Performance and Energy Consumption of 8 metre Mellor Sigma Bus

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Prepared for Shetland Islands Council

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exceliamus

Title:	Performance and energy consumption review for an 8 metre Mellor Sigma bus trialled
Exec summary:	Electric bus operation is viable on Shetland, with terrain and operations within the trial vehicle's capability (and well within larger vehicles with greater performance and range). An 8-metre vehicle was trialled in a range of conditions, configurations and loading, and the performance and reliability of the vehicle was comparable to a diesel vehicle. The vehicle was not operated on the trial with heating in ambient temperatures below 8°C, limiting the results of the work. The performance of the vehicle, and a 12-metre equivalent vehicle, have been modelled to understand the likely performance, but these results have significant caveats. Heating demands, especially in Shetland, will significantly impact the available range during colder months, though heat pump technology could mitigate some of this impact. Charging an electric fleet is likely to be a significant constraint, with poor local grid capacity ahead of strengthening works to 2029.
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Executive Summary

- **Purpose:** Shetland Islands Council trialled an 8-metre electric bus, operating mileage accumulation and shadowing a service bus operation, unladen and with a representative laden mass, to understand the feasibility of such a vehicle on the Islands and to quantify the impact of different terrain and temperatures on performance.
- **Objective:** to assess the performance and energy consumption of an 8-meter electric bus under various operational conditions on island routes in representative environmental conditions.
- **Methodology Overview:** the vehicle was operated on the road but not in service with the public. Trial protocols covered a baseline operation covering the route mileage, then stopping at bus stops, stopping with heating and interior lighting, and finally adding a simulated load of around 25 passengers. Results were gathered manually with energy consumption measured through the dashboard percentage state of charge (SoC) readout.
- **Key Findings:**
    - Confirmed the bus's capability to achieve all required island routes.
    - Quantified the energy consumption increase per °C ambient.
    - Quantified the energy consumption increase on elevated terrain.
    - Considered the suitability for charging a greater number of vehicles, either by distributed 'fast' AC charging or with a dedicated hub for 'rapid' DC charging.
- **Conclusions:**
    - Electric bus operation is viable on Shetland, with terrain and operations within the trial vehicle's capability (and well within larger vehicles with greater performance and range).
    - The performance and reliability of the vehicle was comparable to a diesel vehicle, with some drivers' comments on the cab and body design.
    - The vehicle was not operated on the trial with heating in ambient temperatures below 8°C. The performance of the vehicle, and a 12-metre equivalent vehicle, have been modelled to understand the likely performance, but these results have significant caveats. Heating demands, especially in Shetland, will significantly impact the available range during colder months, though heat pump technology could mitigate some of this impact.

- Charging an electric fleet is likely to be a significant constraint, with poor local grid capacity ahead of strengthening works to 2029
- DC charging in depots will require additional space and constrain the yard layout for manoeuvring and parking.

Recommendations for Further Development in the Near Term:

Vehicle Design and Selection:

1. Examine specifications for equivalent vehicles available in the UK from other manufacturers, comparing battery capacity, available range, charging characteristics and heating technology (see below).
2. Where possible, obtain and trial another larger vehicle in service during winter months to build a better picture of likely impacts of terrain and weather conditions on the operation.

Heat-Pump Heating System:

3. Consider a trial of a heat pump equipped vehicle during winter months, to understand the likely energy impact of this more modern technology in colder climates as an option to extend the vehicle endurance in colder ambient temperatures.

Charging infrastructure:

4. Raise dialogue with SSE to identify suitable sites with night-time power headroom for a larger followup trial.
5. Further work is required to understand the shape of a transition plan to move away from diesel, with growth in the number of EVs on the Islands during the 2026-31 tender life, and subsequent contracts from 2031 where any new vehicles into the fleet will need to be zero emission.
6. Engage with SSE's grid strengthening programme to understand and inform future rapid charging depot locations, to fit the renewed grid infrastructure and the fleet requirements for the island's next generation of vehicles.

Recommendations for further development:

7. Develop a comprehensive operational strategy for an electric bus fleet, including driver training on energy-efficient driving techniques.
8. Explore potential for smart charging and energy management systems to maximise the potential of each grid connection.

9. Consider battery storage, V2G and behind-the-meter renewables as part of these sites, as an option to sweat the asset and maximise the revenue from a larger grid connection.

10. Develop a long-term strategy for 100% electric bus fleet transition to achieve net-zero by 2045, including financial modelling of capital and revenue expenditure, and a phased implementation plan to smooth the required investment. Consider the impact of stranded assets if diesel vehicles are required or purchased after 2030.

1. Introduction

- **1.1 Background and context of electric bus adoption:**

The target set by Scottish Government is to be net-zero by 2045, with interim emissions reduction targets of 75% by 2030 and 90% by 2040 against 1990 emissions levels. In response to this, the Shetland Islands Council has made commitments on climate change within their corporate plan. For transport, the Council are aware that sales for new diesel vehicles will end by 2040, and the community will need to deliver net-zero by 2050 in any case.

With buses operating on a fifteen year asset life or longer, there’s a practical limit for procuring new vehicles beyond 2030, which will affect any new vehicles required even before the end of the forthcoming five year bus contracts to begin in 2026.

- **1.2 Objectives of the trial:**
    - To evaluate the real-world energy consumption of an 8-meter electric bus under simulated operational scenarios.
    - To assess the bus's range capability against existing island routes.
    - To identify factors influencing energy efficiency (e.g., ambient temperature, terrain, operational profile).
    - To provide data for future fleet electrification planning and infrastructure development.
- **1.3 Scope of the report:**
    - a summary of key performance indicators and any identified data limitations, to understand the live vehicle trial and its data.
    - characterisation of the trial route(s), including topographical analysis and operational pattern analysis.
    - quantification of the energy requirements of the trial route(s) based on mileage, temperature, and sundry consumption

2. Methodology

- **2.1 Trial bus specifications:**

Shetland Islands Council received funding to trial electric vehicles on the Shetland mainland, operating on 26 variants of 8 services across the island.

The vehicle chosen for road trials was a Mellor Sigma 8, an 8.7 metre narrow-bodied door-forward vehicle suitable for light urban routes and operation on narrow rural roads. The trial vehicle has 27 seats in single-door configuration. With 127kWh of battery capacity and fitted for 22kW AC or 100kW DC charging.

The Sigma range is a rebranded Wisdom vehicle built in Zhangzhou, China. This range is no longer available through the UK's Mellor brand, though there are European dealers remarketing or distributing the same products. Various capacities are available from the manufacturer, from 7 metre to 12 metre variants.

One of the areas of interest for the trial was the impact of low temperatures of a Shetland winter on the performance and endurance of the vehicle, especially with the heating, lighting and wipers during the winter season. Data was gathered on the daily conditions and on how the drivers were using the vehicle each day.

No telematics or metered grid data was available to the trial, so battery state of charge (displayed % SoC) was measured each day, before and after each journey. This data was analysed with assumptions for the linearity of the display and the usable energy remaining in the battery (state of health), and validated with a small number of charging sessions where the grid input meter readings were obtained before and after charging.

- **2.2 Trial route description:**

The routes generally operate inter-urban services between settlements and points of interest and employment around the Mainland. The terrain is predominantly rural, and while the landscape is dramatic the road network avoids the highest land, so the bus routes are characterised by steep climbs for relatively short distances, without the large gross changes in elevation seen in some hillier areas of the UK – generally the major road network's elevation is below 150m, not remarkable for UK operations outside of London.

The timetable and inferred speed data across these routes indicates a rural operating pattern with low population density and few stops per mile.

2.3 Trial phases and procedures:

The trial operation ran in four distinct configuration phases:

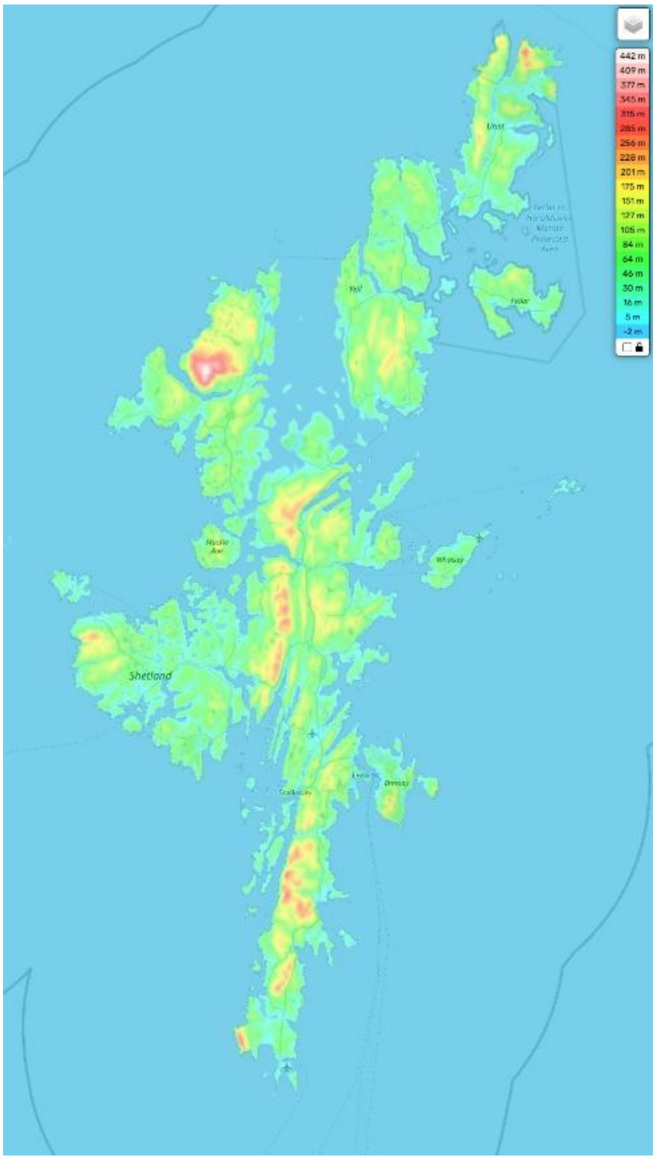


Fig A: Elevation on Shetland does not exceed 450m and bus operations are at lower altitudes.

- **Phase 1: Running around the route (Unladen, out of service)**
- **Phase 2: Stopping at bus stops (Unladen, out of service):** shadowing the driving pattern of a vehicle in service
- **Phase 3: With heat and light turned on (Unladen, out of service)**
- **Phase 4: With a simulated load on board (Out of service)**: running with 2080kg of water in 81x 25 litre drums, adding 23% to the unladen weight to simulate ~25 passengers on board.

- **2.4 Charging infrastructure used in trial:**

The vehicle was charged each night using a supplied 22kW AC charger. This used a standard commercial 415V three phase industrial supply, and is sufficient to fully charge the vehicle from zero in around ten hours including a balancing period for the cells.

This type of charger was sufficient for the trial operation (except for a small number of occasions at the beginning of the trial where charging did not complete successfully, which appear to be related to familiarity with the charger and vehicle systems, or with specific faults with this vehicle.

- **2.5 Data acquisition and instrumentation:**

For each phase, the trial operated over a range of different services and parameters were recorded manually each day, including the battery state of charge, ambient temperature, precipitation and prevailing wind speed and direction.

In order to calibrate the dashboard state of charge (SoC) readings to an energy consumption, a small number of start- and end- meter readings were obtained towards the end of the trial. These confirmed that the battery capacity and health was broadly in line with the manufacturer's original specifications, with few repeated points to calibrate the dashboard SoC readout. A linear relationship between the dashboard and the stored energy capacity is assumed.

Fig B: the same Mellor Sigma vehicle MX23 LDV on a preceding trial in Loughborough with the author's former operation under the Kinchbus brand in August 2023.

3. Results

- **3.1 Test phase results**

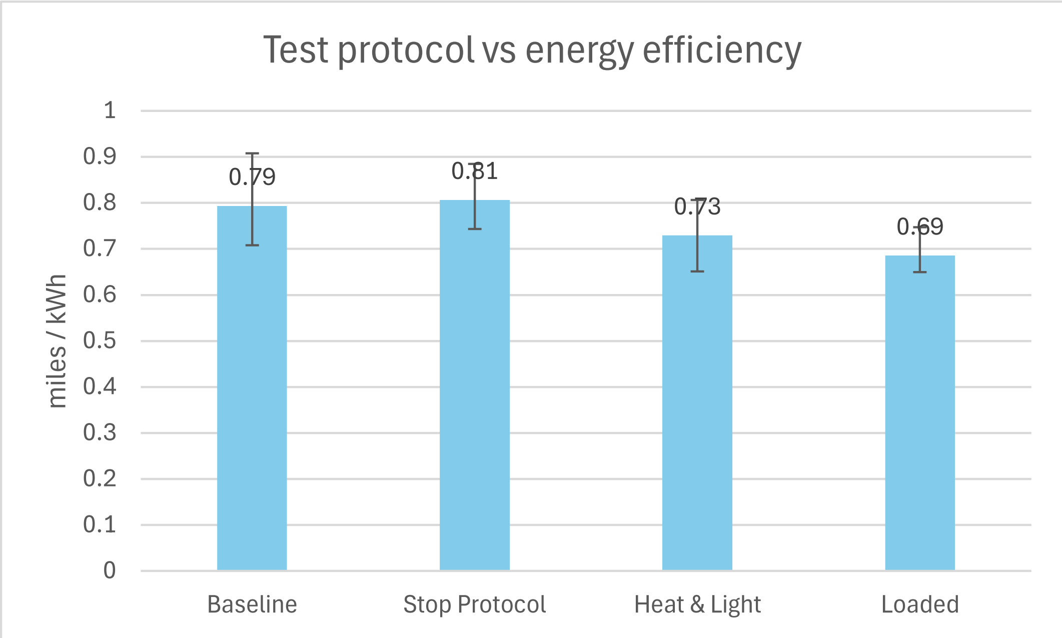


Fig C: Energy efficiency by test protocol phase, showing median value and interquartile range

During baseline testing the vehicle returned an average of 0.79 mi/kWh at an average of 6.3°C in operation. Correlation with wind speed (average or gust speed) is not statistically significant, with a reasonable number of samples (n=56).

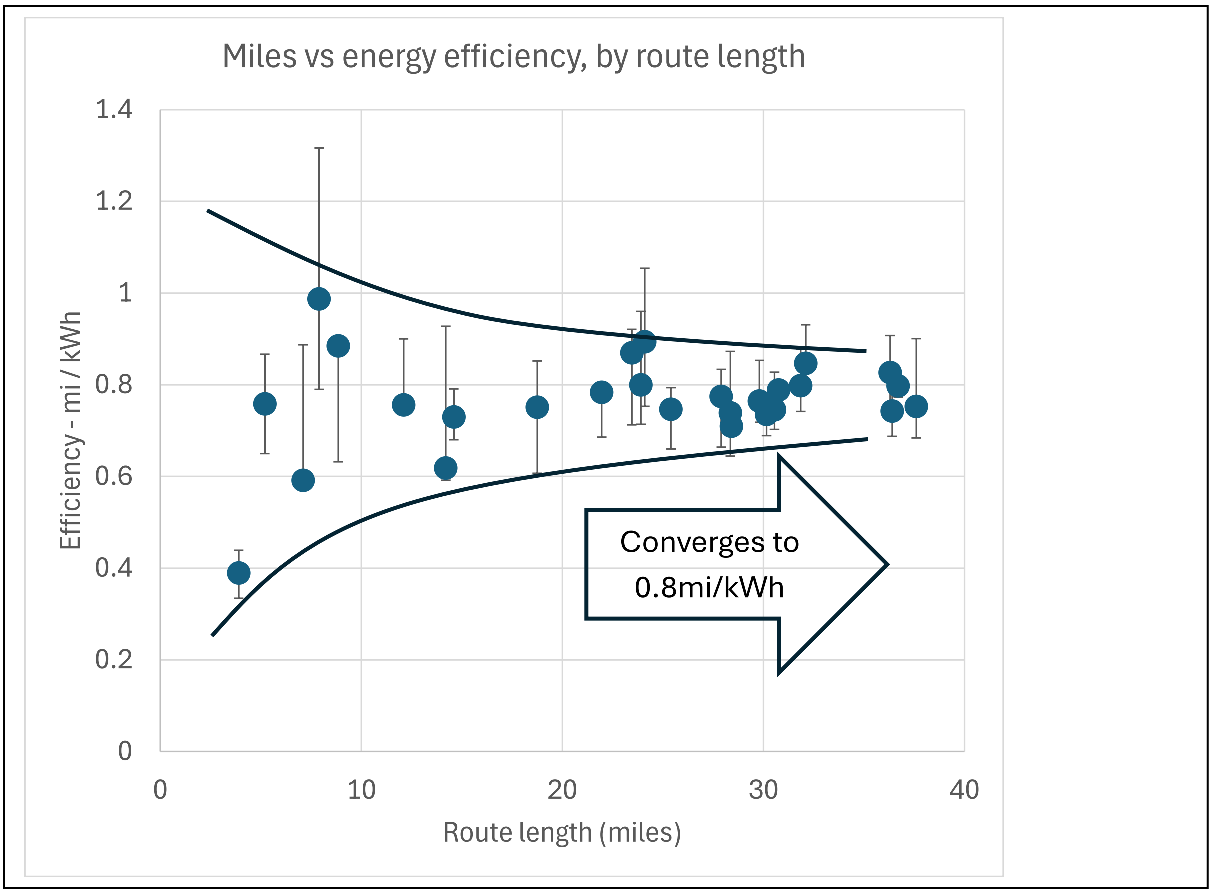
With a stopping operation the vehicle returned an average of 0.81 mi/kWh at an average of 7.7°C in operation. Correlation with wind speed (average or gust speed) is not statistically significant, with a reasonable number of samples (n=76).

With heating and lights and a stopping operation, the vehicle returned an average of 0.73 mi/kWh at an average of 10.9°C in operation. Correlation with wind speed (average or gust speed) is not statistically significant, with a reasonable number of samples (n=48).

With the vehicle loaded and stopping, the vehicle returned an average of 0.69 mi/kWh at an average of 12.2°C in operation. Correlation with wind speed (average or gust speed) is not statistically significant, and with a small number of samples (n=17).

- **3.2 Route results**

Energy consumption did not strongly correlate to the route, with some edge-effects noted on the longest and shortest routes. The median energy efficiency is shown for each route by route length, with error bars to show the interquartile range. For most routes the vehicle returned 0.7 to 0.9 mi/kWh regardless of the terrain operated, excluding the shortest work, for example on service 1 (Lerwick town, trial routes A, B, C & D). The indicated longest route (Sunday loop, trial route Z) fits this pattern well; generally, a greater distance covered meant the result converged towards circa 0.8 mi/kWh, reflecting smaller error for the distance covered and any effects from idling time, heating consumption while static etc.



3.3 Temperature results

The impact of temperature on the operation can be seen within each test protocol phase. While no protocol spanned the full temperature range, the gradient of each line shows the impact of the ambient temperature, around 0.15 miles per kWh added to the vehicle's endurance for each 1°C of warmer ambient temperature in the baseline, heat/light and loaded test protocols.

The stopping protocol reflects a flatter gradient (less influenced by temperature in this testing regime) but with a statistically significant dip in efficiency at 10°C. This is likely to relate to other factors affecting testing on these days, where three of the four daily results show supernormal energy consumption.

It is likely to be significant that the test protocol with heating was not used in ambient temperatures below 8°C so performance cannot be evaluated here.

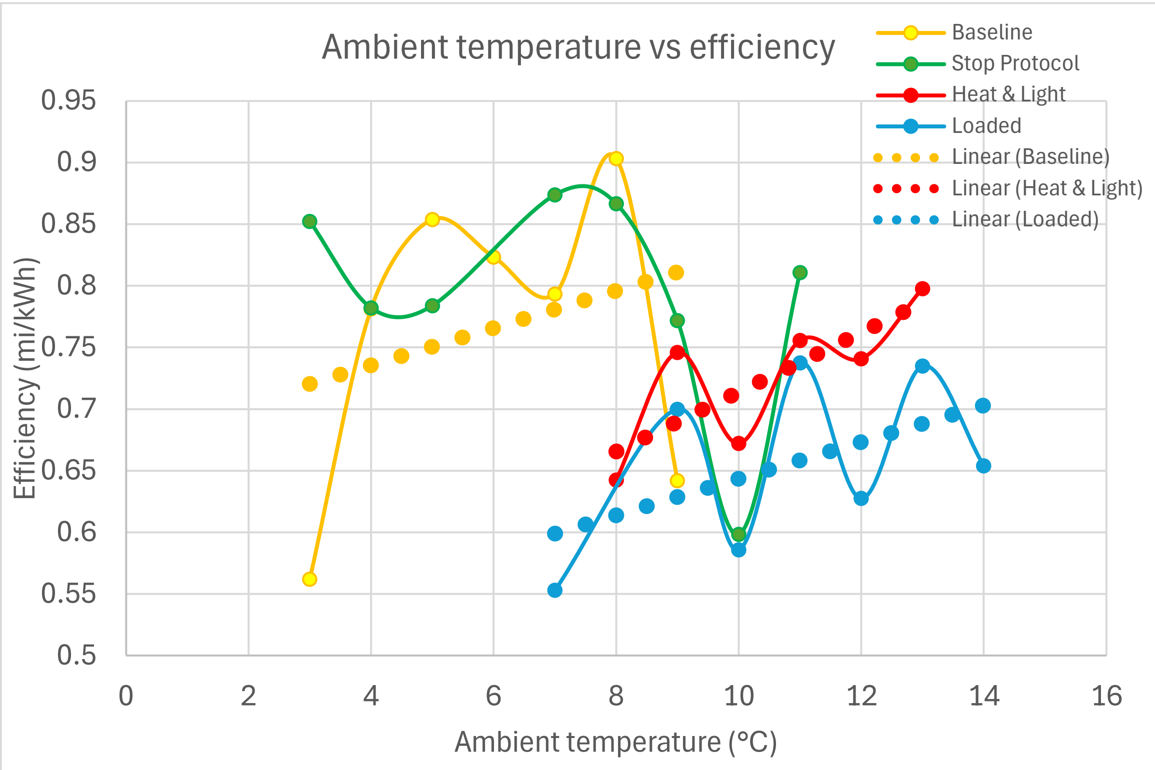


Fig E: Energy efficiency by ambient temperature (°C) showing average consumption at the tested condition.

- **3.4 General commentary on trial phases:**

The trial results allow a good evaluation of the Mellor Sigma 8 performance on routes around Shetland's mainland. The range of terrain on Shetland didn't show a significant impact from route to route and the vehicle delivered generally 0.8 miles per kWh, or a range in service around 102 miles on this duty cycle and ambient conditions in Shetland. However, the vehicle wasn't operated in service, at temperatures below 0°C nor below

8°C ambient temperatures with the heating switched on, so no data was gathered for these regimes. It is possible to interpolate with caution between the datasets where the vehicle was operated under different conditions, but not to extrapolate beyond the bounds of the tested conditions.

The impact of driving normally versus adopting a stopping pattern at bus stops showed no impact on the vehicle's consumption, and operation was dominated by the loads from heating and operating laden.

If the vehicle was continuously fully loaded, the consumption would likely be reduced to ~0.63 miles per kWh, around a 22% impact or 22 miles reduction in range to 80 miles.

These results show the range would be further reduced by around 25% by a 10° drop in ambient temperatures. It is not wise to extrapolate beyond the coldest temperature seen in the trial, 3°C ambient, but it is likely that the impact of thermal loads (both from the vehicle heating and the reduction in efficiency of the battery chemistry) would become disproportionate compared to the results seen during the trial. With these caveats, an estimate of the likely energy consumption and range for an unladen, heated vehicle on an aggregate average of Shetland's routes down to 0°C is shown at Figure F.

From the figures obtained in the trial the limiting range and consumption for this vehicle would likely be around 63 miles (0.5 mi/kWh) at 0°C for a stopping service with heating. In lower temperatures these figures would be further impacted by energy consumption from heating.

3.5 Comparison with 12-metre bus performance:

It hasn't been possible yet to trial a diverse range of vehicles to understand the sensitivity of the energy consumption from different factors on the trial results. A larger vehicle is of interest for some of the routes on Shetland, so it is sensible to extrapolate from the 8-metre vehicle's trial data to understand how a 12-metre vehicle might perform.

A larger vehicle will consume more traction energy, and a model has been built to project the traction energy broadly proportional to the vehicle's unladen weight. The heating loads have been assumed to be proportionate to the cabin size, assuming similar insulative losses and a representative pattern of door opening etc. Modelling the equivalent Mellor Sigma 12 vehicle, this model has a much larger battery capacity for the larger vehicle at 420kWh, and this capacity is broadly in line with similar competing 12-metre products from other manufacturers supplying the UK market. The 8 metre vehicle as trialled in Shetland has 127kWh of battery storage on board.

This larger battery allows a greater range for the larger vehicle, more than offsetting the additional energy consumption. Over 250 miles is achievable in good conditions, though a range around 200 miles should be assumed for year-round operations.

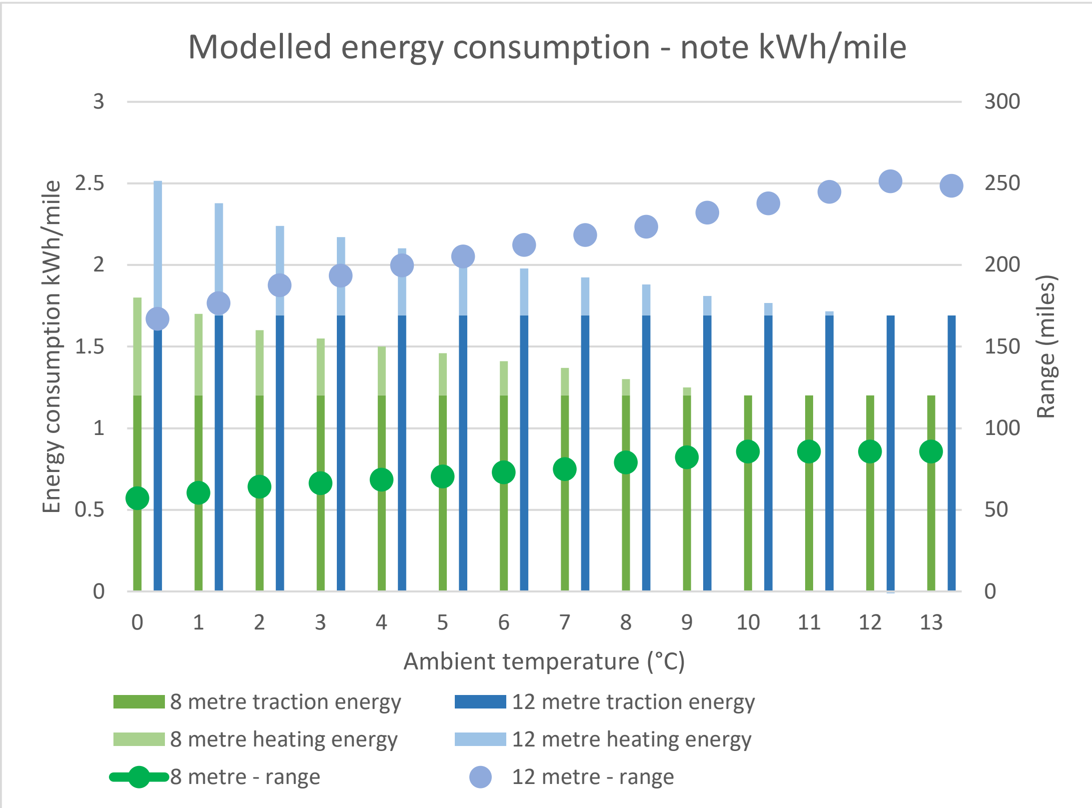


Fig G: Modelled energy consumption of 8-metre and 12-metre vehicles with heating, and range (including estimates and projections for 12-metre vehicle and below 8°C)

- **3.6 Performance in service:**

From the records provided, the vehicle suffered some initial poor reliability with charging as familiarity of the required procedures improved, and then showed a recurring issue related with poor starting from an issue with the low voltage battery, which was replaced once obtained on long-lead from China.

Towards the end of the trial the vehicle showed some issues with overheating and derating the motor performance on long climbs at Scord of Weisdale, Windy Grind and Ladies Drive. These aren't disproportionate climbs for UK operations; the Scord of Weisdale is a 2km climb at an average 6% gradient, 1 in 16, and the steepest gradient is 9%, 1 in 11, for 200 metres. The vehicle should be able to operate in these conditions without issue and it is suspected that a thorough service of the cooling pack would improve performance.

Driver feedback was broadly positive, with 'good handling' and strong acceleration performance at low speeds. Most of the feedback focused on the body and cab design, with comments on reflections, suitability of a touchscreen interface and the layout of sun blinds and cab storage areas. One driver noted that the speed limiter was set lower than 50mph / 80kph, and a higher limit would be preferable for rural operations. Comments on timekeeping suggest that performance on the road is comparable to a diesel bus, with slightly quicker acceleration when pulling away from a stop.

4. Discussion

The vehicle completed trials across a range of routes and through the late winter and spring seasons on Shetland. The vehicle completed the routes on most days with no range issues and reliability which was comparable with an equivalent diesel vehicle.

The Mellor Sigma range of vehicles is no longer available through their original importer, though the base vehicle may soon be available directly through the OEM in China or via another European agent. Other brands of electric buses are available in the UK market, and these tend to be larger vehicles at 10 or 12 metres length, with disproportionately more energy stored in larger batteries for greater operational endurance. These vehicles may be better suited to Shetland operations, allowing for battery degradation during the life of the vehicle without impacting on the available daily range.

- **4.1 Heating impact**

The vehicle completed trials across a range of routes and through the late winter and spring seasons on Shetland. The test protocol drove a series of layered phases, adding a stopping protocol and introducing heating and a laden weight. The season improved and the temperature generally rose during the trial, meaning that the impact of heating and the weighted load weren't assessed at the lowest temperatures. The impact of the heating energy consumption especially isn't proportional as the ambient temperature falls, and at very cold temperatures on a slow route the energy for heating could exceed the traction energy, halving the apparent energy consumption per mile compared to the best results seen during the trial

Since no data was gathered during the lowest temperatures with the saloon heating switched on, it's difficult to extrapolate consumption to these levels, other than to say the specific energy consumption at very cold ambients is likely to exceed the worst efficiency seen during the trial despite vehicles rarely operating fully laden in service all day.

The trial vehicle used PTC resistance heating, using c.1kWh of energy to produce 1kWh of heat into the cab. A heat pump system with a coefficient of performance around 3.0 in service could deliver the same heat with a third of the battery energy. This is likely to be significant in low ambient temperatures such as Shetland's winter climate, reducing the energy consumption by 30-40% on cold days, delivering a return through the year and allowing the vehicle to maintain a reasonable endurance throughout the year.

- **4.2 Charging infrastructure considerations:**

The trial used a Kempower T-800 series portable charger, using a 63A three phase input to provide DC charging to the vehicle at 40kW. This is around a third of the rate that a purpose-built depot charging provision would deliver and around a tenth of the potential for most buses available in the UK market. However this low rate was sufficient to conduct a trial on a single vehicle. The portable charger is sufficient to recharge fully the trial vehicle's modest battery in around 5h30mins, though it's rare that the vehicle will return with no charge remaining to require this full period to replenish.

A long-term electric bus operation would require permanent charging infrastructure for a fleet of vehicles, and the planning for this infrastructure should consider the longer term fleet plan, with sufficient capacity in supply, transformers and chargers to provide energy for the wider fleet. It will be important to plan passive provision for the most expensive elements of this wider rollout, and then install partial elements for the initial electric fleet according to the capital budget at the time.

At present and in common with much of the UK's supply grid, the electrical supply network on Shetland is constrained. A grid strengthening programme is underway with completion scheduled for June 2029, and this should unlock capacity to charge a fleet of vehicles at that time. It is recommended that Shetland Islands Council engages with SSE to make plans for power provision now to ensure that the future fleet charging demands aligns with the capacity being installed. It is understood that wind power developments on the island and the high voltage DC link due to be commissioned soon will not immediately increase capacity in the extant network on Shetland.

The location of these charging sites will be crucial to ensuring that supply can meet demand; it's likely that bus fleets will charge overnight, though the power requirement profile for each bus can be adapted to fit the operational needs and grid constraints. A small fast charging capacity should be specified for daytime top-up charging, and it may be possible to share this charging facility with an electric refuse-collection fleet too, if shift times, charging speed and yard availability can be aligned.

Installing static charging infrastructure in depots will constrain the yard layout, requiring a static parking plan and reducing the open space available for parking and turning vehicles. The delivery of the infrastructure should also consider vehicle movements on the depot sites as part of the design, minimising reversing wherever possible.

In the near term it may be possible to charge a smaller number of vehicles ahead of the completion of the grid strengthening work, depending on the overnight grid capacity at specific sites, as the trial operation managed. Where night time demand is lower and local substations have capacity within their constraints (eg when cooling is less constrained during lower ambients at night and in winter) it may be possible to charge up to ten vehicles at specific sites; this approach needs dialogue with SSE to identify suitable sites with sufficient night-time headroom for 200-500kW of continuous load.

5. Conclusions

- Electric bus operation is viable on Shetland, with terrain and operations within the trial vehicle's capability (and well within larger vehicles with greater performance and range).
- The performance and reliability of the vehicle was comparable to a diesel vehicle, with some drivers' comments on the cab and body design.
- The vehicle was not operated on the trial with heating in ambient temperatures below 8°C. The performance of the vehicle, and a 12-metre equivalent vehicle, have been modelled to understand the likely performance, but these results have significant caveats. Heating demands, especially in Shetland, will significantly impact the available range during colder months, though heat pump technology could mitigate some of this impact.
- Charging an electric fleet is likely to be a significant constraint, with poor local grid capacity ahead of strengthening works to 2029
- DC charging in depots will require additional space and constrain the yard layout for manoeuvring and parking.

6. Recommendations for further development:

Vehicle design and selection:

1. Examine specifications for equivalent vehicles available in the UK from other manufacturers, comparing battery capacity, available range, charging characteristics and heating technology (see below).
2. Where possible, obtain and trial another larger vehicle in service during winter months to build a better picture of likely impacts of terrain and weather conditions on the operation.

Heat-pump heating system:

3. Consider a trial of a heat pump equipped vehicle during winter months, to understand the likely energy impact of this more modern technology in colder climates as an option to extend the vehicle endurance in colder ambient temperatures.

Charging infrastructure:

4. Raise dialogue with SSE to identify suitable sites with night-time power headroom for a larger followup trial.

5. Further work is required to understand the shape of a transition plan to move away from diesel, with growth in the number of EVs on the Islands during the 2026-31 tender life, and subsequent contracts from 2031 where any new vehicles into the fleet will need to be zero emission.
6. Engage with SSE's grid strengthening programme to understand and inform future rapid charging depot locations, to fit the renewed grid infrastructure and the fleet requirements for the island's next generation of vehicles.

Wider considerations:

7. Develop a comprehensive operational strategy for an electric bus fleet, including driver training on energy-efficient driving techniques.
8. Explore potential for smart charging and energy management systems to maximise the potential of each grid connection.
9. Consider battery storage, V2G and behind-the-meter renewables as part of these sites, as an option to sweat the assets and maximise the revenue from a larger grid connection.
10. Develop a long-term strategy for 100% electric bus fleet transition to achieve net-zero by 2045, including financial modelling of capital and revenue expenditure, and a phased implementation plan to smooth the required investment. Consider the impact of stranded assets if diesel vehicles are required or purchased after 2030.