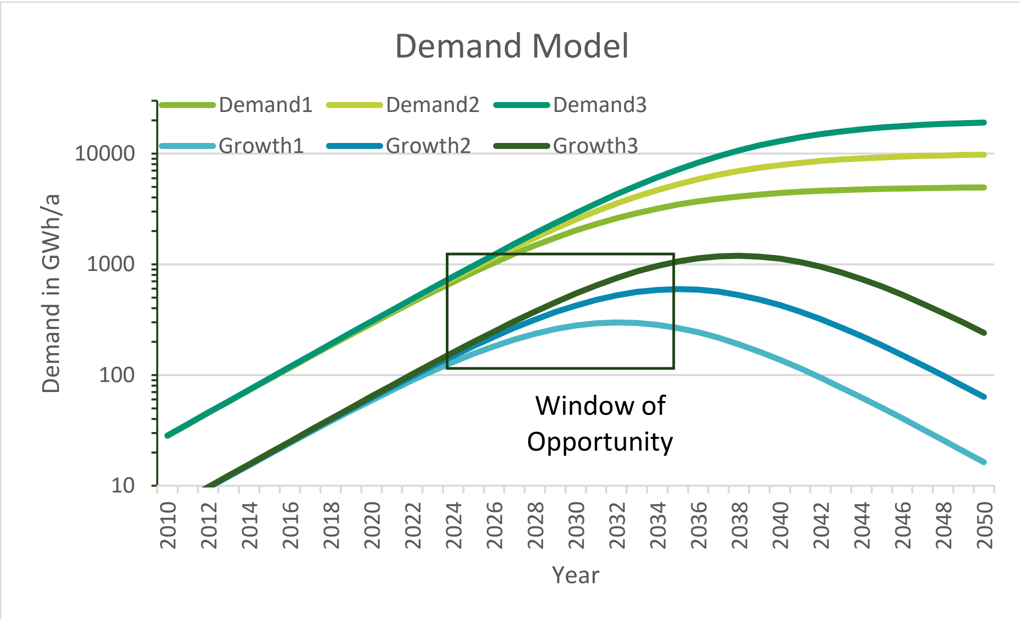

Figure 16: Technology Transition Model

The result is shown in Figure 16. The logarithmic scale highlights the exponential growth and the approaching of the set market limit. Critically, this model offers a window of opportunity for the building industry during the rapid absolute increase in demand over the next decade. This is when most new factories and suppliers are required, and supply chain shortages are likely. By 2035, the government and EU goal is to have achieved 100% ZEV sales for passenger vehicles, and demand will grow much more slowly from then on, which means that the

[41] AP Benson: Mapping the Electronics and Electrical Equipment Sector in Scotland, 2012-01-01, accessed 2023-08-14.
[42] C. Chikwama: 7. Electronics/ Electrical Manufacturing Sector - Scotland National Strategy for Economic Transformation: industry leadership groups and sector groups, ISBN 9781804351468, 2022-03-1.
[43] J. Fleischman et al: Lithium-ion battery demand forecast for 2030, McKinsey, 2013-01-16, accessed 2013-08-11.

industry will rely on established supply chains. Competing with those will make setting up new manufacturing capacity much more complicated than during this decade.

The window for repowering technology is also limited. Because a bus needs to have a significant life left to be viable for repowering, and diesel bus sales are quickly declining, the supply of donor vehicles will shrink significantly in the 2030s. Repowering needs to be established by then, or the opportunity is lost.

4.5 Global Context

Modern powertrains have a global supply chain complicated by trade barriers and geopolitics. Figure 17 illustrates this by showing the locations of gigafactories in the UK vs gigafactories in China[44] (the data is from 2021, and China has since progressed, while the picture in the UK remains unchanged).

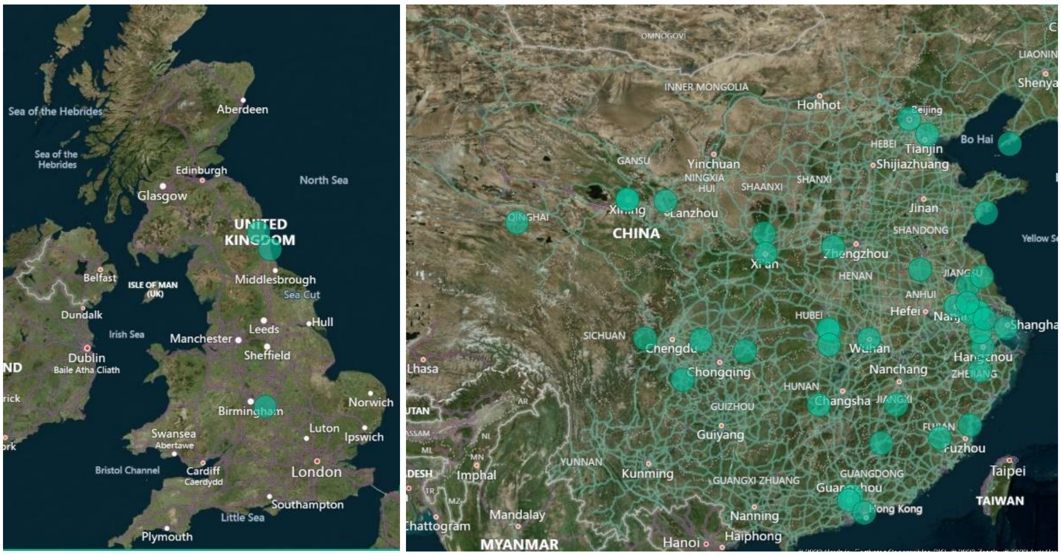

Figure 17: Gigafactories in the UK vs China

The situation in China is greatly affected by the industrial strategy, which has supported so-called "new energy vehicles" since 2009 to set up a self-sufficient domestic supply chain for the critical components of modern powertrains. This includes the lithium used in batteries, the rare earth metals used in the magnets of automotive motors, and the electronics to control them.

Western countries have responded slowly to this challenge, and as a result, China has captured most of the manufacturing of batteries[45] and neodymium-iron-boron magnets[46]. Since the UK left the Single Market, this created additional trade barriers because The EU-UK Trade and Cooperation Agreement[47] specifies increasingly challenging rules of origin for the duty-free trade of vehicles.

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[44] CUC energiGUNE: World map of Gigafactories | CIC energiGUNE, posted 2021-10-21, accessed 2023-08-13.
[45] Green Car Congress: Benchmark: China dominates Li-ion battery supply chain, 2022-10-09, accessed 2023-08-14.
[46] Benchmark Minerals: Rare earth permanent magnet production advances outside of China, 2023-07-27, accessed 2023-08-14.
[47] European Commission: The EU-UK Trade and Cooperation Agreement, 2021-04-31, accessed 2023-08-13.

The USA recently started a concerted effort to reshore battery production using the Inflation Reduction Act 2022[48]. There are significant tax rebates for production in the USA. While it is questionable whether this violates subsidy control, it is undoubtedly effective: the USA is planning to build tens of gigafactories in the next few years[49], which would satisfy most of the domestic demand. This demonstrates how critical public subsidies are in this industry.

The rules of origin define whether products are deemed to originate in the UK or the EU, which is a prerequisite for duty-free trade.[50] These rules limit the proportion of imports from outside the UK and the EU that can be used to create the product. A six-year phase-in period to a permanent state from 2027 for pure EVs, HEVs, and EV batteries exists. From 2027, the UK can export any number of EVs and PHEVs into the EU market at a zero tariff under the following conditions: EVs must have 55% UK/EU content and an originating battery pack. An originating battery pack must have either 65% UK/EU content for the cell or 70% for the battery pack.[51]

The high value of imported batteries and motors makes it likely that electric vehicles will not satisfy these rules of origin. This market barrier cuts both ways: it may help protect the UK market while hindering the UK from exporting into the Single Market. Changes are possible in theory, but there is no political appetite on either side.

4.6 Batteries

Gigafactories are large-scale battery manufacturing plants that produce batteries for electric vehicles (EVs) and energy storage systems. They are called gigafactories because they produce batteries with a capacity of at least one gigawatt-hour (GWh) per year.

More battery manufacturing capacity in the UK would be helpful, but this requires significant capital investment and political support. There is currently one “gigafactory” (a battery plant with a manufacturing capacity in the order of gigawatts per year) in Sunderland by Nissan, and there are plans to build another one by Tata Group for JLR. But despite the clear demand, the process is turning out to be lengthy and uncertain. Since demand for batteries is increasing for at least the next decade, there is a chance to build a battery factory in Scotland if those obstacles can be overcome.

The case for building a gigafactory in the UK is that the automotive industry needs a local source of batteries. Chinese or other Asian imports will not be an option, partially because of expected supply shortages due to the technology transition discussed above and partly because of rules of origin for exports into the Single Market. While BritishVolt has collapsed into administration[52], Tata is now planning to build a gigafactory in Somerset to supply JLR

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[48] The White House: Inflation Reduction Act Guidebook, 2022-08-16, accessed 2023-08-17.
[49] R. Bellan: Tracking the EV battery factory construction boom across North America, 2023-08-16, accessed 2023-08-17.
[50] Faraday Institute: Brexit-TCA-Rules-of-Origin-for-Batteries, 2021-03-05, accessed 2023-08-13.
[51] UK gov: Rules of origin for goods moving between the UK and EU, 2021-10-06, accessed 2023-08-13.
[52] P. Campbell, et al: Britishvolt collapses into administration as rescue talks fail, Financial Times, 2023-01-17, accessed 2023-08-14.

manufacturing in the Midlands[53], which received an undisclosed amount of public funding, considered to be in the order of hundreds of millions of pounds[54].

The case for a gigafactory in Scotland is more complicated. It rests on the difficulty of transporting batteries due to weight and safety concerns, which means that a local factory is preferable. But setting up a new battery gigafactory is complex, and it requires billions of pounds worth of investment, using a combination of public and private funding. There needs to be more than the demand from the automotive industry in Scotland to justify a gigafactory, even if Alexander Dennis reaches their goal of producing 2500 electric buses a year. Repowering will add additional demand, but this is a temporary industry. A megafactory is being built in Dundee, scaled according to the regional need.[55]

Creating enough demand for a gigafactory requires combining the demand of the automotive and energy sectors. Scotland is the premier producer of wind power in the UK, but the use of this power is often restricted by constraints in the transmission lines leading south. The logical solution is large-scale storage of net zero electricity in Scotland, near where it is generated, using about 100 GWh of batteries. Together with the automotive demand, this would justify the construction of a gigafactory if an industrial strategy can align growth in both the automotive and energy industry.

Currently, Kleanbus preassembles the powertrain in Essex, even if the final installation may happen in Scotland. Batteries are the heaviest part of the powertrain, so once a local supplier is available, this would also help to make a financial case for preassembling the powertrain in Scotland. The same logic applies in the energy sector for battery storage devices, and together, they could offer significant opportunities for economic growth.

4.7 Power Electronics, Machines, and Drives (PEMD)

Driving the Electric Revolution (DER)[56] is a UK-wide initiative to create an industry and supply chains for power electronics, machines, and drives (PEMD) to support the electrification and decarbonisation of transport and stationary applications. DER is heavily invested in state-of-the-art technologies such as high band gap semiconductors for power electronics applications and permanent magnet-free high-efficiency motors. These technologies promise better powertrain efficiency and, therefore, better recuperation performance, which is especially valuable for the typical usage pattern of buses.

The DER Scotland Industrialisation Centre[57] is located at the Power Networks Demonstration Centre (PNDC)[58] at the University of Strathclyde, and it focuses on megawatt-scale power electronics, as they are used in heavy-duty applications, including wind power, waterpower,

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[53] G. Parker, et al: Tata Motors set to announce plans to build UK battery factory, Financial Times, 2023-07-18, accessed 2023-08-14.
[54] G. Parker, P. Hollinger, O. Telling: UK government pays £500mn in subsidies for Tata battery plant, Financial Times, 2023-07-19, accessed 2023-08-14.
[55] AMTE Power: AMTE Power selects Dundee as preferred site for battery cell factory in boost for Scottish net zero jobs, 2022-07-28, accessed 2023-08-13.
[56] DER: Power Electronics, Machines and Drives | DER – Driving the Electric Revolution, Industrialisation Centres (DER-IC), accessed 2023-08-19.
[57]DER: DER-IC - Scotland - PNDC, accessed 2023-08-19.
[58] University of Strathclyde: PNDC, accessed 2023-08-19.

trucks, buses, and off-high machines. Aligning repowering and ZEB production with the DER is an opportunity to bring these advanced technologies into the supply chain. The higher efficiency may reduce the size of batteries required for a specific route.

4.8 Up-Skilling

Based on the operational experience with the eSprinter buses, the main upskilling challenge is for the bus drivers. This is because they represent the highest number of employees affected by the transition and because it does change their jobs quite significantly. Electric buses have different operational requirements (such as preconditioning and opportunity charging) and are much more sensitive to how they are driven (as explained in the vehicle model).

A lot of the kinetic energy during stopping can be recovered via recuperation, but only if the deceleration stays within the limits of the recuperation system. Beyond those limits, friction brakes are used, and the kinetic energy is lost. There is a specific driving style suitable for electric vehicles[59], and it should be taught[60] and supported/reinforced by onboard instrumentation[61].

Workshop staff for support and maintenance will also require upskilling. As a minimum, a course on safely handling electric vehicles is needed, which takes a few days to complete[62]. Further skills for diagnosing and repairing electric powertrains and high voltage systems may be helpful[63], but this is a specialist topic and may not be cost-effective for small workshops. This or a similar qualification would also be required to install repowering solutions in a local workshop. Overall, it is expected that electric powertrains require significantly less maintenance, which could lead to some redundances. General mechanical maintenance is not affected in any significant way.

Finally, the installation of charging infrastructure will see a significant increase in the relevant workforce. This includes construction, groundwork, civil engineering, low (415 V) and medium-voltage (11 kV) electrical work, planning, management, and verification. Scottish and Southern Electricity Networks (SSEN) have detailed this in their EV Strategy[64].

Overall, there are significant opportunities for the creation of new jobs and the up-skilling of existing jobs. Repowering offers more opportunities for local employment than purchasing a new bus, especially if the installation can be performed locally.

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[59] T. Franke, et al: Ecodriving in hybrid electric vehicles – Exploring challenges for user-energy interaction, Applied Ergonomics (55), 2016, pp 33-45, doi:10.1016/j.apergo.2016.01.007.
[60] M. Günther, C. Kacperski, J. F. Krems: Can electric vehicle drivers be persuaded to eco-drive? A field study of feedback, gamification and financial rewards in Germany, Energy Research & Social Science (63), 2020, doi:10.1016/j.erss.2019.101407.
[61] Drivetech: EV Co-Driver, accessed 2023-08-17.
[62] Dundee and Angus College: IMI Level 2/3 Combined Award in Preparing Heavy Electric/Hybrid Vehicles for Vehicle System Repair and Replacement, accessed 2023-08-17.
[63] IMI: Accreditation Electric Vehicle Technician - Full Route, 2013-04-02, accessed 2023-08-17.
[64] SSEN: Electric Vehicle Strategy in EV Connections, March 2020, accessed 2023-08-17.

5 Conclusion

This string of projects (SoctZEB2 Stream 1 to 3) has conclusively demonstrated a case for moving towards electric propulsion for local bus services where feasible. The operating cost is significantly reduced, and choosing the suitable model can offset the higher capital investment required. Toxic emissions are reduced to near zero, except for particulate matter, which is still reduced noticeably. Carbon emissions can be reduced to about 40%, even considering the embedded carbon in the batteries. This is confirmed using a consumption model that considers the peculiar usage profile of local buses.

The case for repowering is twofold, and both arguments rest on extending the lifetime of an existing conventional bus. The capital investment for repowering is much lower than purchasing a new vehicle if the engineering effort can be amortised by having a good number of identical buses. And the carbon impact of production is significantly reduced by using an existing bus. These two points make repowering the preferred solution where feasible.

However, there are significant constraints for repowering. The main technical concern is whether there is enough space for the battery, and this depends on the specific bus model, the battery technology, the usage profile, and the availability of public charging opportunities. The main logistical constraint is that repowering requires economies of scale to be financially viable, and many bus models were only ever sold in small numbers, so this is difficult to achieve. This means that for most buses, repowering is not likely to be an option.

The experience with electric buses at Houston's is generally positive after purchasing four electric buses, and the repowering of a bus is ongoing. Key obstacles are training requirements for drivers and maintenance, the funding model, public charging opportunities, and the high upfront engineering cost for repowering a new bus model. Public funding and policy could help to overcome these issues.

6 Appendix A: Background

6.1 Benefits of Road Transport Electrification

Road transport is a significant cause of poor air quality, noise disturbance, congestion, and climate change impacts across the globe. There are 40.8 million licensed vehicles in the UK at the end of Sep 2022[65]. While road transport is often the only viable option, electrification is a must to reduce the negative impact of vehicles on the environment and our health.

6.1.1 Climate Change

Climate change is causing warming throughout the world and bringing increasingly frequent heat waves. The hottest temperature in summer was 38.7 °C in the UK. The Met Office predicted summer will be between 1 and 6 °C warmer and up to 60% drier in 50 years[66]. Warmer weather will put some coastal cities in the UK at risk of flooding, more drought in the central regions, and more frequent storms that will paralyse traffic and damage houses. The main reason for climate change is greenhouse gas emissions, particularly carbon dioxide (CO_2). As a result, the commitment to achieve net-zero GHG emissions by 2050 (to limit the global temperature rise to 1.5 °C compared to the pre-industrial levels) was adopted by 196 Parties through the Paris Agreement at the UN Climate Change Conference (COP21) in December 2015 and reaffirmed at COP26 in Glasgow in 2021. Transport is one of the high-priority areas to overcome, and the participating countries agreed to ensure the Zero Emission Vehicle (ZEV) transition is genuinely global. In 2020, road transport contributed 26% of the EU's total emissions of CO_2[67]. Similarly, transport is the largest source of greenhouse gas emissions in the UK which produced 108 MtCO2e, which accounted for 27% of total emissions in 2021, of which road transport accounts for 87%[68]. In Scotland, the total greenhouse gas emissions were 41.6 $MtCO_{2e}$ in 2018, and 35.6% of all emissions (27% for domestic transport) were from Scottish transport. The emissions from road transport accounted for 69% of all transport emissions (10 $MtCO_{2e}$)[69]. The breakdown of emissions by sector in Scotland is shown in Figure 18 based on data from CPT[70]. Unlike other sectors that have achieved significant emissions reductions compared to baseline measurements, transport emissions have declined only modestly since 1990, slowing the overall reduction rate across Scotland. The emissions fell by 12% between 2019 and 2020 – half of 1990 levels for the first time. But the fall in 2020 is only temporary,

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[65] RAC: Vehicle in the United Kingdom, https://www.racfoundation.org/motoring-faqs/mobility#a1 .
[66] Met Office: Effects of climate change, https://www.metoffice.gov.uk/weather/climate-change/effects-of-climate-change .
[67] Statista: Distribution of carbon dioxide emissions in the European Union in 2020, by key source, https://www.statista.com/statistics/999398/carbon-dioxide-emissions-sources-european-union-eu/ .
[68] BEIS: Provisional UK greenhouse gas emissions national statistics 2021, https://www.gov.uk/government/statistics/provisional-uk-greenhouse-gas-emissions-national-statistics-2021 .
[69] Transport Scotland: Emissions trends for Scotland, https://www.transport.gov.scot/publication/carbon-account-for-transport-no-12-2020-edition/emissions-trends-for-scotland/ .
[70] CPT: Zero Emission Bus Financing Ideas Pack, 2021, https://www.cpt-uk.org/media/yo2du40i/ze-bus-financing-information-and-ideas-pack.pdf .

largely due to travel restrictions during the pandemic[71]. These trends indicate why vehicle electrification was one of the mitigation goals on the COP26 agenda held in Glasgow in 2021.

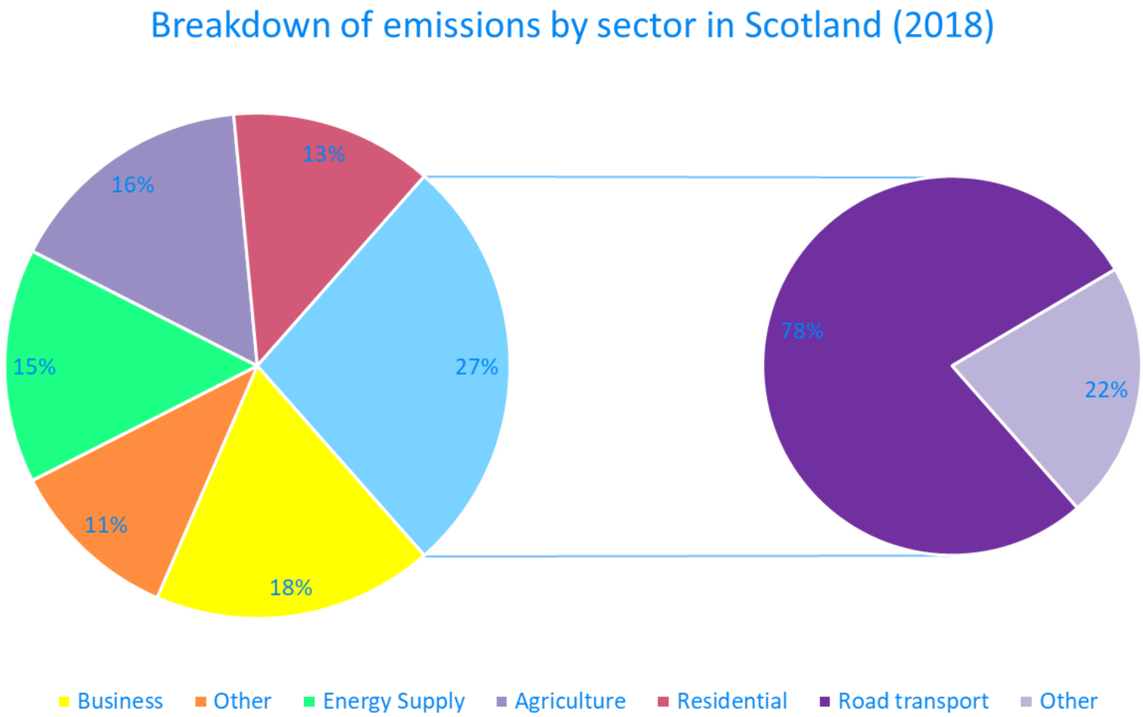

Figure 18: Breakdown of Emissions by Sector in Scotland

6.1.2 Pollution

Besides climate change, the significant health impacts of air pollution caused by road transport are a driver for phasing out fossil fuel vehicles. Vehicles with internal combustion engines emit gases or other substances that impact human health; for example, nitrogen oxides (NO_X) and particulate matter (PM). Air pollution has a strong connection with disease and life expectancy[72]. Transport accounted for a large share of these air pollutants in the UK and, in 2020, was responsible for one-third of nitrogen oxides, 14% of $PM_{2.5}$ emissions, and 12% of PM_{10} emissions[73]. Emissions of exhaust-related pollutants (except CO_2) fell between 1990 and 2020; NOx emissions from transport were reduced by 77.5%[74], PM_{10} emissions from 35 kt to 19 kt, and PM2.5 emissions from 30 kt to 13 kt. However, even very low-level $PM_{2.5}$ and PM_{10} concentrations result in negative outcomes. Electric vehicles avoid those exhaust-related pollutants. Noise pollution is the second biggest impact of road transport after air pollution.

[71] CCC: Scotland's climate targets are in danger of becoming meaningless, https://www.theccc.org.uk/2022/12/07/scotlands-climate-targets-are-in-danger-of-becoming-meaningless/ .

[72] GOV.UK: Air pollution: applying All Our Health, https://www.gov.uk/government/publications/air-pollution-applying-all-our-health/air-pollution-applying-all-our-health .

[73] Department for Transport: Transport and environment statistics 2022, 2022-10-20, accessed 2023-08-17.

[74] NAEI: Pollutant Information: Sulphur Dioxide https://naei.beis.gov.uk/overview/pollutants?pollutant_id=8 .

The annual social cost of urban road noise in England is estimated to be £10 billion[75]. The main noise source for road vehicles in urban areas is engine noise[76]. Reducing urban noise levels by 3dB can reduce annoyance effects by 30 per cent. Based on the average speed profile in London, electric vehicles (EVs) can improve the noise by 8.9 dB[77]. Non-exhaust-related PM emissions, such as from tyres and brake wear, are also significant. Internal Combustion Engine (ICE) vehicles mainly use disc brakes to slow the car down, which emit particle pollution. Electric vehicles use regenerative braking, which can reduce particle emissions as it restores braking energy back to the vehicle's battery to power the vehicle[78]. Overall, EVs eliminate emissions from engine exhaust and significantly reduce emissions from brakes compared to ICE vehicles.

6.2 Road Transport Electrification Progress

6.2.1 Scotland Level

The Scottish Government aims to achieve a 75% reduction in greenhouse gas emissions by 2030 and a legally binding target of net zero by 2045. However, the Scottish Government has not set a national target for the number of electric vehicles in Scotland but has set out a bold ambition to phase out the need for new petrol and diesel cars and vans by 2030[79]. The transport sector is currently the greatest contributor to emissions, emitting 13.9 million tonnes of CO_{2e} in 2019, with road transport contributing the most. Supporting the uptake of electric vehicles is an important component of the Scottish Government's Climate Change Plan. The government has made commitments to phase out the need for new petrol and diesel cars and vans by 2030, remove petrol and diesel cars from the public sector fleet by 2025[80], and the need for any new petrol and diesel light commercial vehicles by 2030[81]. With the investments from the Scottish government, 2,163 charging points with 783 000 charging sessions have been created by 2022,[82] and by the end of 2022, electric vehicles accounted for 12.7% of new car sales. Scottish government further provided over £30 million in 2022 to accelerate the shift to electric transport. The funding is now being prioritised to focus on used electric vehicles, operating light commercial vehicles for businesses and people living in rural areas, and the taxi sector[83]. While the decarbonisation of passenger vehicles is happening with increasing speed, heavy-duty vehicles are a much more difficult challenge. 3 700 buses are operating on the

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[75] Department for Transport: New trial to banish loud engines and exhausts on Britain's noisiest streets, 2022-04-30, https://www.gov.uk/government/news/new-trial-to-banish-loud-engines-and-exhausts-on-britains-noisiest-streets .

[76] M.P.S. Brand, et al: Hybrid and electric low-noise cars cause an increase in traffic accidents involving vulnerable road users in urban areas, International journal of injury control and safety promotion, vol. 20, no. 4, pp. 339-341, 2013.

[77] LSG: The case for electric vehicles, https://www.local.gov.uk/case-electric-vehicles .

[78] M. Barisione: Electric vehicles and air pollution: the claims and the facts, EPHA, 2021-03-05, https://epha.org/electric-vehicles-and-air-pollution-the-claims-and-the-facts/ .

[79] Transport Scotland: Statistics on the number of electric vehicles in Scotland: FOI release, 2019-02-06, https://www.gov.scot/publications/foi-19-00181/ .

[80] Transport Scotland: Report on Public Electric Vehicle (EV) infrastructure in Scotland - Opportunities for Growth, 2021-07-21, accessed 2023-08-17.

[81] cpt: Bus Decarbonisation Taskforce, https://www.cpt-uk.org/news/bus-decarbonisation-taskforce/ .

[82] EIR: Electric vehicle (EV) charging point numbers: EIR release, https://www.gov.scot/publications/foi-202200272119/ .

[83] Transport Scotland: £30 million to support the shift to zero emission transport, 2022-06-06, accessed 2023-08-17.

road, and emissions from those buses account for 5% of road transport emissions. Although several bus fleets committed to engaging the net zero project to deliver battery electric or hydrogen buses to society, only 6% of the total Scottish buses were electric by the end of 2022[84]. The electrification of buses is far behind the overall plan due to the upfront capital cost for new technologies and associated infrastructure and the pandemic.

6.2.2 UK Level

The UK government has committed to ending the sales of new fossil fuel cars and vans by 2030, while for the buses, coaches, and minibuses, the deadline is no later than 2032[85]. The UK government aims to make every new car, van, and bus on the road a zero-emission vehicle by 2050. To help achieve these targets before the deadline, the UK government delivered several plans, such as the transport decarbonisation plan and 2035 delivery plan. It confirmed introducing an electric mandate from 2024 by setting annual targets for the proportion of new cars and vans that are zero emission. In 2022, 1 in 5 cars sold were battery-powered electric vehicles, and some months have seen new registrations of electric cars overtake those of petrol and diesel. About a quarter of all government-owned cars are ultra-low emission vehicles (ULEV), and the target is for the entire fleet of around 40 000 vehicles to be fully zero emission by 2027. The number of licensed ULEVs in the UK increased from 9 000 to 991 000 at the end of 2022[86]. However, the proportion of electric vehicles in the total number of vehicles is still very low; only 5.5% of licensed vehicles were electric vehicles, and some of them are plug-in and range-extended electric vehicles[87]. The UK government is also committed to setting an end date for selling new non-zero emission buses. An initial consultation took place in the Spring of 2021, and in March 2022; the government consulted on setting an end date between 2025 and 2032. The outcome of the consultation is not yet available. £525m investment has been allocated to support the delivery of 4 000 zero-emission buses, but only £320m has been allocated so far for around 2 000 buses. 31 400 buses operate in England, but only 3% are battery-electric buses. The average age of a bus on the road in the UK is 12 years, and around 5% of the fleet is over 20 years. At current fleet turnover rates, the transition to zero-emission buses through banning the sale of new non-zero-emission buses will take many years and could be at risk of being beyond 2050.

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[84] Department for Transport: Annual bus statistics: year ending March 2022, https://www.gov.uk/government/statistics/annual-bus-statistics-year-ending-march-2022/annual-bus-statistics-year-ending-march-2022 .
[85] UK gov: Transitioning to zero emission cars and vans: 2035 delivery plan, 2021, https://www.gov.uk/government/consultations/consulting-on-ending-the-sale-of-new-petrol-diesel-and-hybrid-cars-and-vans/consulting-on-ending-the-sale-of-new-petrol-diesel-and-hybrid-cars-and-vans .
[86] H. Edwards et al: Electric vehicles and infrastructure, 2023, https://researchbriefings.files.parliament.uk/documents/CBP-7480/CBP-7480.pdf .
[87] Department for Transport: Vehicle licensing statistics data tables VEH1103, https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables .

7 Appendix B: Project Context

This chapter introduces the project objectives and explains why bus repowering is a feasible and pragmatic solution. The project participants and their contributions are introduced at the end of this chapter.

7.1 Objectives

Following the trend of electrification and responding to the call of the government and COP26, this project aims to explore repowering an existing in-service bus to speed up the zero-emission bus rollout, focusing on SME bus operators. The objectives are to provide valuable insights in the following areas:

- Capture the process of repowering from the perspective of the bus operator.
- Describe the impact of repowering on energy consumption, emissions, and cost.
- Consider the changes in the industry required and the opportunities for growth in Scotland.

This report also further discusses relevant future considerations, for example, potential battery customisation benefits and financial options, particularly for SME bus operators.

7.2 Motivation for Repowering

In addition to working towards the goals set out at COP21 and government climate change and air quality targets, ensuring public transport electrification keeps pace with that of private transport will prevent the risk of increasing congestion and social and health inequalities. Buses account for 57% of all journeys on public transport[88]. The current costs and bus fleet turnover rates risk electrification lagging significantly behind private cars and vans. To date, there are only 1 885 battery-electric buses in the UK. Among them, England has 1 424, and Scotland has 313, respectively[89].

Although cost-saving and environmental benefits offered by electric buses have huge potential, the current plan can only support the bus fleets across the UK to buy 4 000 buses in total, which only accounts for 10% of the entire bus fleets of the UK. To date, funds to buy 900 electric buses have been secured, which still leaves a long way to go to deliver 4 000 buses by the end of 2024[90]. Large bus operators like Craig, First, Lothian, McGill, and Parks may have the capital to purchase new electric vehicles as they provide 88% of all local bus vehicle trips in Scotland. Even so, they need an economically viable solution to transition their fleets. However, the Small and Medium-Sized enterprises (SMEs) providing the remaining 12% of all bus trips often rely on second-hand buses or end-of-life coaches but also desire to buy new buses[91]. But SMEs in Scotland face huge obstacles during bus electrification.

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[88] Department for Transport: Transport Statistics Great Britain 2020, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945829/tsgb-2020.pdf .
[89] Zemo: Low, Ultra Low & Zero Emission Buses Areas of Operation, https://www.zemo.org.uk/work-with-us/buses-coaches/low-emission-buses/areas-of-operation.htm .
[90] UK gov: UK on track to reach 4,000 zero emission bus pledge with £200 million boost , 2022-03-26, accessed 2023-0817.
[91] T. Howgego: the-future-of-the-bus-vehicle-market-in-scotland, ClimateXchange, 2022, doi:10.7488/era/2825.

First is the finance issue. A double-decker bus can cost more than £500k, and a single-decker bus costs up to £340k,[92] while second-hand diesel buses only cost as low as £12k. SMEs cannot afford to replace all their old diesel buses with new electric buses before 2032, especially since they just suffered from the COVID-19 lockdown and only carry 80% of the passengers they used to, and revenue is down[93]. The second issue is the secondhand and end-of-life buses market. The pool of vehicles in the end-of-life market could almost be halved by the mid-2030s, and the price of the mid-life buses in the market already increased due to the supply and demand imbalance. In the next ten years, the cost of purchasing second-hand electric buses for small and medium-sized enterprises will be higher due to the lack of electric buses in the second-hand market. In the worst case, although SMEs are willing to replace diesel buses as soon as possible, the supply of second-hand electric buses in the market is in short supply. Oversized onboard battery packs are another reason that may hinder their electrification progress. For example, school transport contracts are predominantly operated by SMEs and often prioritise cost and therefore attract the use of near-end-of-life vehicles. Across the UK, 750 000 school children rely on bus and coach services to get them to school[94]. School bus duty cycles are typically minimal, consisting of just two-round trips per school day, which means they get the oldest buses in the fleet. However, there will not be too many end-of-life electric coaches within the next decades, which will undoubtedly delay the electrification of buses and coaches.

Bus repowering shows great potential to speed up phasing out fossil fuel buses and extend current bus life cycles without purchasing new electric buses. If well maintained, buses with internal combustion engines can last multiple decades. However, substantial maintenance costs of the powertrain system, interior, and bodywork can threaten this long service life. Bus repowering removes the diesel engine and replaces it with a new electric powertrain. This new solution requires less maintenance, and a 10-year-old bus could remain useful for another 15 years. With the help of repowering, SMEs could avoid the effect of the shortage of second-hand electric vehicle buses on the market and the cost and lead time for purchasing new electric buses. Moreover, bus repowering allows the operator to match the vehicle battery size to the route or location, reducing the size of the battery to match the route requirement and diversity. Furthermore, most of the ordered electric buses in the UK (some supported by government investment) are manufactured by overseas companies. For instance, First Bus ordered almost 200 BYD ADL Enviro200EV single-deck and Enviro400EV double-deck vehicles in 2021,[95] and 250 electric buses from Zhengzhou Yutong were imported to the UK in 2022[96]. Bus repowering may reduce the dependence of electric buses on overseas companies and, at the same time, develop local industrial chains and jobs to help the local economy.

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[92] C. Marius: How much a London bus actually costs and why they're more expensive than Ferraris, My London, https://www.mylondon.news/news/zone-1-news/how-much-london-bus-actually-22355188 .
[93] D. Henderson: Warning over bus fare hikes if Covid grant ended, https://www.bbc.co.uk/news/uk-scotland-63087559 .
[94] BBC: Back to school: Extra buses to help get children to school, https://www.bbc.co.uk/newsround/53948414 .
[95] Move Electric: How Alexander Dennis is leading the UK's electric bus charge, https://www.moveelectric.com/e-world/how-alexander-dennis-leading-uks-electric-bus-charge .
[96] D. Laister: 250 electric buses to be introduced to UK public transport fleets after £60m funding deal success, BusinessLive, https://www.business-live.co.uk/retail-consumer/250-electric-buses-introduced-uk-25492593 .

8 Appendix C: Technical Evaluation

This chapter assesses the technical feasibility, identifies the technical challenges that arise, and how these have been overcome through detailed design and system testing, and highlights the technical considerations during the repowering process. An overview of the repowering process is covered below. It is important to note that this is the process for a new make and model. Once a solution has been certified, subsequent repowers can happen at scale and with minimal disruption to the operators, with the bus only being out of service for days.

8.1 System Requirement Capture

The activities required to understand and document the customer's needs are conducted. These inputs are then combined with existing needs from other stakeholders to derive the system-level requirements, which are eventually broken down into implementable requirements for all the different functional teams to work on. The customer needs are validated as part of an initial feasibility study, which is issued to the customer for approval to kickstart the project. This process ensures any technical challenges are identified at the earliest possible stage and overcome during the design, development and integration stages. Further detail of each stage is provided in Table 8 below.

Table 8: System Requirements Capture

Step	Description
Drive cycle capture	Speed-time curve and gradient profile of the entire bus service requirements is captured (including empty running) from preexisting telematics or by installing a data logger. This information is a critical input into the vehicle simulation stage, where the vehicle is modelled and its expected performance estimated.
User story capture	Seeks to capture the day-in-the-life of the product. All the interactions the vehicle will have during its day-to-day are documented in great depth. It is through this activity that the customer's needs are captured.
Vehicle simulation	the above-captured information is adopted to simulate the bus with the new system to find preliminary performance details.
ECM cloning	Legacy Controller Area Network (CAN) signals are studied to ensure a smooth transition to the Electronic Control Unit (ECU) when the vehicle is repowered.
Bus stripping and cleaning	The legacy parts are stripped out and recorded in a delete list.
3D scanning	The stripped engine bay is 3D scanned to inform the new Electric Propulsion Motor (EPM) design. An example Optare Solo 3D scan is shown in Figure 19.
Documentation and Review	All captured information, required documentation, and vehicle scans are reviewed.

Figure 19

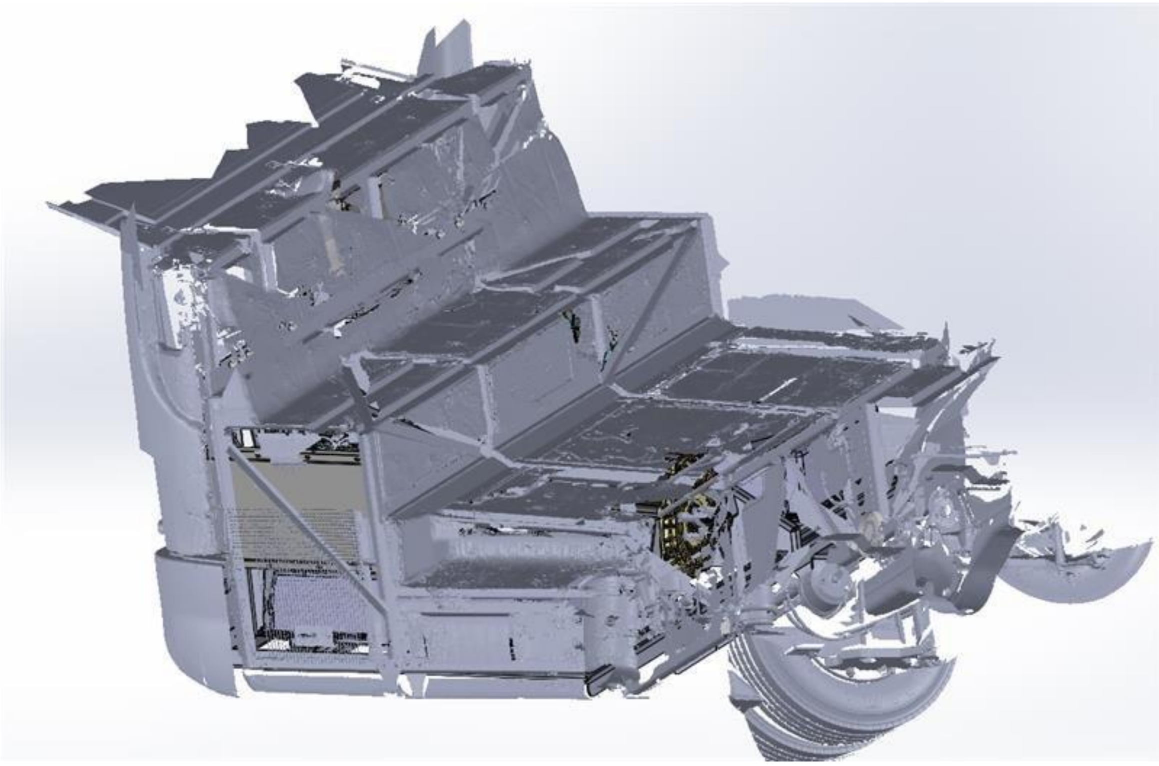

Figure 19: Optare Solo 3D Scan of the Available Space

8.2 Software Development

Software development is important to repowering because it ensures the new powertrain works together seamlessly with the rest of the bus. The overall process is outlined in Table 9 below.

Table 9: Outline of the Software Development Process

Step	Description
Functional specification	Requirements are turned into specific functions for the Vehicle Control Unit (VCU).
Technical specification documentation	This document has all the required technical details – hardware, software, programming language, database design, and sub-division into modules, each with a specific function.
Programme specification	Developers use technical specifications to produce a detailed design of their modules and their interface with other modules.
Coding	ECU is required to be coded to meet the safety requirements.

8.3 System Integration

System integration is the wider engineering process of ensuring all components work together to form a cohesive system. The selection of components is essential for this, but so are the connections between the components. This can be an iterative process, and the general process is shown in Table 10.

Table 10: Outline of the System Integration Process

Step	Description
Component procurement	Identify, evaluate and assess suppliers based on multiple criteria and order components.
LV/HV schematic	Design low-voltage and high-voltage architecture.
Integration	• Subsystem integration onto the EPM • Component integration into the cabin • EPM integration into the vehicle

8.4 Mechanical Design and Development

Using the 3D Scan, components are arranged into the space according to regulations and component specifications. An optimal packaging solution is derived considering the available packaging space, component installation requirements, and mechanical considerations derived from system-level requirements. The packaging design is shown in Figure 20. In the newly designed system, the space of the engine bay is fully utilised. The two battery packs are distributed on the left and right sides of the lower part of the engine bay. A motor is installed in the middle. Two cooling fans are installed above the battery packs to cool the engine bay. Other electronics, for example, the air conditioning system and battery management system (BMS), are installed in the rear of the engine bay.

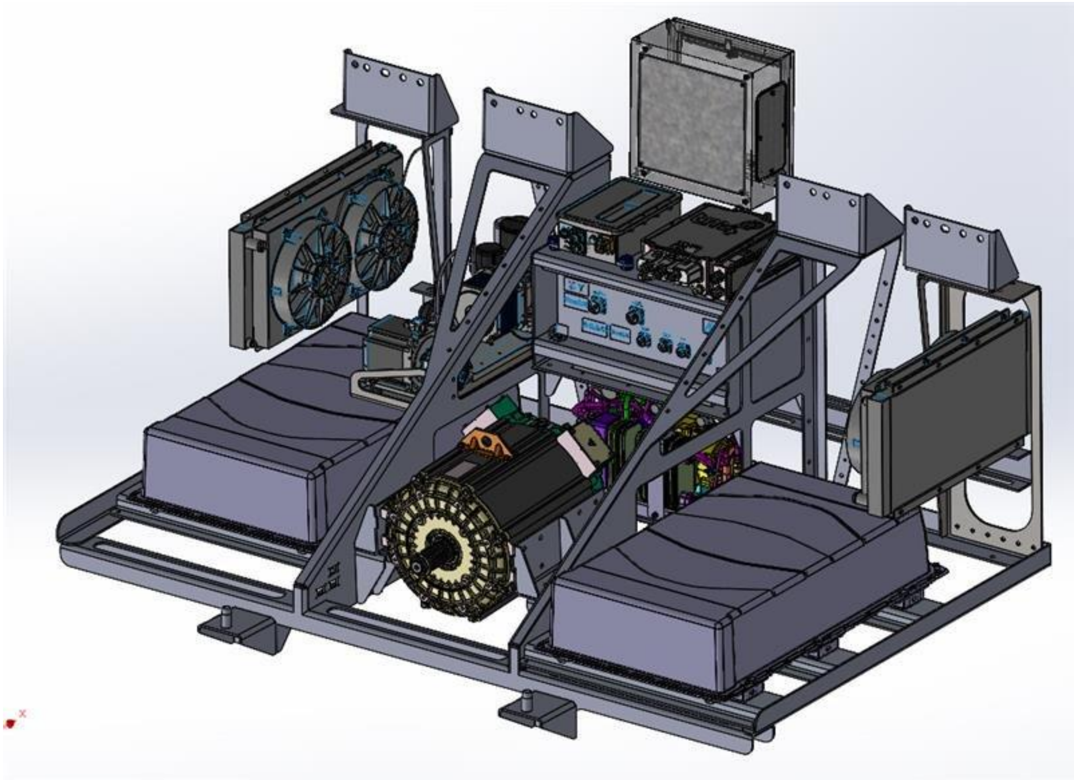

Figure 20: Packaging Design

8.5 Testing

Testing is an important step of engineering. The first time a new model is repowered, a full homologation is required to make sure that the repowered vehicle applies to relevant regulations. Once the design is homologated, further vehicles of the same time only need a test of the functionality to verify that the installation was successful.

9 Appendix D: Feasibility Analysis

9.1 Economic Analysis

The analysis presented in this sub-chapter considers the operational (including maintenance) costs of diesel, electric and repowered buses. The current capital costs of purchasing new electric buses and the asset value of the repowered buses are also presented.

9.1.1 Fuel Costs

Operating cost from a fuel cost perspective for diesel and electric buses is discussed and shown in Figure 21. The diesel price has increased dramatically since 2022, reaching £1.76/L[97]. Although its price slightly declined in early 2023, it is still higher than the average value between 2017 and 2020. Assuming the annual driven distance of a bus is 100 000 km, the annual fuel cost for a diesel bus would be £77 799 in 2023 (Fuel consumption based on ZEMO[98]). But for a repowered bus, the electricity cost for the same usage is only £26 185 (electric consumption based on SustainableBus[99]). The fuel cost saving is £51 614, and the saving is even more in 2022, which is £57 515. Even if diesel prices return to 2017-2021 levels, the annual fuel saving is still over £40 000. Changes in operating fuel costs scale linearly with usage: the more a bus is used, the more can be saved by electrification.

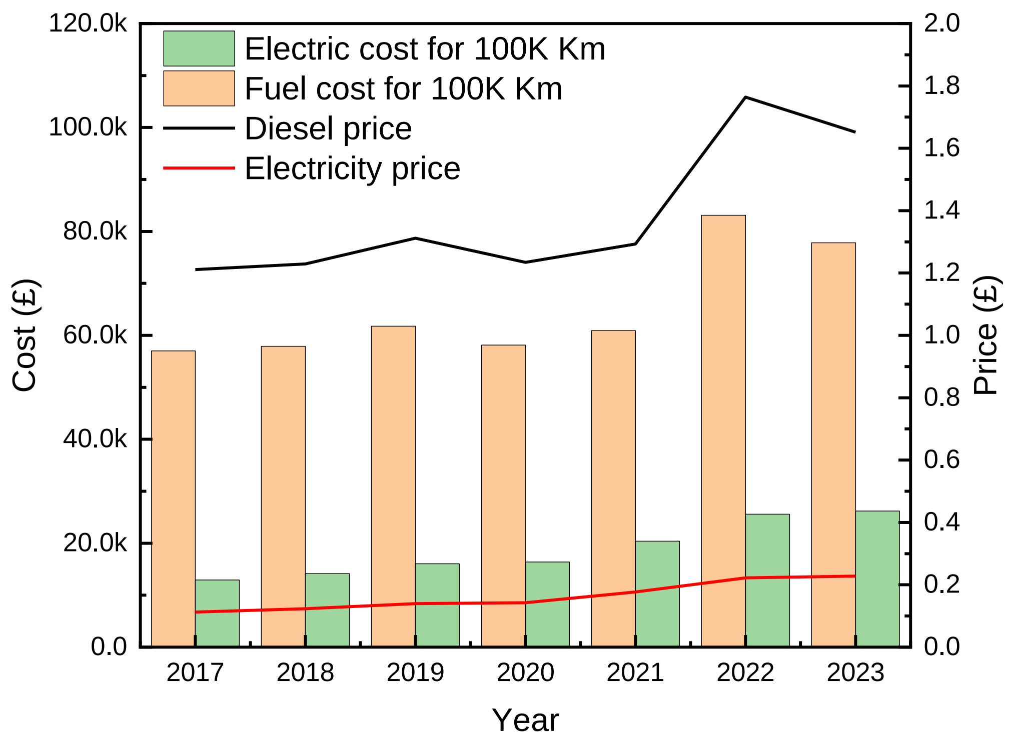

Figure 21: Variation of Diesel and Electricity Costs from 2017 to 2023.

[97] UK gov: Weekly road fuel prices, https://www.gov.uk/government/statistics/weekly-road-fuel-prices .
[98] Zemo: Low Emission Bus Scheme Certificate , 2017, https://www.zemo.org.uk/ugc-1/uploads/pageblocks/1460/b7341eff26c24897d77783ab355bee7d.pdf .
[99] SustainableBus: Electric bus energy consumption in ViriCiti's spotlight. A report on e-bus performances, https://www.sustainable-bus.com/news/electric-bus-consumption-energy-report-viriciti/ .

9.1.2 Subsidies: NSG and BSOG

The Bus Service Operators' Grant (BSOG) was a subsidy paid to bus operators for running routes. It is a devolved competence, and Scotland has replaced BSG with the Network Support Grant (NSG) in Scotland. While the BSOG used to pay more for low-emission vehicles (LEVs), the NSG pays a flat rate of 14.4p/km to bus operators in Scotland, although legacy commitments for buses purchased under previous schemes are still paid. This means that low and zero-emission buses must be commercially viable without additional subsidies.

9.1.3 Maintenance Cost

Bus maintenance can be divided into two aspects: internal and external. Regarding the maintenance of the external body, including tyres, lights, seats, windows, etc., there is no significant difference between diesel buses and repowered buses, as repowered buses will keep using those components. However, the difference in the maintenance of the internal components is significant. Poor maintenance of internal diesel components can result in a component or part failure that leads to further problems for the entire vehicle. For example, the fuel injectors of the diesel engine are one of the most important parts that need to be maintained regularly to avoid a catastrophic chain of events. However, the propulsion system in an electric bus relies on a much simpler mechanical design. There is no longer a need for the exhaust system, distributor, starter, clutch, drive belts, hoses, spark plugs, catalytic converter, or fuel tank full. An estimate based is shown in Figure 22[100].

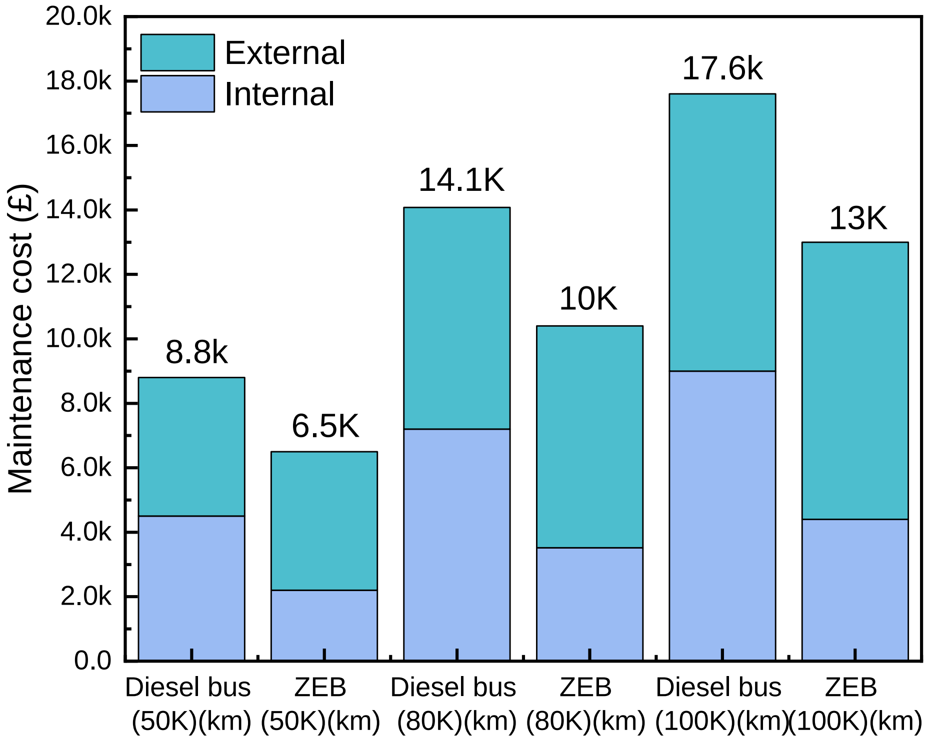

Figure 22: Maintenance Costs for Diesel Buses and Repowered ZEBs

[100] C40-Cities: UNDERSTANDING ZERO-EMISSION BUS MAINTENANCE, https://cff-prod.s3.amazonaws.com/storage/files/B8G9Z1M19Edh4sOvRWNRhpbhMfS3G9NtleSk1lEQ.pdf .

9.1.4 Increased Asset Value

For an end-of-life diesel bus, specific upgrades may be required. Sometimes, it is not worth the effort and time to fix due to irreparable damage to core components. At this point, to keep the vehicle running, an engine replacement may be required. Repowering avoids these costs, so the net cost of repowering becomes even more compelling. Compared to buying a new ZEB, bus repowering aims to use as many existing components as possible from the old diesel bus, such as the bus chassis, bus body frame, and bus interior design. According to First Bus's recent purchase, the price of a new ZEB is around £410k[101]. However, bus repowering will only cost 1/3 of buying a new ZEB, including a new powertrain[102] and a battery pack[103]. Of course, the result of repowering is a used electric bus, and the market for those is so small that it is nearly impossible to establish a fair market value. But the utility benefit is significant, and given the 8-year battery warranty, there should be no major repairs necessary for eight years. In contrast, a conventional bus requires a full overhaul every six years or 400 000 km[104]. This means that electric buses will depreciate differently from conventional buses.

9.1.5 AdBlue Consumption

AdBlue™ consumption refers to the amount of diesel exhaust fluid (DEF) or AdBlue that a diesel-powered vehicle uses to reduce harmful NOx emissions. AdBlue is a solution containing urea injected into the vehicle's exhaust system. When the AdBlue comes into contact with the hot exhaust gases, it breaks down into ammonia, which then reacts with the NOx in the exhaust to convert it into harmless nitrogen and water. Usage for commercial vehicles will depend on the tonnage of the vehicle – rates usually range from 3-6% of diesel consumption. Bus consumption of AdBlue usually equates to around 5% of diesel consumption. However, this depends on the vehicle's usage pattern – city buses typically use 20-30 litres each month, compared to 40 litres per month for buses operating over longer, cross-country routes[105]. The prices of AdBlue vary with the quantities of a one-time purchase. Prices start from 56p per litre when purchasing high quantities of 5L containers, while other packaging may cost 71p per litre[106]. Most SMEs only operate light commercial buses (up to 18 tonnes), and the AdBlue cost could vary from £16.8/week to £319/week depending on the litres of diesel used per week and AdBlue quantities purchased one-time. A ZEB does not need AdBlue.

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[101] Intelligent Transport: First Bus places one of the UK's largest ever electric bus orders, https://www.intelligenttransport.com/transport-news/139042/first-bus-uks-largest-ever-electric-bus-orders/ .

[102] Kleanbus: Kleanbus Reveals Modular Platform Capable of Repowering any bus from diesel to electric, https://kleanbus.com/2022/12/15/kleanbus-reveals-modular-platform-capable-of-repowering-any-bus-from-diesel-to-electric/ .

[103] EERE: Electric Vehicle Battery Pack Costs in 2022, https://www.energy.gov/eere/vehicles/articles/fotw-1272-january-9-2023-electric-vehicle-battery-pack-costs-2022-are-nearly .

[104] GlobalSpec: Fuel Cell Bus Meets Diesel Engine Life Expectancy, https://insights.globalspec.com/article/5862/fuel-cell-bus-meets-diesel-engine-life-expectancy .

[105] Online Lubricants: AdBlue Consumption Guide, https://www.online-lubricants.co.uk/blog-post/adblue-consumption-guide .

[106] QUS: AdBlue Prices, https://www.qus.uk/adblue-prices/, accessed 2023-0817.

9.1.6 Aftertreatment Maintenance

The Diesel Particulate Filter (DPF) is a filter to reduce the amount of particulates in the exhaust. Cleaning involves aqueous cleaning technology and specialist chemicals to reduce soot emissions. It is important for reducing the emissions of particulate matter (PM) from diesel engines. PM is a type of air pollution that can have serious health effects, including respiratory problems and cancer. Diesel engines produce PM as a byproduct of the combustion process. DPFs are designed to capture and remove this particulate matter from the exhaust gas before it is released into the atmosphere. They work by trapping PM in a honeycomb-like structure made of ceramic or metal fibres, which allows exhaust gases to pass through while trapping the particulate matter. Over time, the trapped PM accumulates, and the filter needs to be cleaned or regenerated to prevent it from becoming clogged.

Selective Catalytic Reduction (SCR) is an advanced emissions control technology to reduce nitrous oxide (NOx) levels. While it does require a reducing agent (AdBlue), it is otherwise mostly maintenance-free.

Therefore, proper maintenance of DPFs and SCRs, such as cleaning or replacement, is crucial for optimal performance and longevity. Generally, DPFs must be cleaned or replaced every 150 000 to 250 000 km or every three to five years, whichever comes first[107]. The cost may be different depending on different situations and annual driving ranges. Details are shown in Figure 23[108].

Assuming the average frequency for cleaning DPFs is 200 000 km, for a EURO IV bus with an average annual driven distance of 50 000 km, the DPF annual maintenance cost is £131, while for a EURO VI bus and a EURO IV to VI bus with SCR system, the annual maintenance cost is £109.8 and £209 respectively. The higher the usage, the higher the DPF or SCR maintenance cost, as it is much easier to meet the maintenance requirements. The maintenance cost is higher for those buses with SCR systems than pure DPF due to its complicated system. Furthermore, if the DPFs or SCRs are not maintained well, the price range for replacement can be between £750 to £3 000, including labour costs[109].

[107] MYREE: Diesel Particulate Filters: Everything You Need to Know About DPF Filters, https://www.myteeproducts.com/blog/ultimate-guide-to-dpf-filters/ .
[108] AESC: What does a particle filter cleaning cost? https://advanpure.com/en/2021/05/04/what-does-a-particle-filter-cleaning-cost/ .
[109] Cardoc: DPF Replacement Cost, https://car-doc.co.uk/dpf-replacement-cost/ .

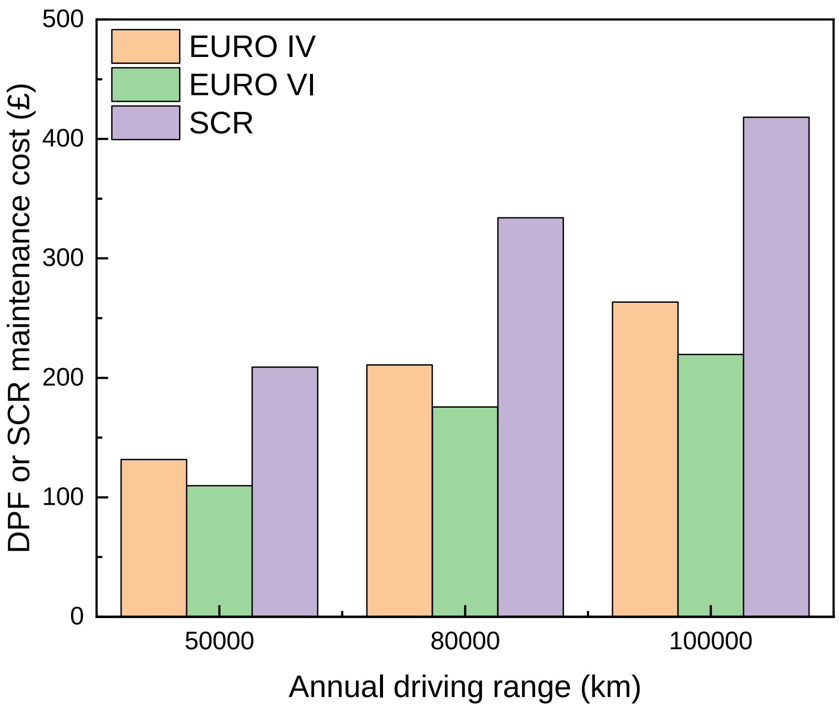

Figure 23: Maintenance Cost of DPF and SCR Over Driving Distance

9.1.7 Labour Demand

Labour is an important part of operating a bus fleet. There are four types of labour in a bus fleet: Drivers, maintenance and repair technicians, dispatchers and supervisors, and administrative staff. Maintenance and repair technicians are critical for a bus fleet and are responsible for keeping the buses in good working order. The number of technicians required will depend on the size of the fleet, the age and condition of the buses, and the level of preventive maintenance practices in place. The number of maintenance and repair technicians required for a bus fleet will depend on the fleet size and the maintenance level required. A larger fleet will require more technicians to ensure all buses are properly maintained and repaired promptly. In addition, the age and condition of the buses will also impact the level of maintenance required, which may impact the number of technicians needed.

ZEBs generally possess simpler propulsion systems with fewer moving parts, requiring less regular mechanical maintenance than a traditional diesel bus. Based on the data from Leslie Eudy[110], an estimation of the labour implications for a fleet of repowered buses to electric buses is conducted and shown in Figure 24. For an SME that operates buses with an average annual driven distance of 50 000 km, 1 FTE can cover 10.3 diesel buses but 12.7 repowered BEBs. Similarly, if the annual driven distance is about 80 000 km, 1 FTE can cover 23% more BEBs compared to maintaining diesel buses. Assuming an SME owns 25 buses in total, and the annual salary for a bus technician is £33 500[111]. As shown in Figure 24, SMEs with 25 buses can

[110] M. J. L. Eudy: Zero-Emission Bus Evaluation Results: County Connection Battery Electric Buses, National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy19osti/72864.pdf .
[111] Talent: Bus Mechanic average salary in United Kingdom, 2023, https://uk.talent.com/salary?job=bus+mechanic, accessed 2023-0817.

save £15 615 per year in hiring maintenance and repairing technicians, and the advantage increases with the increase in bus usage.

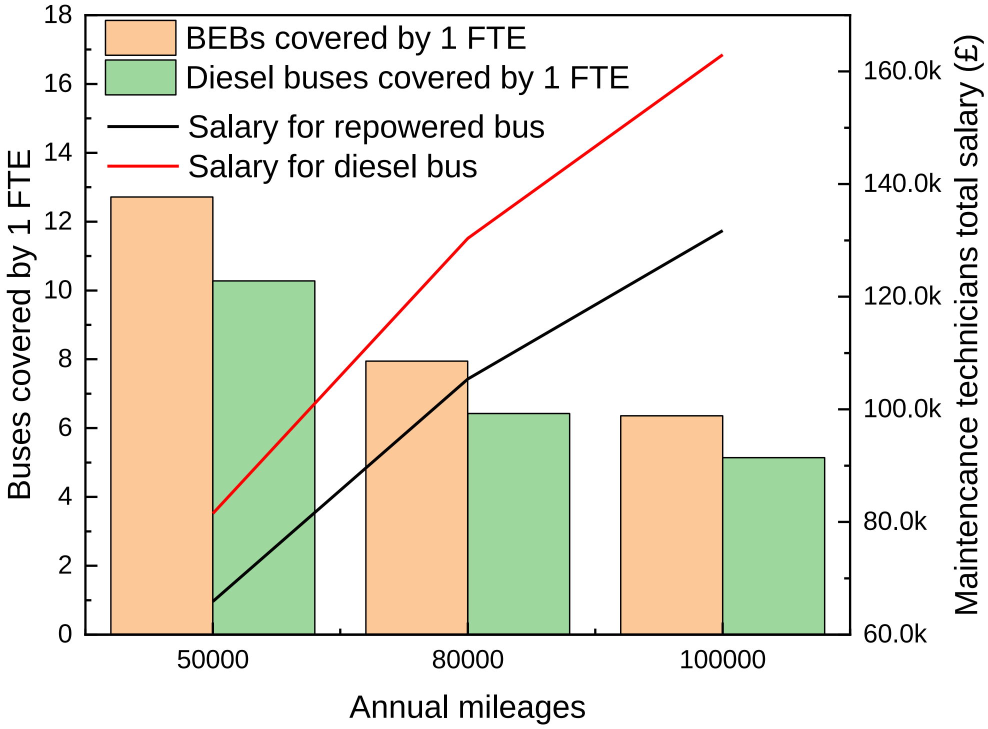

Figure 24: Labour Implications For Repowering Buses

9.2 Social Contribution

This sub-chapter discusses the social contribution brought by bus repowering, such as job creation, benefits for the local supply chain, policy promotion, and impact on disadvantaged communities. Research and information have been gathered and updated throughout this project.

9.2.1 Job Creation

Bus repowering refers to upgrading or retrofitting older buses with newer and more efficient engines or electric motors. The process of bus repowering can create jobs in several ways. Firstly, there is a need for skilled labour to perform the actual repowering work, which involves the removal of the old engine or motor and the installation of the new one. This requires trained technicians with experience working with engines, transmissions, and other vehicle systems. Additionally, the production and installation of new engines or electric motors require manufacturing and supply chain workers. These workers are involved in producing components and materials needed for the new engines or motors, as well as installing these components in the buses. Furthermore, there is a need for project managers, software and mechanical engineers, and other support staff who can oversee and coordinate the bus repowering process. These individuals are critical in ensuring the project is completed on time, within budget, and to the required quality standards. For this repowering project, at least two experienced, skilled labourers are required to retrofit one existing diesel bus, and there is also a need for additional support staff such as project managers, software and mechanical engineers, and administrative staff to oversee and coordinate the project. As a result, at least eight labourers are necessary for the initial solution for a distinct vehicle make and model. Once there is a solution in place for a make and model, this can be applied to tackle hundreds of buses in a short space of time, and the labour switches to the manufacturing and assembly of the EPM, low voltage and high voltage harnessing and the subsequent fitment to the vehicles. It is important to note that repowering a bus is a complex process that requires specialised knowledge and expertise. The existing workforce of operators can be trained on the assembly side of things so that the EPM can be applied on-site, and they are equipped to tackle first-line maintenance requirements in the future. This upskilling of the existing workforce is appealing to operators looking to redeploy their, until now, predominantly ICE-based skillsets. The exact number of skilled labourers required will depend on the project's specific needs. Hence, it will create massive opportunities for local labour markets directly and indirectly.

9.2.2 Benefits for Local Supply Chain

The transition from manufacturing diesel buses to zero-emission buses (ZEBs) necessitates substantial modifications to the interconnected systems offered by primary suppliers and for components and systems in the broader supply network, particularly concerning energy systems (such as batteries, fuel cells, and hydrogen storage), power electronics, thermal management systems, and software systems. The current biggest BEBs supplier is ADL&BYD, estimated to provide over half of the electric buses in 2022[112]. BYD, an overseas supplier, provides their products' core battery and energy systems. One of the disadvantages of using overseas supply chains is uncertainty control, which peaked during COVID-19. Repowering buses can support local supply chain development, reducing delivery uncertainty and shortening delivery time whilst ensuring the money and job creation circulates within the local region rather than being sent overseas. A recent study revealed that there is little current supply of UK components that meet the market requirements as the market prefers adopting matured solutions provided by Tier 1 OEMs[113]. However, this does not mean the UK cannot meet these requirements. According to the power electronics, motors, and drives (PEMD) sector's responses, production-ready solutions in other market segments could be adapted. Bus repowering can allow existing or new local supply chains to design and build subsystems based on their products. In addition, bus repowering requires new skills and expertise, and the development of training and education programs can create job opportunities and support the growth of local supply chains. By investing in training and education programs, ZEB operators and bus repowering solution providers can build local expertise and create a workforce equipped to support the growth of the ZEB industry.

9.2.3 Policy Promotion

Bus repowering will accelerate bus electrification and decarbonisation, which will help the government to meet its economic, social, and environmental targets.

Bus repowering can play a significant role in supporting economic policy in Scotland. One of the main barriers to transitioning to ZEBs for bus fleets, especially SMEs, is the upfront cost of

[112] ADL&BYD: 1000th BYD ADL electric bus joins Stagecoach's fleet in Aberdeen, https://www.evbus.co.uk/1000th-byd-adl-electric-bus-joins-stagecoachs-fleet-in-aberdeen/ .

[113] Transport Scotland: Impacts on the supply chain, https://www.transport.gov.scot/publication/meeting-trials-and-supply-chain-zero-emission-truck-taskforce-23-june-2022/impacts-on-the-supply-chain/ .

purchasing a ZEB. However, bus repowering can provide an opportunity for SMEs so that they do not need to pay a huge upfront cost and save operating costs. Those economic advantages will stimulate social and economic vitality and keep SMEs alive during transport electrification. Repowering can enable fleets to be converted to zero-emission in a substantially quicker timeframe (and certainly more economically viable) than purchasing new ZEBs. With repowering expected to result in a bus being out of service for less than two weeks, the disruption is minimal, and scheduling constraints are manageable. Furthermore, bus repowering can also create new job opportunities in Scotland's clean energy sector, such as manufacturing, installation, and maintenance of ZEBs and charging infrastructure. This can help to support local economic growth and job creation. Moreover, Scotland is known for its natural beauty and attracts many tourists yearly. The use of ZEBs in tourist transportation can help support sustainable tourism, which is increasingly important to the country's economy, and create more stable and predictable economic conditions in the long run.

For social policy, the Scottish Government has set a goal for 2030 to establish a Scotland that is fair, intelligent, and inclusive, where individuals can experience a sense of belonging, where fair employment contributes to the growth of enterprises and job creation, where poverty levels rank among the lowest in Europe, and where all individuals have equitable access to opportunities[114]. For many people, buses provide them with access to core services like healthcare and education, especially for the elderly and disabled people. Also, buses connect rural areas and urban areas or jobs and homes. This benefit can be magnified by bus retrofitting. Bus repowering can provide cost savings for SMEs, allowing them to expand their operating routes to evenly cover more areas. As a result, bus repowering has the potential to play a key role in supporting new housing developments if it can be extended and fully integrated within the planning of new sites. In addition, bus retrofits could accelerate bus electrification, which would significantly reduce operating costs for SMEs, further reduce bus travel costs, and improve equal opportunity for all. Furthermore, local job creation brought by bus repowering may reduce the poverty rates in Scotland.

For environment policy, with the help of bus repowering in the electric bus transition, not only large bus operators but SMEs can also achieve the net zero goal very soon so that Scotland can reduce its reliance on fossil fuels and move towards achieving its goal of net zero emissions. Moreover, electric buses can help reduce noise and air pollution in urban areas, positively impacting public health and well-being.

9.2.4 Impact on Disadvantaged Communities

By accelerating the transition to electric buses, bus repowering can help improve air quality in these communities, which are often located near busy roads and experience higher pollution levels. Reducing emissions from electric buses can improve public health and quality of life, particularly for vulnerable populations such as children and the elderly. Also, cost saving brought by bus repowering to the bus fleets can help them improve their service, which can improve the travel experience of a passenger who lives in disadvantaged communities. Furthermore, bus repowering can allow bus operators to extend their routes and lower ticket

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[114] Gov Scot: FAIRER SCOTLAND ACTION PLAN, 2016, https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2016/10/fairer-scotland-action-plan/documents/00506841-pdf/00506841-pdf/govscot%3Adocument/00506841.pdf .

prices to benefit disadvantaged communities. In addition, adopting electric buses can create economic opportunities and job creation in these communities. This can include roles in the installation and maintenance of charging infrastructure and in the manufacturing of electric buses and components.

9.3 Environmental Benefits

This sub-chapter assesses the direct reductions in CO_2, NO_x and noise compared to continuing to use diesel buses. It also considers the entire vehicle life cycle by tracing the indirect CO_2 reduction (CO_2 produced when manufacturing raw materials) compared to purchasing new electric buses.

9.3.1 CO_2 Reduction

One of the main advantages of repowering a bus is CO_2 reduction. The well-to-wheel (WTW) CO_2 emissions of different types of buses are concluded in Figure 25. A EURO IV bus could save 1324g/km WTW CO2eq if repowered to a ZEB[115]. Due to the strict emission limits of EURO VI, the improvement provided by bus repowering is lower than EURO IV. However, bus repowering can still reduce 664g/km WTW CO_{2eq}. In addition to the operating CO_2 emissions, there are also massive CO_2 emissions caused by bus manufacturing. The carbon intensities used for the battery production are 119kg CO_{2eq}/kWh[116]. Based on the Volvo diesel and electric bus data[117], the CO_2 footprint of a new electric bus is 150 tonnes CO_{2eq}, and the electric powertrain and battery account for 6.7% and 30%, respectively.

On the other hand, the operational CO_2 footprint of the traditional ICE powertrain is 10 tonnes CO_{2eq}, and most of this can be avoided by electrification. At 80 000 km per year, the break-even point for a new ZEB is 13.5 years compared to an existing conventional bus and only 2.3 years compared to a new EURO VI diesel bus.

Bus repowering only generates about 60 tonnes of CO2eq emissions, so it amortises in less than half the time. Therefore, repowering buses is a good way for SMEs to fulfil social and environmental responsibilities quickly and cheaply.

[115] Zemo: THE LOW EMISSION BUS GUIDE, 2016, https://www.zemo.org.uk/assets/reports/LowCVP%20LEB%20Guide%202016%20interactive%20V3.pdf .

[116] A. Nordelöf, M. Romare, J. Tivander: Life cycle assessment of city buses powered by electricity, hydrogenated vegetable oil or diesel, Transportation Research Part D: Transport and Environment, vol. 75, pp. 211-222, 2019, doi:10.1016/j.trd.2019.08.019.

[117] K. W. Lie, et al: The Carbon Footprint of Electrified City Buses: A Case Study in Trondheim, Norway, Energies, vol. 14, no. 3, p. 770, 2021. https://www.mdpi.com/1996-1073/14/3/770 .

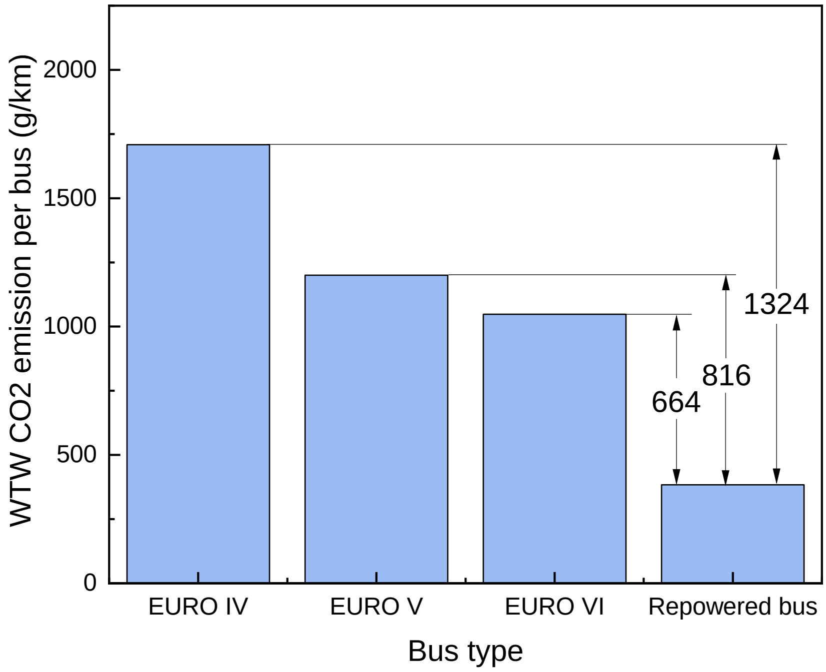

Figure 25: Diesel Bus and Repowered Bus WTW Operating CO2 Emissions

9.3.2 NOx Reduction

NOx emissions can harm human health and the environment, resulting in significant costs related to healthcare, crop and forest damage, and reduced ecosystem productivity. Therefore, reducing NOx emissions can lead to societal damage cost savings by preventing these negative effects. The savings associated with NOx emissions reduction depends on the extent of the reduction and the severity of pollution in the area. Reducing NOx pollution has the potential to result in significant cost savings by avoiding the negative impacts of air pollution. The operating NOx emissions of city buses and the indirect NOx emissions difference between buying a new ZEB and repowering a diesel bus are shown in Figure 26. The operating NOx emissions for typical diesel IV, V, and VI buses are 9.53 g/km, 11.34 g/km, and 0.33g/km, respectively[118]. However, as there is no tailpipe emission from the repowered bus and new ZEB, the operating emissions for those two types are 0. According to the analysis, in the case of small and medium-sized enterprises (SMEs) operating buses with an annual driven distance of 80 000 km, the repowering of a diesel VI bus would prevent 26 kilograms of NOx emissions. Similarly, if a diesel V bus is repowered, it has the potential to prevent up to 904 kilograms of NOx emissions. These findings suggest that the repowering of diesel buses could be an effective measure for reducing harmful NOx emissions in the transportation sector.

In addition, bus repowering also has benefits compared to buying a new ZEB as the frame and body of the old diesel bus is continued to be used. A typical bust without an electric powertrain is normally 13 tonnes[119]. The steel and aluminium-alloy ratio is considered as 2:3 based on the

[118] Unilink: Travel by bus to help improve our city's air quality, https://www.unilinkbus.co.uk/travel-bus-help-improve-our-citys-air-quality .
[119] M. Manning: Metro's Battery Electric Bus Overview https://assets.ctfassets.net/ucu418cgcnau/7qMYdhgNMsmkgCUGGukWmQ/8aa892a5e4190e4955c8f88cf0da14fc/7_Bus_and_Truck_Working_Council_October_2018_Metro___s_Battery_Electric_Bus_Overview.pdf .

design in Fu[120]. To estimate the environmental impact of repowering, we referred to the research conducted by Wang[121] and Abdollahi[122], which analysed the NOx emissions during steel and aluminium production, respectively. Based on our calculations, Figure 26 illustrates that repowering a bus could potentially prevent approximately 16.8 kg of NOx emissions compared to purchasing a new ZEB.

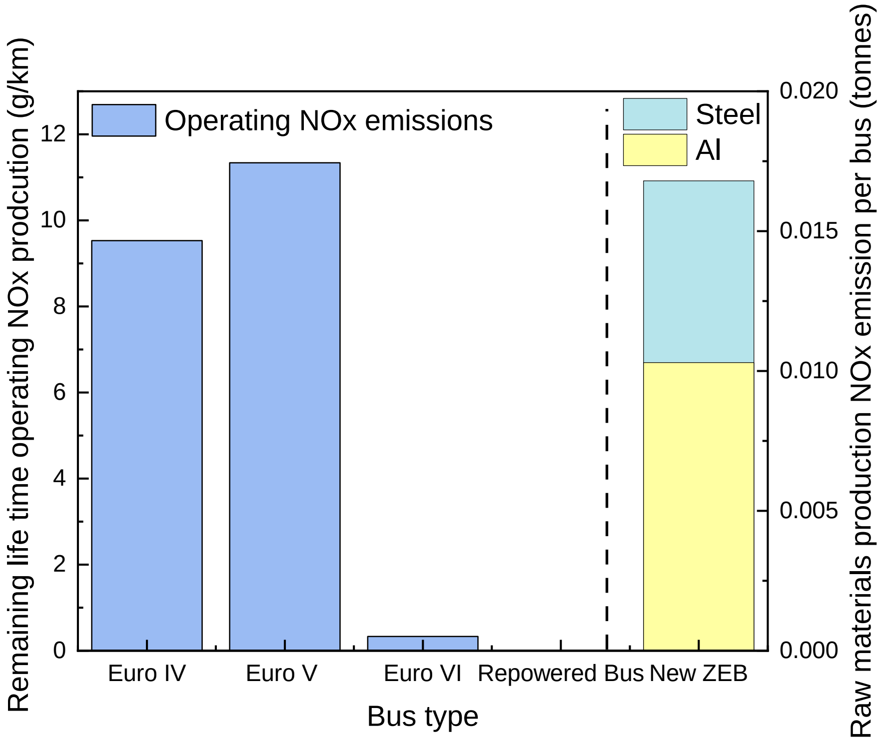

Figure 26: NOx Emissions Saving of City Buses

Based on the same operating assumptions mentioned above, the NOx saving cost for an end-of-life bus is discussed in

Table 11. By repowering EURO IV and V buses to ZEBs, significant cost savings can be achieved over the remaining lifetime of the vehicle, even when considering just a single vehicle. As a result, repowering an end-of-life diesel bus to a ZEB can lead to high NOx savings costs, resulting in net savings even after accounting for the repowering cost. This approach provides a cost-effective solution for SMEs to reduce their environmental impact. Compared to buying a new ZEB, repowering a bus can contribute to a NOx emission cost saving of £145 per vehicle

[120] C. L. Fu, et al: Design optimization of a newly developed aluminum-steel multi-material electric bus body structure, Structural and Multidisciplinary Optimization, vol. 60, no. 5, pp. 2177-2187, 2019, doi:10.1007/s00158-019-02292-w.
[121] X. Wang, et al: A unit-based emission inventory of SO2, NOx and PM for the Chinese iron and steel industry from 2010 to 2015, Science of The Total Environment, vol. 676, pp. 18-30, 2019, doi:10.1016/j.scitotenv.2019.04.241.
[122] J. Abdollahi et al: Environmental impact assessment of aluminium production using the life cycle assessment tool and multi-criteria analysis. Ann Environ Sci Toxicol 5(1): 059-066, 2021, doi:10.17352/aest.000038.

based on the industry rate, and the value will be huge if much more bus fleets decide to repower their old diesel bus instead of buying a new ZEB.

Table 11: NOx Emissions Cost Saving (£) per Vehicle

Bus original type	NOx damage cost (£/tonne)[123]	Annual driven distance (km)	Remaining years	Cost saving from NOx reduction (£)
Diesel EURO IV	11 682	80 000	13.5	120 236
Diesel EURO V	11 682			143 072
Diesel EURO VI	11 682			4 163
New ZEB	8 635 (Industry rate)	/	/	145

9.3.3 Particulate Matter Reduction

Particulate Matter (PM) is a complex mixture of small, solid, and liquid particles in the atmosphere. PM is comprised of various components, such as dust, dirt, soot, and smoke. The size of the particles is a crucial determinant of their health impacts, with smaller particles posing greater risks to human health. PM is classified according to its size, with PM_{10} particles being those with a diameter of 10 um or less and PM2.5 particles having a diameter of 2.5 um or less. These minuscule particles can penetrate deep into the lungs and cause a wide range of health issues, including respiratory and cardiovascular diseases and lung cancer. Old diesel buses and school coaches operated by SMEs may contribute to higher health risks next to bus stops and the bus route. Children are more susceptible than adults to the adverse health effects of air pollution, so this is especially a concern for school buses.

Bus repowering can solve the bus PM emissions from the tailpipe entirely and even reduce the PM emissions caused during the production of raw materials. Details are shown in Figure 27, with different sources for EURO IV[124], EURO V[125], and EURO VI[126]. If repowering a EURO IV diesel bus, 0.044g PM emission could be saved per kilometre. Although there is no operating PM emissions difference between repowering a bus and buying a new ZEB, from raw materials production perspective, as bus repowering only needs to replace the powertrain of a diesel bus, 0.0612 tonnes of PM emissions could be saved from manufacturers. Due to the negative effects on human health and the environment caused by PM emissions, costs for dealing with those outcomes are significant. The health costs of PM are extensive and include premature mortality, hospitalisations, medical expenses, and lost workdays due to illness. The economic costs of PM include increased healthcare costs, reduced productivity, and decreased quality of life. The environmental costs include damage to ecosystems and reduced agricultural yields due to reduced sunlight and changes in precipitation patterns. Therefore, as shown in Table 12,

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[123] Ricardo: Air Quality damage cost update 2023 –FINAL Report, https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2301090900_Damage_cost_update_2023_Final.pdf .

[124] Defra: Particulate Matter in the United Kingdom, https://uk-air.defra.gov.uk/assets/documents/reports/aqeg/ch4.pdf .

[125] Transport for London: TfL bus fleet - emissions standards, https://www.london.gov.uk/who-we-are/what-london-assembly-does/questions-mayor/find-an-answer/tfl-bus-fleet-emissions-standards .

[126] Transport for London: In service emissions performance of Euro 6/VI vehicles, 2015, https://content.tfl.gov.uk/in-service-emissions-performance-of-euro-6vi-vehicles.pdf .

with the help of bus repowering, great PM emissions cost savings could be achieved. It should be noted that the PM damage cost saving from repowering a diesel bus rather than buying a new ZEB is even higher than continuing to operate a EURO IV bus for 13.5 years with an annual driven distance of 80 000 km. Hence, it is reasonable and necessary for SMEs to repower more diesel buses instead of buying new ZEBs from the PM societal cost reduction perspective.

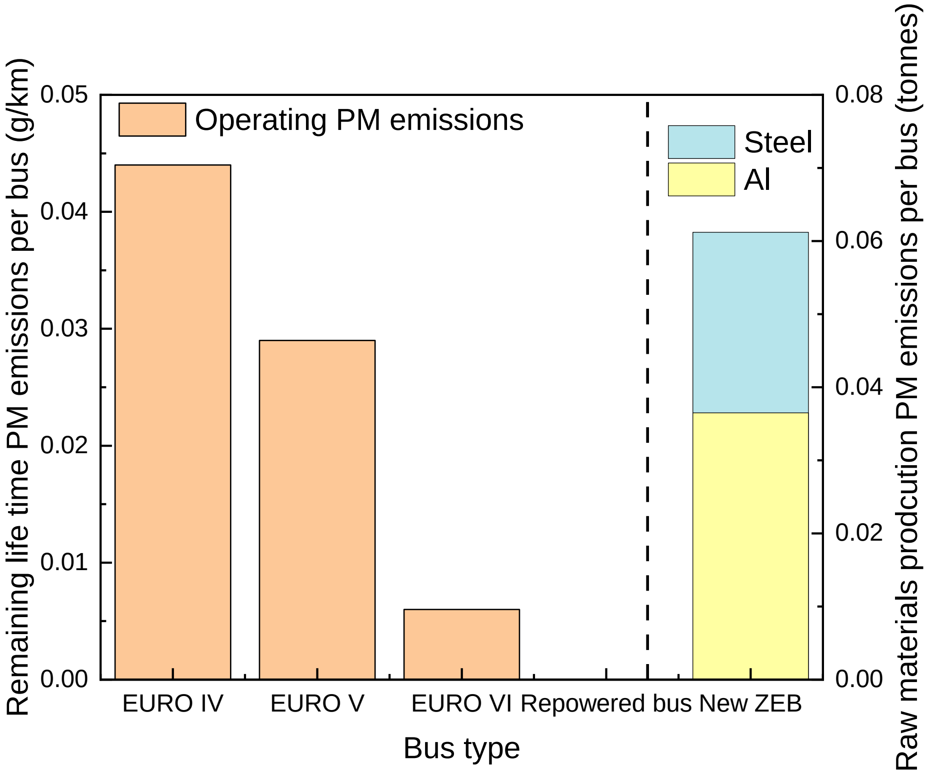

Figure 27: PM Emissions Saving of City Buses

Table 12: PM Emissions Cost Saving (£) per Vehicle

Bus original type	PM damage cost (£/tonne)	Annual driven distance (km)	Remaining years	Cost saving from PM reduction (£)
Diesel EURO IV	84 548	80 000	13.5	4 018
Diesel EURO V				2 648
Diesel EURO VI				548
New ZEB	76 354 (Industry rate)	/	/	4 672

9.3.4 Noise Reduction

Bus noise is an umbrella term encompassing all audible emissions from a bus, including the sound produced by its engine, tyres, hydraulic system, and ventilation system. The magnitude of noise generated by a bus is contingent upon diverse factors such as the bus's age and state of repair, the type of engine utilised, the velocity at which the bus is being driven, and the condition of the road. The adverse effects of bus noise are manifold, ranging from discomfort for passengers to potential health risks for individuals inhabiting or working near bus routes. The deleterious consequences of prolonged exposure to high levels of bus noise may include hearing impairment, heightened stress levels, and other related health issues. Despite noise type approval limits being in force since 1970, there has been no tangible reduction of noise emissions under real driving conditions for road transport; only 2 to 4 dBA reduction was achieved for heavy-duty vehicles[127]. However, repowering buses can provide an opportunity to further improve the noise performance of buses. The noise improvement is shown in Figure 28, based on measurements of diesel bus noise[128] and repowered bus noise[129]. The noise improvement of the repowered bus could be 10.6 dBA compared to a conventional diesel bus under a speed of 30 km/h, which is higher than the achievement before. Although the improvement decreases with the increase of the speed, 5.6% of the noise reduction still can be achieved under 50 km/h.

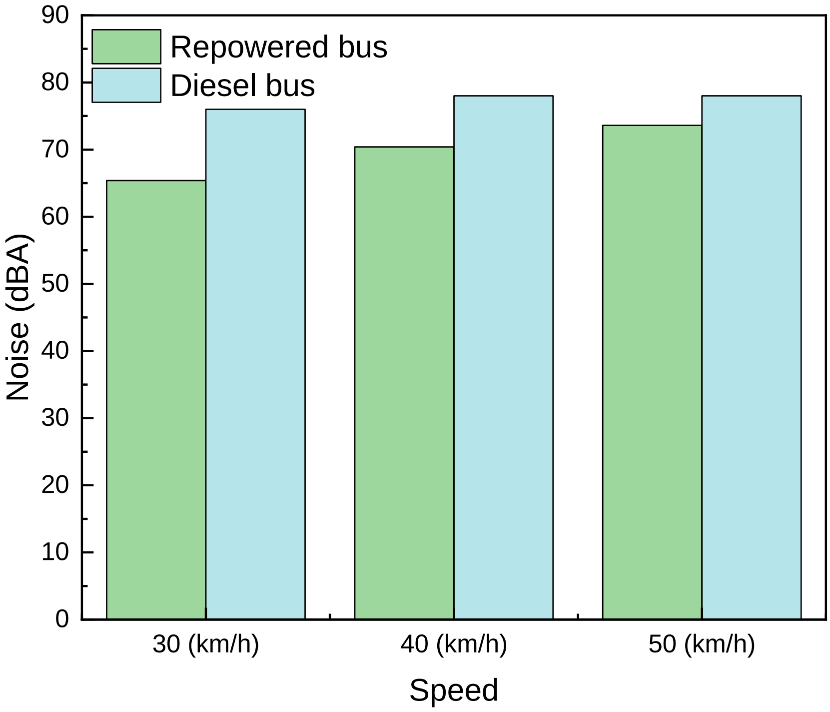

Figure 28: Bus Repowering Noise Improvement

As noise cannot be eliminated from the source side, significant upfront costs should be involved to reduce the daily noise. For instance, installing soundproof windows and doors in a residential building may cost several thousand pounds. In addition to the cost of materials and installation, other factors such as maintenance, energy usage, and compliance with local noise regulations may also affect the overall cost of noise reduction measures. Due to the noise improvement of bus repowering, significant noise reduction costs can be expected. The noise cost reduction of a repowered bus is shown in Figure 29[130]. Assuming repowering a diesel bus

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[127] L.C. den Boer, A. Schroten: Traffic noise reduction in Europe, Delft, 2007, https://www.transportenvironment.org/wp-content/uploads/2021/05/2008-02_traffic_noise_ce_delft_report.pdf .

[128] F. Laib, A. Braun, and W. Rid: Modelling noise reductions using electric buses in urban traffic. A case study from Stuttgart, Germany, Transportation Research Procedia, vol. 37, pp. 377-384, 2019, doi:10.1016/j.trpro.2018.12.206.

[129] S. Borén: Electric buses' sustainability effects, noise, energy use, and costs, International Journal of Sustainable Transportation, vol. 14, no. 12, pp. 956-971, 2020, doi:10.1080/15568318.2019.1666324.

[130] VTPI: Transportation Cost and Benefit Analysis II – Noise Costs, 2022, https://www.vtpi.org/tca/tca0511.pdf .

that can be kept operating for 13.5 years with an annual driven distance of 80 000 km, a repowered bus could save £14 040 in noise pollution if operating in an urban area. Furthermore, a 41.2% noise cost reduction could be achieved if the repowered bus operates in a rural area. Therefore, bus repowering can significantly reduce noise and increase the noise cost reduction at the same time.

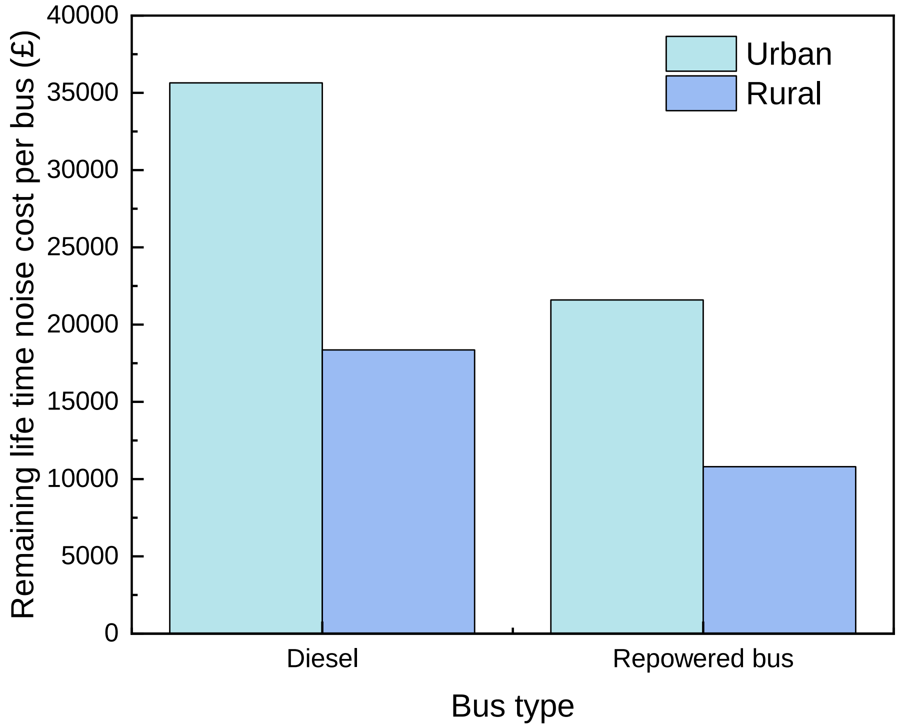

Figure 29: Remaining Lifetime Bus Noise Reduction Cost

10 Appendix E: Further Considerations

10.1 Battery Customization and Opportunity Charging

In this subsection, one of the biggest additional benefits of bus repowering, battery customisation for different routes (town, rural area, suburban area), is discussed. For the regional route from Dumfries to Edinburgh operated by Houston's, the one-way distance is about 130 km. 101 single-deck bus is used to provide the service. Along the route are 22 main stops from Monday to Saturday and 24 main stops on Sunday. And there will be around 60mins stop at the destination according to the timetable[131]. Compared to the current single-deck 101 bus, BYD-ADL Enviro 200EV is the best option if Houston's wants to operate a ZEB. The specifications of the BYD-ADL Enviro 200EV are shown in Table *13*. If Houston's decides to buy a new Enviro 200EV, the operational range (260km) is much higher than its one-way distance (80km), which means the battery is over-scaled. However, bus repowering will provide an opportunity to customise the size of the battery pack to save cost and weight. The performance of bus repowering is discussed in Figure 30.

Table 13: Specifications of the BYD-ADL Enviro 200EV[132]

Specification	Value
Type	Pure electric, zero-emission single, deck bus
Dimensions	9.6m, 10.2m, 10.9m or 11.6m length / 2.47m width / 3.4m height
Battery system	BYD lithium iron phosphate battery technology, 348kWh
Charging system	Choice of dual plug 2×40kW AC charging and single plug 102kW DC charging
Operational range	Up to 250 km on a single charge, depending on the duty cycle and operating conditions
Passenger capacity	Up to 80 total passengers with up to 40 seats

The route mentioned above normally takes 3 hours to arrive at the destination. For buying a new Enviro 200EV, the bus departs at 5:30 am with a fully charged battery and arrives at Edinburgh at 08:30 am with 174kWh battery capacity remaining. The fast-charging system can be adopted during the stop at the final station. The bus will leave the station at 09:25 with a battery capacity of 267.5 kWh and finish the round trip with 1/3 of the total battery capacity remaining. The size of the original battery is bigger than the optimal option. However, if Houston's uses the repowered bus, the initial size of the battery pack could be reduced to 280 kWh, and the electricity consumption also decreases with the weight of the battery pack. In this case, the battery weight is estimated based on the battery weight of the Tesla Model 3[133]. With a 280-kWh battery pack, the bus remains 32 kWh when finishing the round trip. Currently, the opportunity can provide 300kW and 450kW charging speeds.

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131 Houston's Coaches: Timetables, https://www.houstonscoaches.co.uk/wp-content/uploads/2023/03/101-101A-102-Dumfries-to-Edinburgh-1.pdf .

132 BYD-ADL: BYD ADL Enviro200EV, https://www.evbus.co.uk/wp-content/uploads/2021/03/BYD-ADL-Enviro200EV.pdf .

133 P. Lima: Comparison of different EV batteries in 2020, https://pushevs.com/2020/04/04/comparison-of-different-ev-batteries-in-2020/ .

Opportunity charging refers to charging an electric vehicle's battery at predetermined natural dwell points within the bus route structure. This means that the vehicle can be charged according to a predetermined schedule at the en-route charging stations, picking up sufficient power to stay above an adequate state of charge. It is a good support technology that can further reduce the battery size and weight of the bus[134]. In this case, 300kW opportunity charging is assumed to be installed in every bus station. With the help of opportunity charging, the initial fully charged battery pack could be scaled down to 165 kWh with the same battery capacity after a round trip compared to a repowered bus without opportunity charging. Moreover, the equivalent energy consumption per km is also reduced with the opportunity charging, which will reduce CO_2 emissions as well.

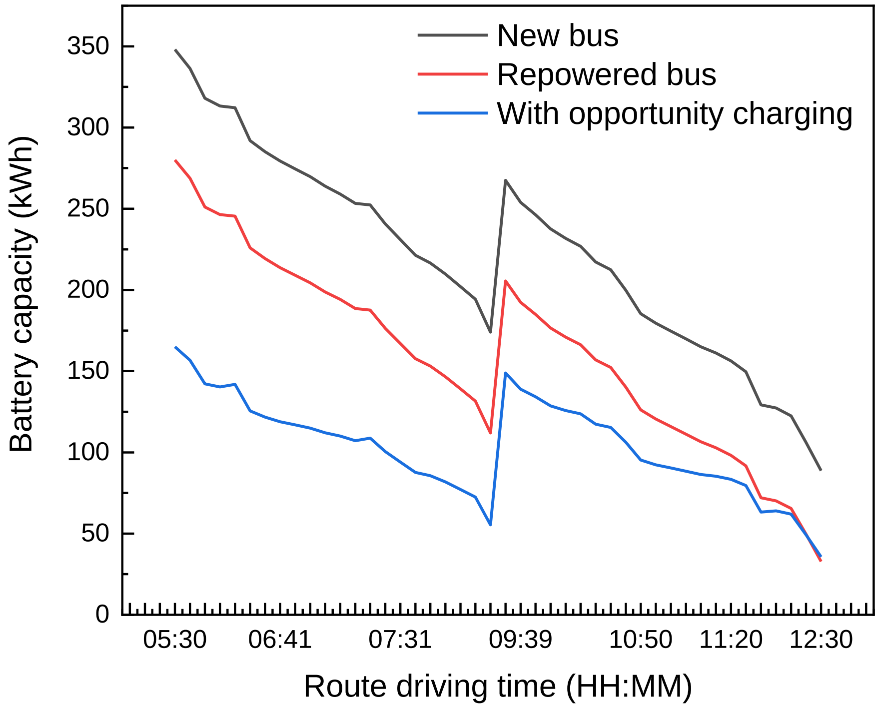

Figure 30: Battery Capacity Variation Along the Regional Route

Due to the smaller size of the battery pack on repowered buses and repowered buses with opportunity charging, not only is it significantly more sustainable and environmentally friendly, but the upfront costs paid by SMEs for battery packs will also be reduced. As shown in

Figure 31, assuming the battery price is £123.3/kWh, the battery upfront cost for the repowered bus is reduced by 19.5%. Furthermore, with the opportunity charging, the capital cost for the battery pack will be further reduced by 41% compared to the repowered bus case without opportunity charging.

[134] SMMT: Feature: How opportunity charging is a boost for electric buses - SMMT, 2017-03-29, accessed 2023-08-18.

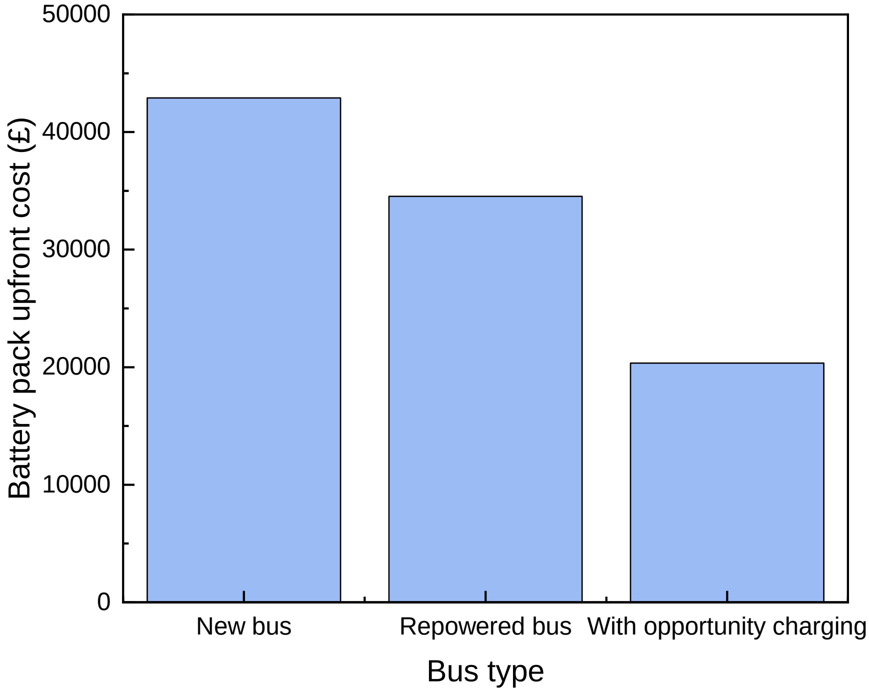

Figure 31: Battery Upfront Cost Comparison Under Regional Operating

For the city route, the route from Clermiston to Seafield (1 Bus Edinburgh) operated by Lothian as an example, the one-way distance is about 25 km. Along the route, there are ten main stops, and the bus will stop at Seafield Street for 7 mins and stop at Clermistion Crescent for 5 mins[135]. For the case of opportunity charging, two 150 kWh opportunity chargers are installed at the beginning and the end of the route to charge the bus while the bus stops. The performance of bus repowering and opportunity charging on the battery capacity is shown in Figure 32. Compared to the regional route with the same operating duration, larger battery capacity remains due to the shorter distance of the route and lower speed in the city, which means urban routes are even less suitable for buying new ZEBs. With the bus repowering, the size of the battery pack could be reduced by 59.8% compared to the size in the new ZEB with 35 kWh battery capacity remaining after a 3-hour operation, and the upfront for the battery pack reduces by £25,646 according to the Figure 33. With the opportunity to charge, the size of the battery and battery cost can be further reduced by 21%. Compared to the regional route, the importance of bus repowering and opportunity charging is different for city routes. For the regional route, opportunity charging plays a more important role than bus repowering, as the route's length limits the smallest battery size. Therefore, the amount of opportunity charging has a bigger potential for regional routes, while the city route is the opposite. But bus repowering and opportunity charging will provide significant savings to operators operating their business in the city and regional routes.

[135] Lothian: Timetables, https://www.lothianbuses.com/timetable/?service_name=1 .

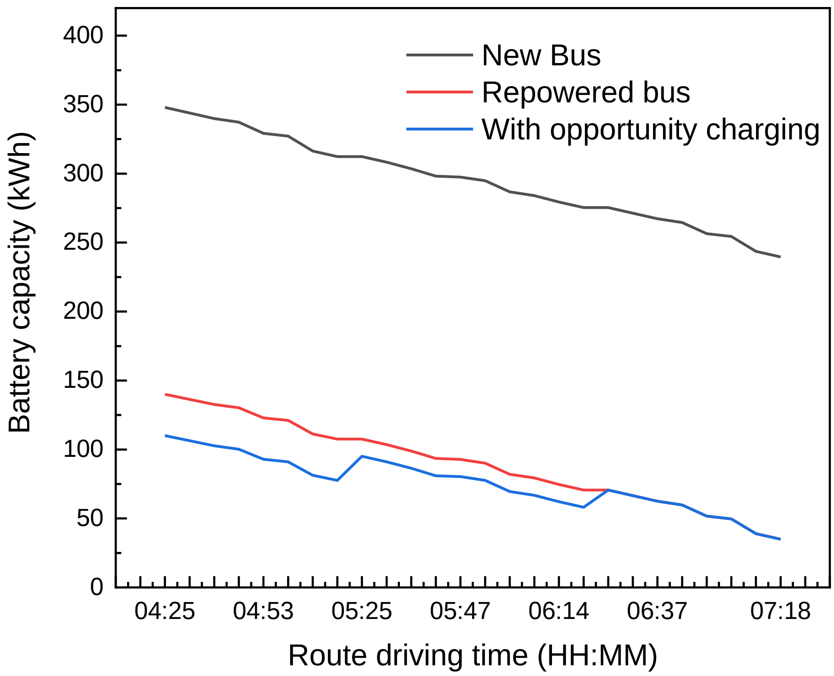

Figure 32: Battery capacity variation along the city route

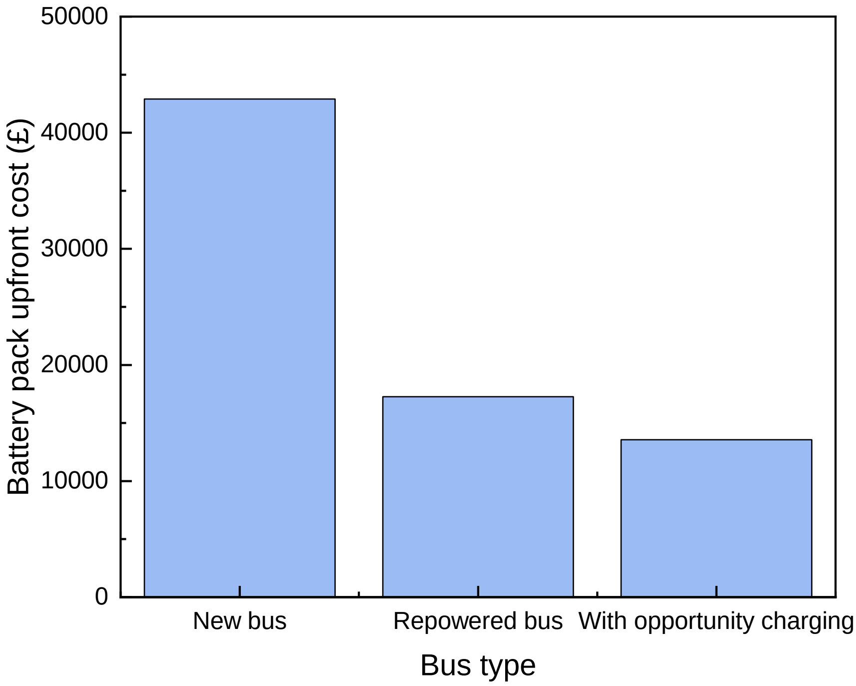

Figure 33: Battery Upfront Cost comparison Under Regional Operating

10.2 Financing Options

To further suit the operator's needs, Kleanbus, for example, offers several different options for financing the repower, as shown in Table 14. Third-party financing options on a commercial basis or from local governments may also be available.

Table 14: Battery Financing Options

Option	Chassis	Repower	Battery	Description
Pay upfront (Capex)	**owned**	**owned**	**owned**	Operators pay all the upfront costs and own the bus and new powertrain, including the battery packs.
Battery-as-a-service	**owned**	**owned**	leased	The operator/leasing company still owns the vehicle but leases the battery from the repower supplier and pays the repower system upfront.
Repower- & battery-as-a-service	**owned**	leased	leased	The operator/leasing company owns the vehicle but leases the repowering system and the battery.
Bus-as-a-service	leased	leased	leased	The operator sells the vehicle to the repower supplier, who leases back the repowered system, including the battery and vehicle. The operators receive the cash for the Net Book Value (NBV) of the diesel bus upfront and align the operational savings to a single monthly leasing cost.

According to the economic analysis in Chapter 5 and the battery lease price fromGoGreenAutos[136], the economic analysis of each financial option (7 years lease term) has to be performed by each bus fleet operators to make informed decisions. The first two options require an upfront payment, so the SME needs to find capital investment to start the repowering process. Based on the financial model from Kleanbus, payback will be achieved with option one within 2.1 years and using option two within 1.9 years, but these values depend heavily on the financial assumptions.

The latter two options do not require an upfront investment. Option 3 provides the repowering as an annual lease, which can be paid out of the savings. This makes the payback immediate and reduces the risk for the SME, although it may cause a higher overall cost in the long term. The final option allows SMEs to sell their old diesel buses to the repower company, freeing assets. The repowered bus is then leased, which is the most expensive option in terms of the lease payment, but it would still be competitive with the operation of a used diesel bus. Presenting various options means that financial constraints should not prevent SMEs from moving to net zero. [137]

[136] GoGreenAutos: Battery lease explained, https://www.gogreenautos.co.uk/buyers-guide/battery-lease-explained .

[137] (This is the end of the report.)