Transport

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BETT Deep Dive
Energy by Usage

Cenex – Transport Team

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Document Control

	Name and Job Title	Organisation
Prepared for:	Steven Birch, Continuous Improvement Manager	Leyland Trucks
Prepared by:	Tom Allerton, Senior Technical Specialist & Chapa Chandrasekara Assistant Technical Specialist	Cenex
Approved by:	Victor Lejona, Modelling & Analysis Team Leader	Cenex

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Company Details

Cenex
Holywell Building
Holywell Park
Ashby Road
Loughborough
Leicestershire
LE11 3UZ

Registered in England No. 5371158

Tel: 01509 642 500

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Project Overview

The Battery Electric truck Trial (BETT) is a research project funded by Innovate UK to trial 20 DAF Electric LF 19-tonne trucks. The trial is being run by DAF with support from Cenex for data collection, analysis and dissemination.

The truck has a range of up to 280 kilometres on each battery charge and can be rapid charged at 150 kW for quick turn-around between shifts. Further information can be found on the project website: https://bett.cenex.co.uk/

This is the fourth deep dive report which focuses on how the energy consumption is affected by usage patterns.

Key Conclusions

- Large ancillary loads such as cab heating and cargo refrigeration can together reduce the range of the BETT vehicles by around 19km over a typical 3 hour shift.

- In very cold conditions, up to 13% of the total energy consumption is used for cab heating and maintaining cargo temperature.

- High payloads unsurprisingly have a big impact on range, and this is most significant in start-stop urban conditions, with a smaller reduction observed in steady-speed motorway conditions. However, high payloads do provide greater energy recovery during braking.

Introduction

The majority of the energy used by a vehicle is for propulsion, but some energy is also used to power ancillary components. In contrast to a typical passenger car, for an HGV the energy requirements for both propulsion and ancillaries can vary significantly due to changing payloads and a wide array of potential ancillary power loads. This report looks at what effect those variations have on the range of the vehicle.

In addition to looking at how the payload affects range, the following ancillary loads have been identified and isolated from the telemetry data to understand what effect they have on range:

- Brake compressor.
- Battery heating and cooling.
- Cab heating.
- DC-DC converter for the low voltage system to power e.g. electronics, lights and tail lifts.
- Cargo refrigeration unit (only installed in some vehicles).

Ancillary Loads

Brake Compressor

This is used to create and maintain pressure in the braking system. Its power consumption is characterised by short "spikes" of compressor use each lasting only 25 seconds but occurring around 25 times an hour. The power of the compressor is approximately 4.5kW which is an average energy consumption of about 0.8 kWh per hour.

Most ancillary loads do not vary with the distance the vehicle is driven; they consume energy at a roughly constant rate, although they can vary by other factors such as temperature.

The effect on range therefore depends most on the duration the vehicle is used. The average daily driving time of a BETT vehicle is just under 3 hours, the tables on this and the following pages show the approximate effect on range from each ancillary for 3 hours and 6 hours of driving time.

Range reduction	3 hours	6 hours
Brake Compressor *	2.5 km	5.0 km

* This is an essential component of the vehicle and would also consume fuel in a diesel vehicle.

Ancillary Loads

DC-DC Converter

Some components operate from the vehicle’s 24V system. This includes essential electronics such as controllers, lights, windscreen wipers, fans and also some optional equipment such as tail lifts. The DC-DC converter provides power to these by converting electricity from the roughly 650V main battery down to 24V. Consumption is particularly high (up to 2.5kW) in the first few minutes after the vehicle is switched on as the 24V battery is charged to recover usage while the vehicle is idle. Consumption then settles to roughly 1 kW for the duration the vehicle is powered on, with occasional spikes for high power equipment.

The efficiency of the DC-DC converter is around 89%

Range reduction	3 hours	6 hours
DC-DC Converter *	3.6 km	7.2 km

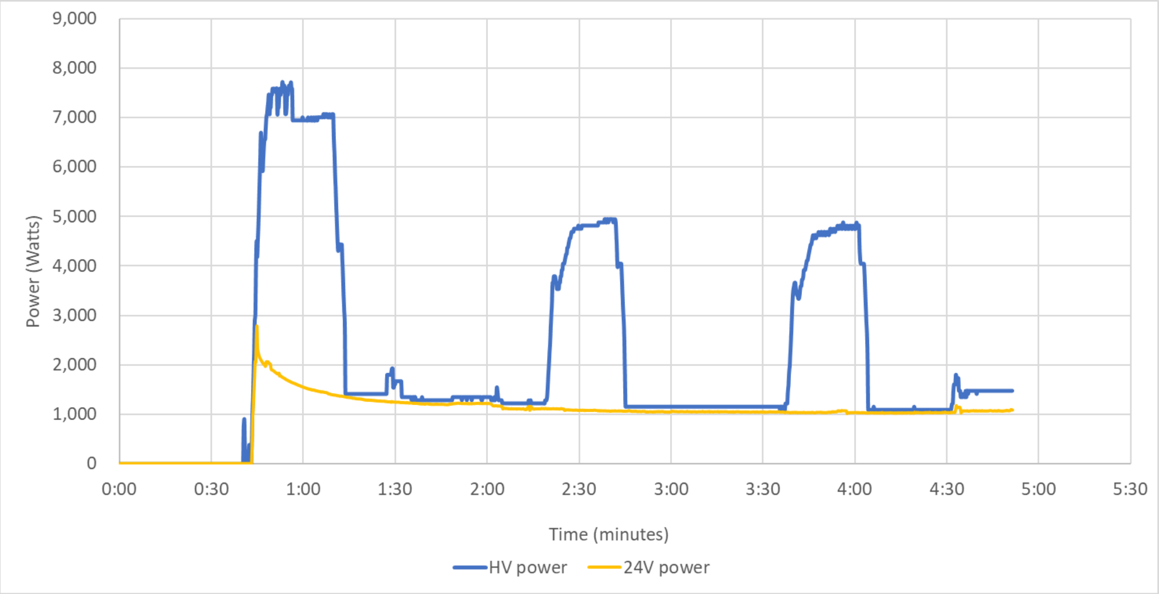
* This is an essential component of the vehicle and would also consume fuel in a diesel vehicle.

Ancillary Loads

This graph shows an example of the 24V DC-DC converter load and several of the brake compressor “spikes” in the high voltage (HV) power signal.

This is from the first few minutes of idling just after the vehicle has been started but before it drives away.

Note how the DC-DC power is higher initially as it charges a slightly drained 24V battery.



Ancillary Loads

Cab Heating

The DAF truck will scavenge heat from the battery to help heat the cabin, but the high efficiency of electric vehicles means there is little excess heat (in contrast to combustion vehicles where more than 70% of the energy is wasted as heat). To augment this, the truck uses resistive heating when needed. The energy consumption varies considerably by ambient temperature.

Unfortunately power consumption data about air conditioning is not available in the telemetry.

Range reduction	3 hours	6 hours
Cab Heating †	0 to 10.5 km	0 to 21.0 km

† The range is due to variation by ambient temperature.

Ancillary Loads

Cargo Refrigeration

Many vehicles require temperature controlled cargo. In general the requirements for this vary wildly depending on the use of the vehicle, with some requiring a frozen or chilled environment.

In BETT, 8 vehicles are fitted with units to maintain an “ambient” temperature of around 20°C, which in the UK climate means they are in fact heating for the majority of the time.

Additionally, BETT vehicles with a refrigeration unit fitted draw roughly 1kW of baseload power regardless of usage of the refrigeration unit. This is in addition to the 1kW baseload of the DC-DC converter.

Range reduction	3 hours	6 hours
Cargo Refrigeration (if fitted) †	3.5 to 8.1 km	7.0 to 16.2 km

† The range is due to variation by ambient temperature.

Ancillary Loads

Other Ancillary

Not all sources of ancillary power consumption can be traced because the vehicle telemetry only provides data on some components. However, whenever the vehicle is not moving any consumption must be due to some ancillary device and not propulsion. For the purpose of analysis whatever can't be accounted for is lumped into a category called "unknown idling". There will be unidentified ancillary consumption when the vehicle is driving too, but this cannot be separated from the power consumption of the propulsion system.

Range reduction	3 hours	6 hours
Unknown Idling *	1.5 km	3.0 km

* This is presumably an essential part of the vehicle operation and would also consume fuel in a diesel vehicle.

Ancillary Loads - Summary

This table summarises the effects of ancillary consumption on range.

Range reduction	3 hours	6 hours
Brake Compressor *	2.5 km	5.0 km
DC-DC Converter *	3.6 km	7.2 km
Cab Heating †	0 to 10.5 km	0 to 21.0 km
Cargo Refrigeration (if fitted) †	3.5 to 8.1 km	7.0 to 16.2 km
Unknown Idling *	1.5 km	3.0 km

* This is an essential component of the vehicle and would also consume fuel in a diesel vehicle.

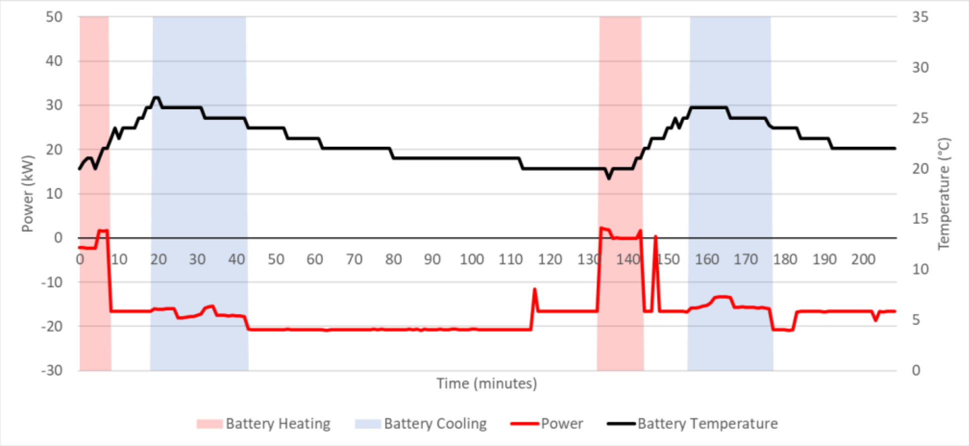
† The range is due to variation by ambient temperature.

Ancillary Loads

Battery Heating and Cooling

Lithium ion batteries like moderate temperatures between around 20-25°C, especially when being charged, so if the battery is significantly outside of this range it is heated or cooled. In the BETT vehicles, the battery is heated if it is below 17°C and is cooled if it exceeds 26°C. The heater power is 20 kW, while cooling is a more modest 4 kW.

This graph shows both heating and cooling during a fast (22kW) charge session where negative power indicates charging. During the brief battery heating periods, the entire charge power is consumed, however while this does slightly lengthen charge times, it does not reduce range and should help prolong the battery's lifespan.



Temperature dependence of heating

Both cab heating and cargo refrigeration are dependent on the ambient temperature. The exact effect will depend on various additional factors including:

- The driver preference for cab heating, or required cargo temperature.
- Number of times the driver’s or cargo doors are opened.
- The typical duration of a journey, for shorter journeys a greater proportion of the energy will be used to initially heat or cool the space to the required temperature.
- Solar irradiation.

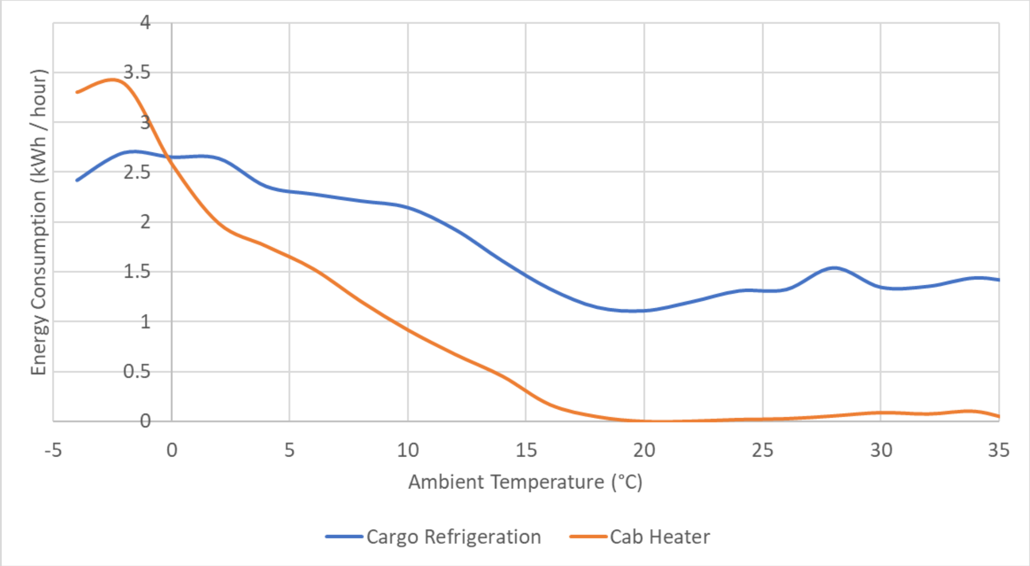
Because the BETT vehicles that are fitted with cargo refrigeration units aim to maintain 20°C in the cargo area, higher energy consumption is seen in cold conditions when the units need to heat the cargo.

Temperature dependence of heating

This graph shows how the typical energy consumption of both the cargo refrigeration unit and cab heater vary by ambient temperature.

The cab heater uses negligible energy above about 20°C, but increases as the temperature drops.

The refrigeration unit has a baseload power consumption of around 1kW regardless of its operation. Above 20°C consumption increases as it cools the cargo area, while below 20°C consumption is even higher as it works to heat the cargo area.

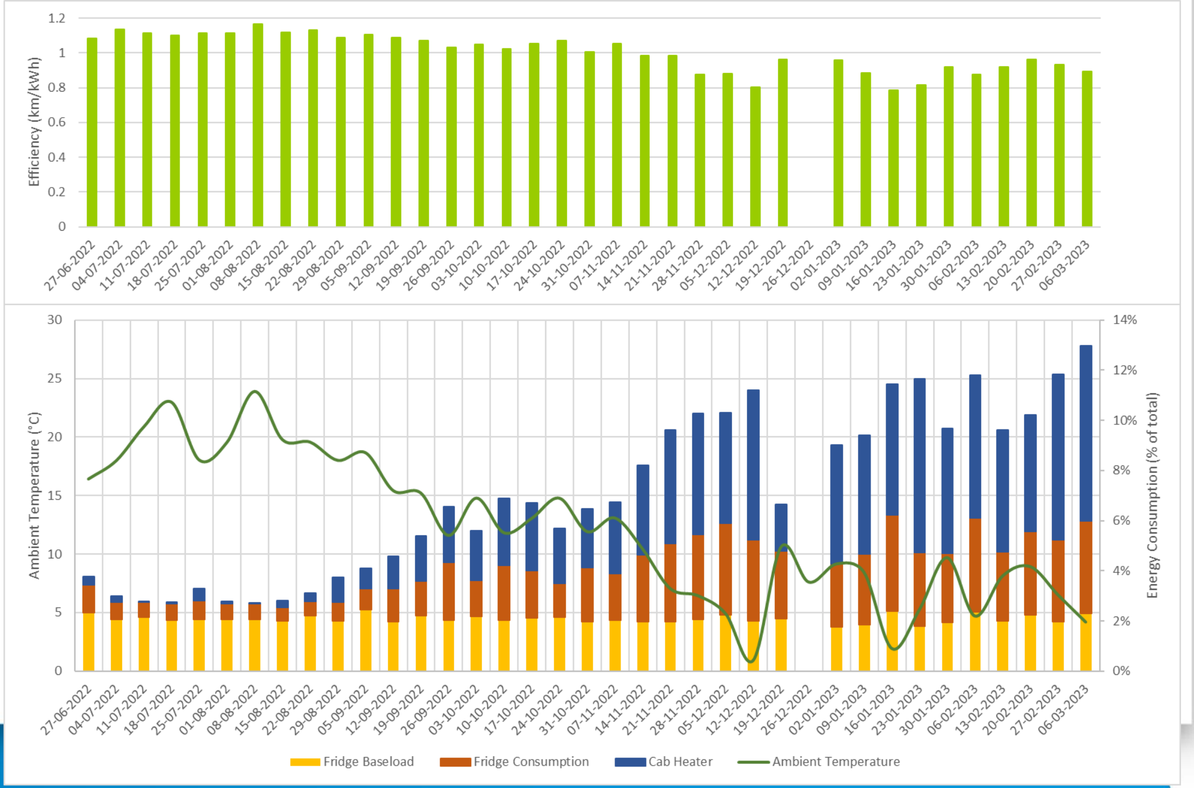


Temperature dependence of heating

Looking at only the vehicles with cargo refrigeration units, the top graph shows how the overall vehicle efficiency in km/kWh has declined between summer and winter.

Some of this is due to increased ancillary consumption, and the bottom graph shows how the energy consumption of the cargo refrigeration unit (split by the constant baseload and the actual usage) and the cab heater, as a proportion of total energy consumption, increases with reduced ambient temperature.

Note there was very little operation over Christmas so no data is shown for the week of 26th December.

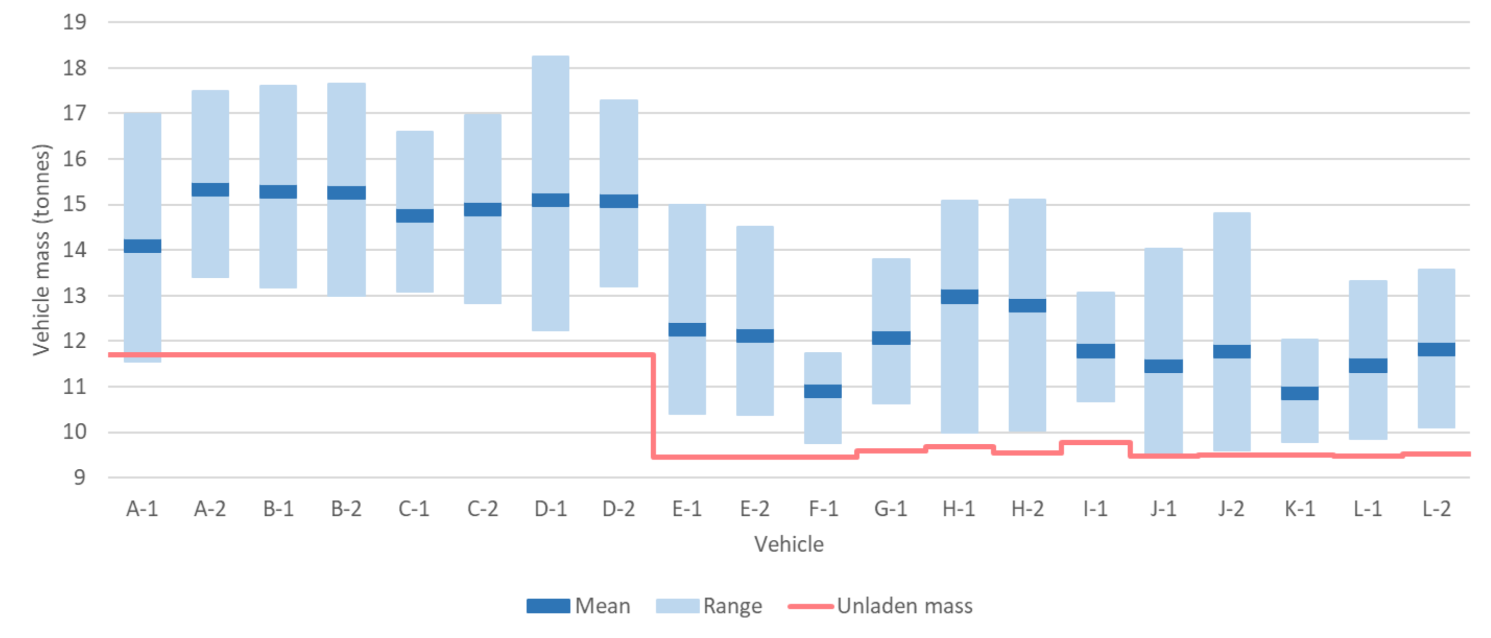


Payload

The mass of the vehicle changes as payload is added and removed. The vehicle's on-board controllers estimate the mass so it can ensure optimal operation of the vehicle. This graph shows the approximate range of total mass for each vehicle in the BETT trial as calculated by this controller.

The red line is the approximate unladen mass of each vehicle.

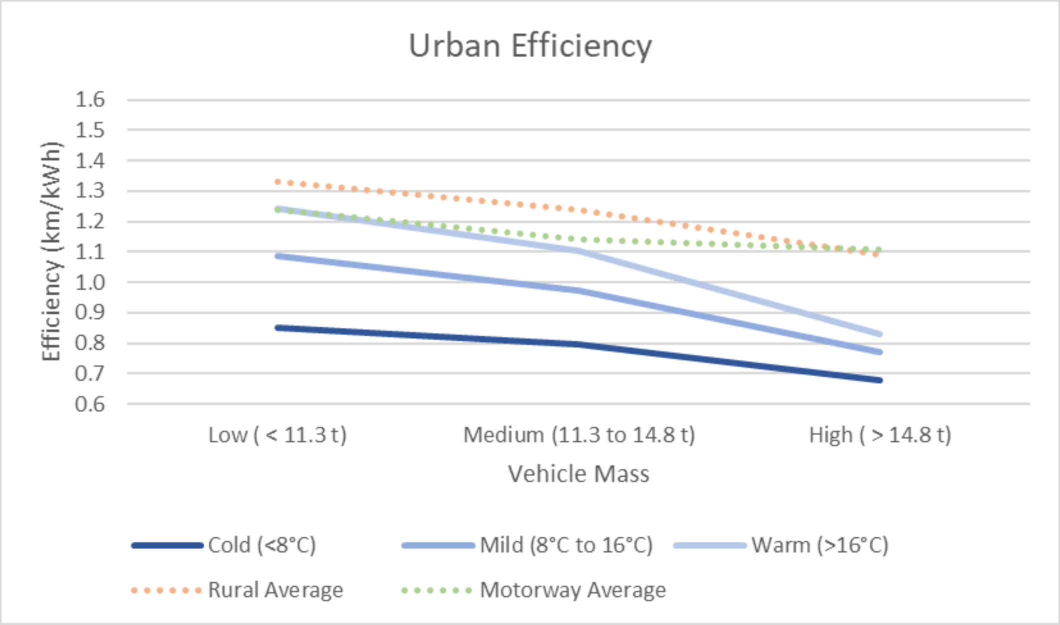
Vehicles with refrigerated bodies are heavier.



Payload Urban Efficiency

The graphs on this and the following slides show how the energy efficiency changes with both payload and ambient temperature. The payload is split into the bottom, middle and top thirds of measured total vehicle mass.

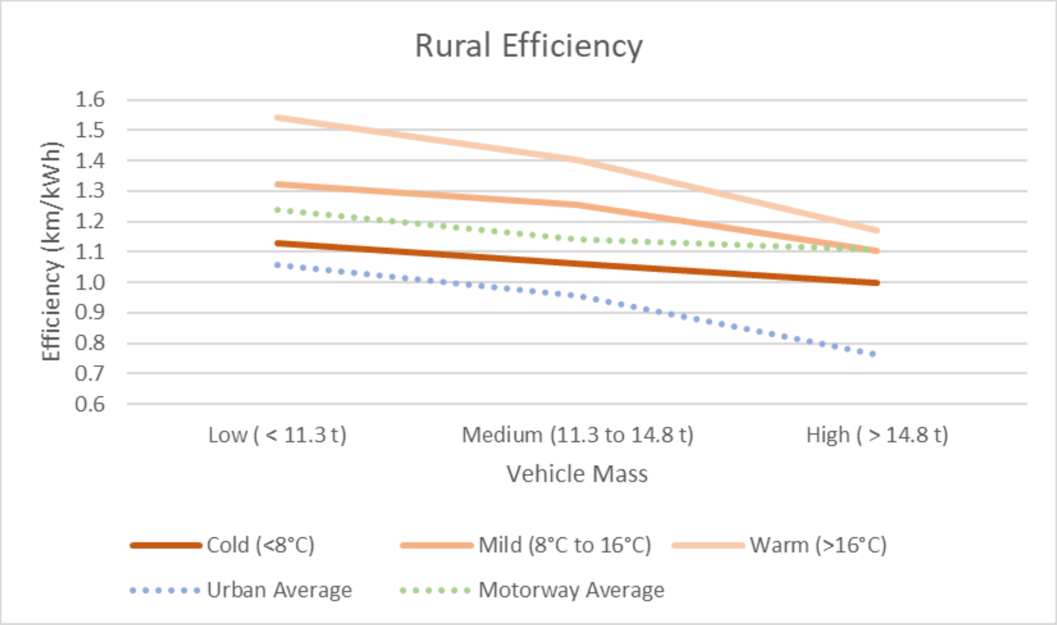
This graph shows the efficiency in the urban drive cycle indicating higher efficiencies in warmer weather and reduced efficiencies as the payload increases. The average of all temperatures for the other two drive cycles is shown for comparison, and the equivalent range on a full charge (averaged over all temperatures) is shown in the table below.



Payload	Low	Medium	High
Range (km)	265	239	190

Payload Rural Efficiency

Rural efficiencies are higher overall, and are impacted a little less by payload than urban driving due to less start-stop operation.



Range is average over all temperatures.

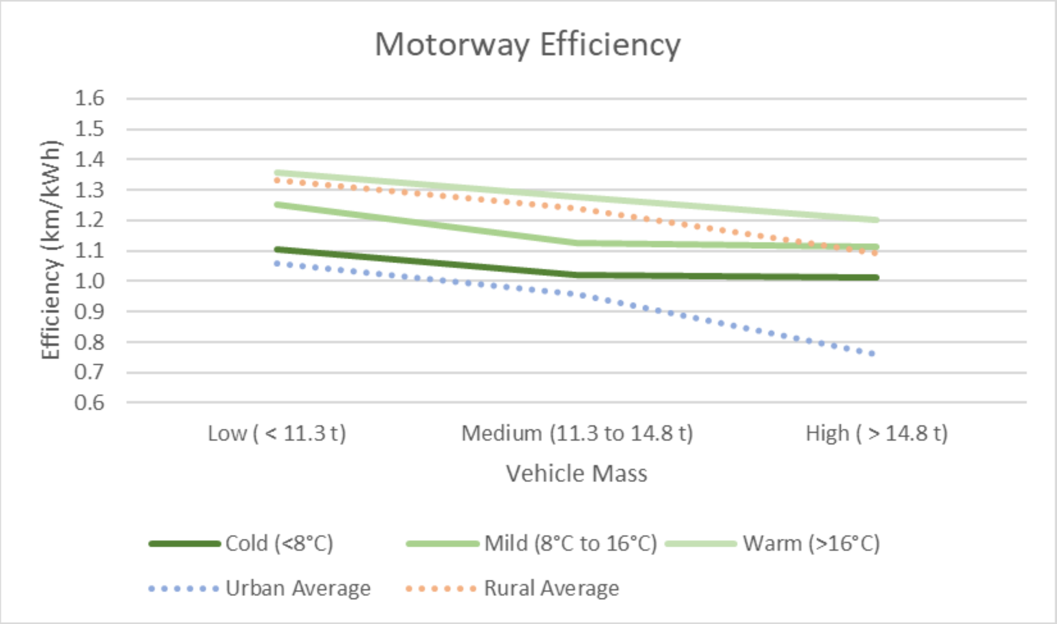
Payload	Low	Medium	High
Range (km)	333	310	273

Payload Motorway Efficiency

The payload of a vehicle affects energy consumption mostly when accelerating and decelerating, so the steady speed of motorway driving means high payloads have only a small effect on energy efficiency and range.

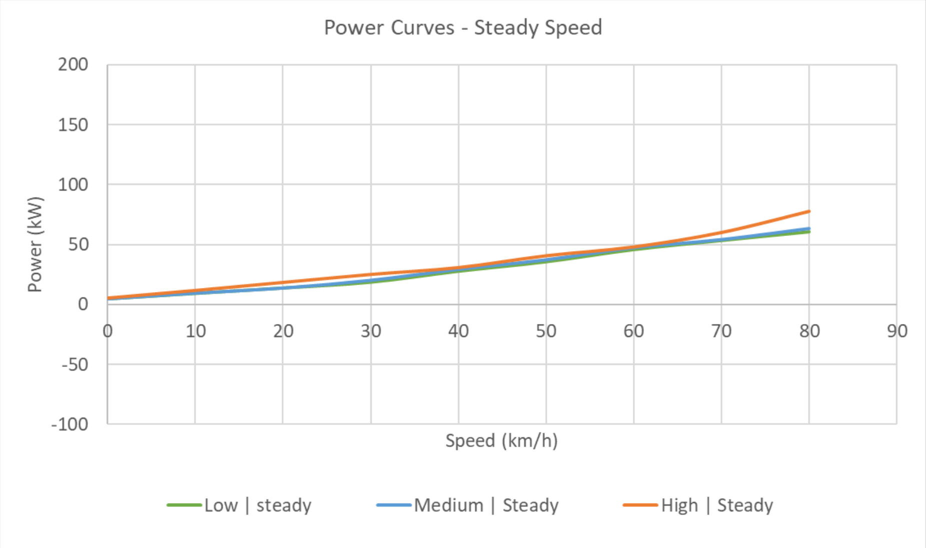
Range is average over all temperatures.

Payload	Low	Medium	High
Range (km)	309	285	277



Power Curves – Steady Speed

We can see how the power required to accelerate varies by payload. For this report we look only at the power requirements on flat roads. We start by looking at the power required at a constant speed, for a low, medium and high payload.

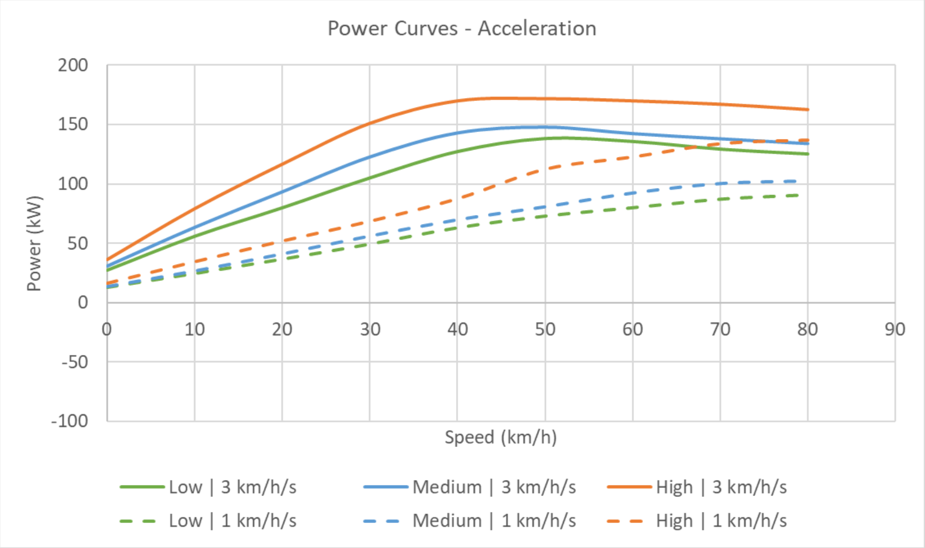


We would not expect the power requirement to vary much because at a steady speed on a flat road power is mostly required to overcome air resistance. Indeed, the power requirements are similar regardless of the payload.

Typical urban speeds (30 to 50 km/h) require around 25 to 45 kW, maintaining the observed peak speed (80 km/h) requires around 70 kW.

Power Curves – Acceleration

Acceleration requires more power than maintaining a steady speed, and more power is required to accelerate vehicles with higher payload. This graph shows the power required to accelerate at both 1 and 3 km/h/s at low, medium and high payload levels.



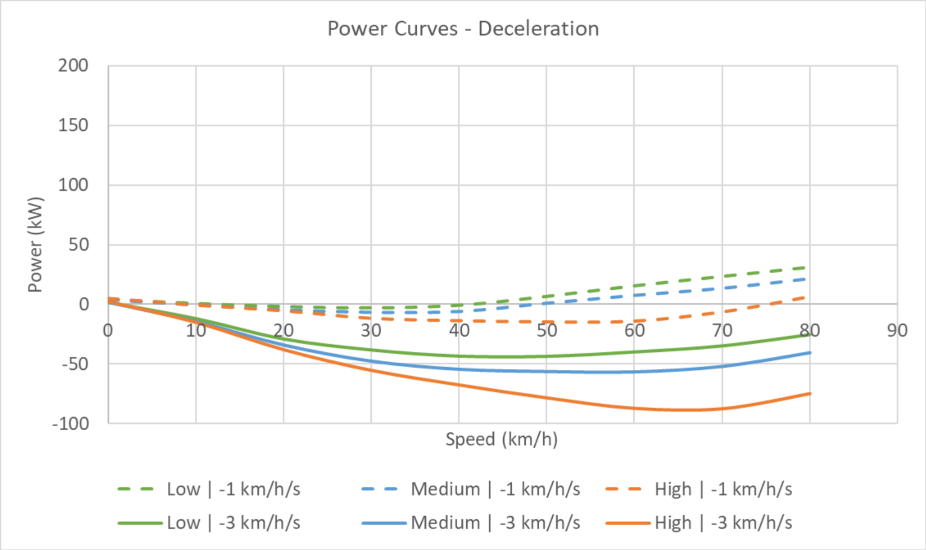
At moderate acceleration of 1 km/h/s it can take an additional 30 to 50 kW to accelerate above 50 km/h with a high payload compared to a low payload.

At a higher acceleration rate of 3 km/h/s the additional power requirement is also significant at lower speeds.

Note, the apparent reduction in power at higher speeds for 3 km/h/s acceleration is likely an artefact due to having limited data for these relatively rare conditions.

Power Curves – Deceleration

For deceleration, the power recovered through regeneration is similarly higher when the payload is higher reflecting the additional braking force that needs to be applied.



At 1 km/h/s regeneration is negligible, and due to air resistance at higher speeds power still needs to be applied even during gentle deceleration.

At a higher deceleration rate of 3 km/h/s regeneration power is significantly higher, with energy recovery noticeably greater for high payload vehicles than those with a low payload.

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To keep up to date with the trial, visit bett.cenex.co.uk

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