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# Kinetic Energy Recovery

ACHA 5010

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## 1 Introduction

This report aims to examine the possibility of implementing of a Kinetic Energy Recovery System (KERS) within a chosen vehicle. Firstly, the chosen vehicle, using both researched and measured data, resistive forces which it would face will then be calculated. Once the operation dynamics are acquired, using the data from the World Harmonised light Vehicles Test Procedure (WLTP) the performance and efficiency of the vehicle can be looked at in more detail, and more information can be attained. This information will give the theoretical underpinnings and practical considerations for retrofitting a KERS system.

Key components such as electric motors, controllers and storage systems are critically evaluated for their energy efficiency and potential in real-world applications. This report will also address the system operation, driver experience due to the installation of a KERS system and assumptions that have had to be made.

## 2 Vehicle Selection

The selection of an appropriate test vehicle is pivotal as it must adhere to the WLTP class 3 standard but also a vehicle which is a popular commercial vehicle within the UK in order for the results to have useful realworld applications.

### 2.1 Chosen Vehicle and Specifications

The chosen vehicle is a mk2 Renault Trafic, also available as a Vauxhall Vivaro and a Nissan Primastar. Due to its widespread use in commercial activities, it is a representative model of the medium-sized van segment within the UK.

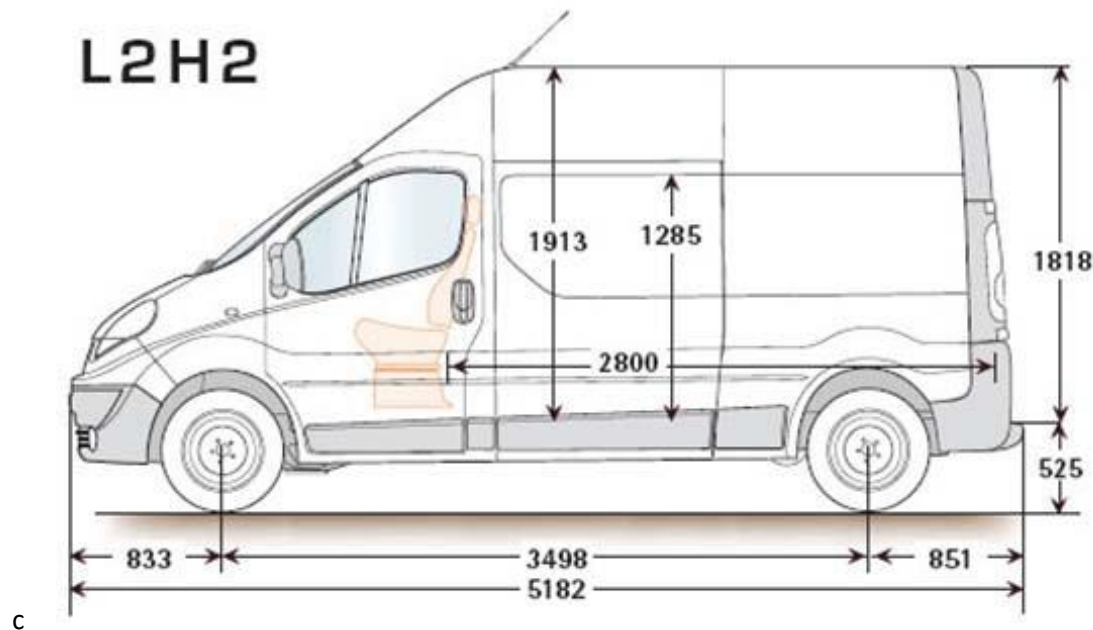


Figure 1 - Renault Trafic LWB High Roof Measurements (thetvp.co.uk, 2021)

The chosen model is a 2.0 litre diesel, long wheelbase and comes in high top specification. The largest option of this medium sized vehicle. Some of the key points to consider are:

Engine Size: 2.0 Diesel

Power: 84kw

Torque: 290Nm

LWB High Roof: as per *figure 1*, 2485mm 1904mm 5182mm

Gross Payload: 1236kg This will come into consideration when choosing energy storage devices.

Kerb Weight: 1724kg

(Car.info, 2024)

This is vital when choosing a storage system for a vehicle without affecting its payload capacity. The report will investigate the vehicle's resistances and aerodynamic profile further.

## 2.2 Justification of Chosen Vehicle

Using Government Data to validate retrofitting an older vehicle for efficiency gains:

- 82% of vans in private ownership are second-hand.
- Many vans are over 10 years old, ideal for retrofitting.
- Average van mileage per year is 13,200.
- Majority of van usage is considered local; 51% stay within 15 miles of registered base.
- Vans on the road has increased by 93% over 25 years.

(GOV.UK, 2021)

Highlighting the need for a sustainable solution for an ever-growing fleet of aging vehicles.

### 3 Chosen Vehicle Calculations

This section will cover the equations used to calculate resistance faced.

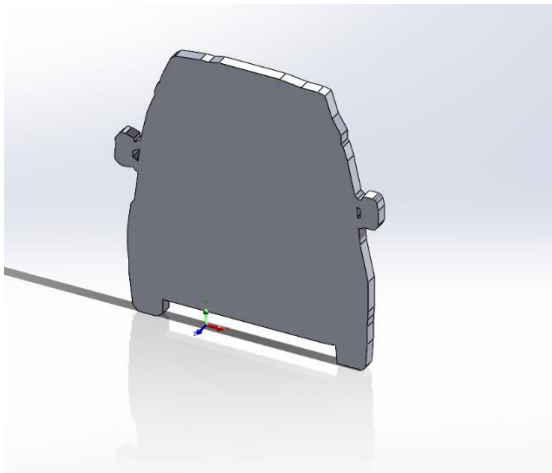
#### 3.1 Measuring The Frontal Area

Firstly, a measurement of the front of the vehicle must be made.



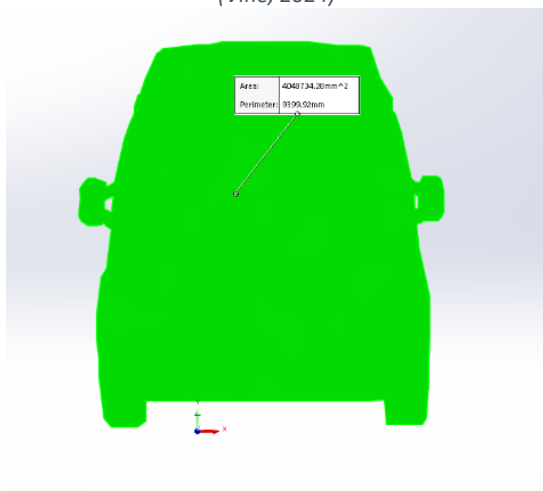
Figure 2 - Renault Trafic Head on Photograph (Vine, 2024)

A front on photo of the Vehicle is taken. Once this has been done, it must be outlined and measured.



Using SolidWorks, the vehicle is precisely measured and then extruded into a 3d model.

Figure 3 - Extruded SolidWorks Model of Renault Trafic (Vine, 2024)



SolidWorks is then able to measure the extruded area.

Frontal Area:  $4.05m^2$

Figure 4 - Renault Trafic Measured Frontal Area (Vine, 2024)

### 3.2 Calculating Aerodynamic Drag

To calculate the aerodynamic drag the following equation was used:

*Equation 1 - Aerodynamic Drag Equation (Crowford, 2014)*

$$\frac{1}{2} \cdot \rho \cdot C_d \cdot A \cdot V^2$$

$\rho$  = Air density at  $1.23 \text{ kg/m}^3$

$C_d$  = The coefficient of drag at 0.40, reflecting the shape of the vehicle, a lower coefficient is expected from a larger, squarer commercial vehicle such as this one.

$A$  = The front area is  $4.05 \text{ m}^2$ , as calculated in section 3.2

$V^2$  = Velocity is  $36.5 \text{ m/s}$ , this is the top speed reached by the vehicle.

The aerodynamic drag at maximum velocity is  $1319.33 \text{ N}$ .

### 3.3 Calculating Rolling Resistance

The more rolling resistance there is, the more energy is required to overcome it. For example, a 30% increase in rolling resistance can create up to 3-5% fuel overconsumption (Chambriard, 2024).

This will remain constant throughout.

The next equation was used:

*Equation 2 - Rolling Resistance Equation (Kamran, 2023)*

$$rrc \cdot m \cdot g$$

$rrc$  = 0.008, Rolling Resistance Coefficient, with ultra-low resistance tyres. (Ehsani et al, 2019)

$m \cdot g$  = mass, using the WLTP test mass of  $1824 \text{ kg}$  multiplied by gravity at  $9.81 \text{ m/s}^2$

Total Rolling Resistance =  $143.14 \text{ N}$

## 4 Selecting the Correct Worldwide Harmonised Light Vehicle Test Procedure (WLTP)

This section will look at the specification of the vehicle and which category the Renault Trafic will use.

### 4.1 Selecting the Correct Category

Looking at figure 5, the vehicles Power-to-Mass Ratio (PMR) and Top Speed must be considered. As seen in 2.1 the vehicle has a kerb weight of 1723kg and 84kw of power.

*Equation 3 - Calculating the PMR of the Vehicle (Vine, 2024)*

$$PMR = \frac{84000W}{1723kg} = 48.75$$

Therefore, putting the Renault Trafic into the Class 3b.

| Category | PMR, W/kg     | v_max, km/h | Speed Phase Sequence                         |
|----------|---------------|-------------|----------------------------------------------|
| Class 3b | PMR > 34      | v_max ≥ 120 | Low 3 + Medium 3-2 + High 3-2 + Extra High 3 |
| Class 3a |               | v_max < 120 | Low 3 + Medium 3-1 + High 3-1 + Extra High 3 |
| Class 2  | 34 ≥ PMR > 22 | -           | Low 2 + Medium 2 + High 2 + Extra High 2     |
| Class 1  | PMR ≤ 22      | -           | Low 1 + Medium 1 + Low 1                     |

*Figure 5 - WLPT Categories (Dieselnet.com, 2019)*

### 4.2 Class 3b

The WLPT Class 3b is designed for more powerful vehicles, with a PMR great than 34w/kg this will cover most modern cars and light commercial vehicles. It includes adding a passenger of 75kg and 25kg of cargo to reflect real world usage.

The cycle is differentiated by an Extra-high-speed phase, acknowledging the motorway speeds of most European countries and the speed capabilities of today's vehicles. The cycle used also aims to match typical driving conditions much more than previous tests, with faster acceleration and more variable loads. (Dieselnet.com, 2019)

## 5 Resistance Faced and Power Required for a KERS System

This section will consider area of the WLPT in which kinetic energy could be recovered and therefore has the potential to be stored. The forces put upon the vehicle and lastly the amount of power the vehicle will need to overcome these forces.

### 5.1 Identify areas of the cycle where kinetic energy could be recovered.

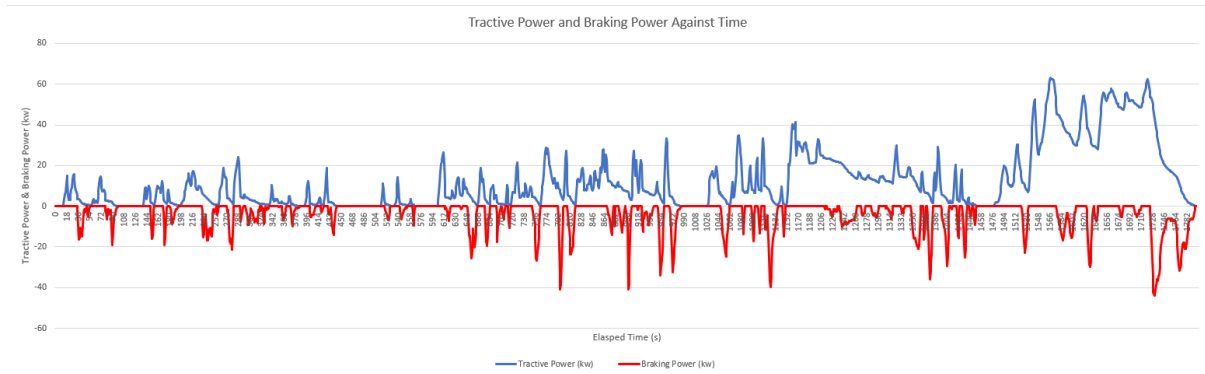


Figure 6 - Tractive power and Braking Power (Vine, 2024)

### 5.2 Forces on the Vehicle and Power Required to Overcome Them

#### 5.2.1 Velocity Time Graph

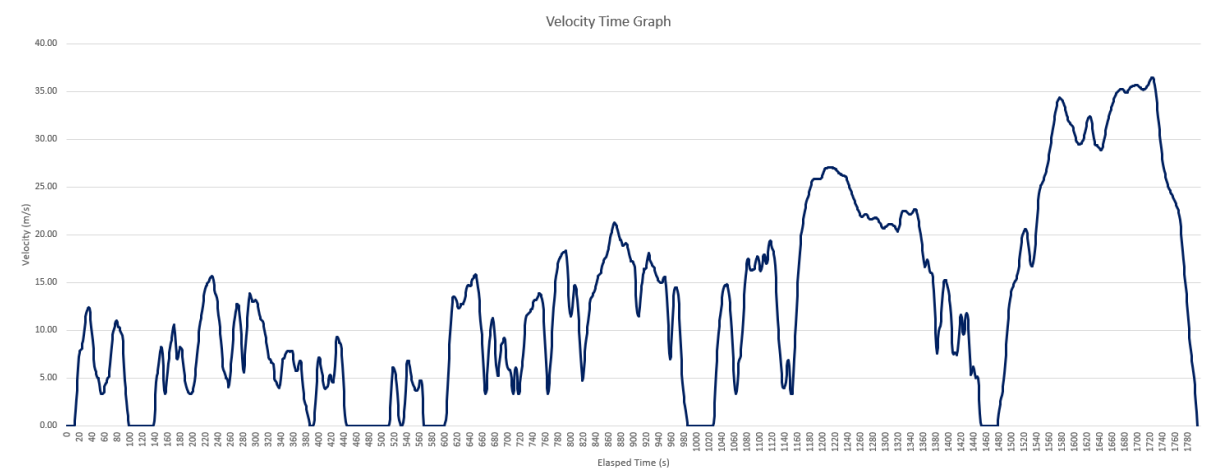


Figure 7 - WLTP Velocity Time Graph (Vine, 2024)

### 5.2.2 Total Resistances



Figure 8 - Combined Forces Against Time (Vine, 2024)

- Dark Blue: Velocity in m/s
- Light Blue: Positive Resistive Forces (Combined)
- Yellow: Aerodynamic Resistance
- Brown: Rolling Resistance (Consistent)
- Green: Positive Acceleration Resistance
- Red: Negative Resistive Forces (Combined)

### 5.2.3 Power Required

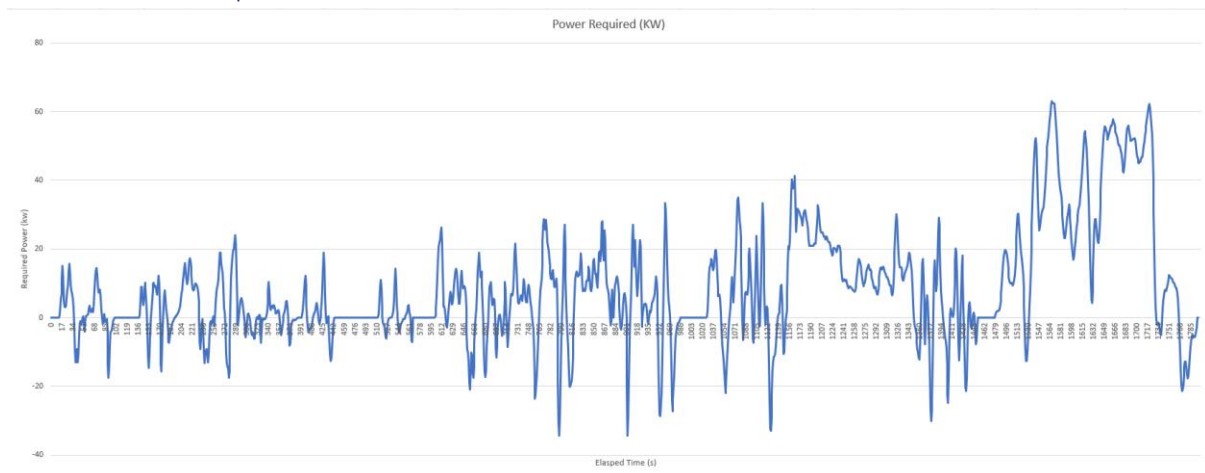


Figure 9 - Power Required in kW (Vine, 2024)

### 5.3 Plot Cumulative Tractive Energy Require and Braking Energy Required

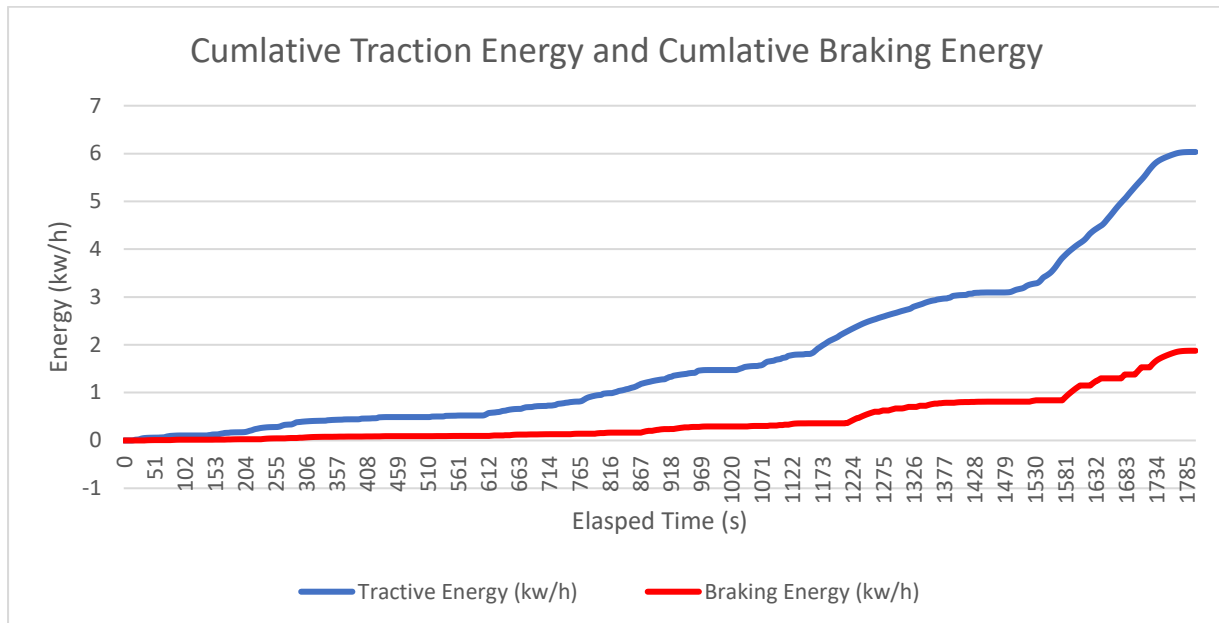


Figure 10 - Tractive and Brake Energy (Vine, 2024)

Figure 10 shows the cumulative tractive energy, notable increases as at the fast section of the WLTP as the aerodynamic drag increased squared. The braking energy represents energy that can potentially be claimed during deceleration. The disparity between them highlights the demand at higher speeds due to the excessive resistant forces.

## 6 Identify Possible KERS power input and Energy Storage Requirements.

This section assesses the kinetic energy available during deceleration periods. Identifying braking instances where the power lever as substantial enough to warrant energy recovery. With this information, a suitable KERS system can be chosen.

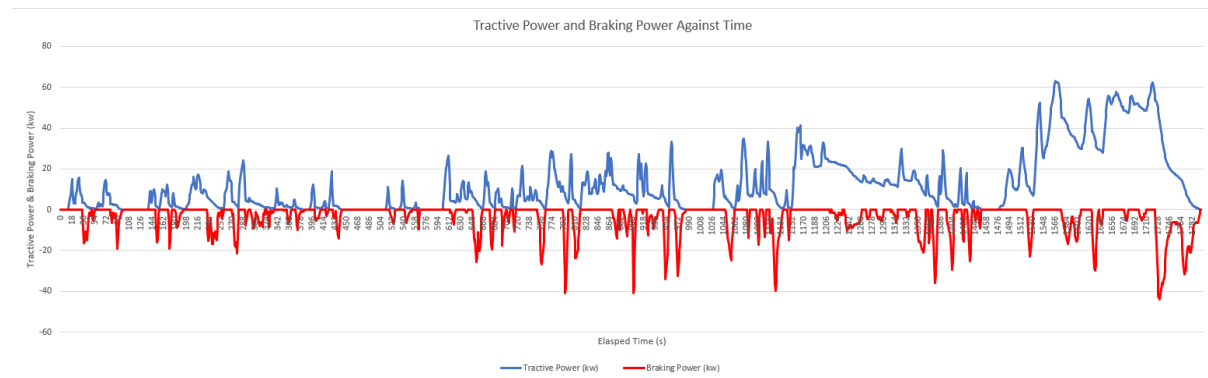


Figure 11 - Tractive and Brake Energy Against Time (Vine, 2024)

### 6.1 Identifying Notable Deceleration Zones

Table 1 - Braking Areas LOW (Vine, 2024)

| Notable Braking Areas - Low |                    |                |                       |
|-----------------------------|--------------------|----------------|-----------------------|
| Area of WLTP                | Braking Power (kW) | Time Taken (s) | Braking Energy (Kw/h) |
| Low                         | 15.9               | 19             | 0.066                 |
| Low                         | 29.80              | 20             | 0.116                 |
| Low                         | 64.67              | 22             | 0.395                 |
| Low                         | 58.68              | 21             | 0.342                 |

Table 2 - Table 1 - Braking Areas MIDDLE (Vine, 2024)

| Notable Braking Areas - Middle |                    |                |                       |
|--------------------------------|--------------------|----------------|-----------------------|
| Area of WLTP                   | Braking Power (kW) | Time Taken (s) | Braking Energy (Kw/h) |
| Middle                         | 49.1               | 9              | 0.123                 |
| Middle                         | 115.04             | 10             | 0.32                  |
| Middle                         | 130.9              | 20             | 0.727                 |
| Middle                         | 124.86             | 19             | 0.659                 |

Table 3 - Table 1 - Braking Areas HIGH (Vine, 2024)

| Notable Braking Areas - High |                    |                |                       |
|------------------------------|--------------------|----------------|-----------------------|
| Area of WLTP                 | Braking Power (kW) | Time Taken (s) | Braking Energy (Kw/h) |
| High                         | 98.54              | 21             | 0.579                 |
| High                         | 848.38             | 45             | 10.605                |
| High                         | 150.17             | 15             | 0.626                 |
| High                         | 162.5              | 15             | 0.677                 |

Table 4 - Braking Areas EXTRA-HIGH (Vine, 2024)

| Notable Braking Area – Extra High |                    |                |                       |
|-----------------------------------|--------------------|----------------|-----------------------|
| Area of WLTP                      | Braking Power (kW) | Time Taken (s) | Braking Energy (Kw/h) |
| Extra-High                        | 124.86             | 19             | 0.659                 |
| Extra-High                        | 539.56             | 18             | 2.698                 |
| Extra-High                        | 1114.82            | 29             | 8.98                  |
| Extra-High                        | 1247.97            | 69             | 23.919                |

Focusing more on practical and frequent driving, more datapoints were taken from the middle and high section, prioritising these zones as they represent a truer look at operational speeds opposed to the extra-high speeds which are motorway speeds.

By knowing which section to focus on, the KERS can be effectively tailor to enhance the vehicles efficiency, the power values identified during these deceleration phases suggest there are considerable energy changes which, with the right system in place, could be harnessed effectively.

## 6.2 Storable Energy

The sizing calculations for the supercapacitor bank are made using specifications from Maxwell's BCAP0010 cells (Maxwell, 2024)

Table 5 - Driving Scenarios and Potential Storable Energy (Vine, 2024)

| Figures without Discharging Power |                    |                    |                                  |                               |
|-----------------------------------|--------------------|--------------------|----------------------------------|-------------------------------|
|                                   | 30 minutes Driving | 60 Minutes Driving | 120 Minutes of Driving (2 Hours) | 300 Minutes Driving (5 hours) |
|                                   | WLTP               | Short Journey      | Longer Journey                   | Extended Driving              |
| kJ                                | 6753.96            | 13506              | 27015.84                         | 67539.6                       |
| kWh                               | 1.8761             | 3.7522             | 7.5044                           | 18.761                        |
| kW                                | 55                 | 55                 | 55                               | 55                            |

Using both the WLTP results and calculated journeys with assumptions that there is no discharge in power, mean the estimated needs of the supercapacitor should be overestimated to cover any failure of single cells, discharge systems or excessive losses in the system.

### 6.2.1 Energy Storage Requirement

Each cell has a capacitance of 10 Farads and is rated at 3 Volts, translating to an energy storage capacity of around 9.81kw/h. This capacity is derived from the cell's specific energy.

Therefore, using the cumulative braking energy of the WLTP the figure of 1.8761 kWh would be used for the storage calculator.

$$\frac{1.8761 \text{ kW/h}}{9.48 \text{ kWh/Cell}} = 0.198 \text{ cells.}$$

### 6.2.2 Peak Power Demand

For peak power handling, each BCAP0010 cell can deliver up to 2257.5kW. The number of cells needed will be based on the peak power calculations, ensuring the supercapacitor can manage the highest power demands anticipated during the regenerative braking process.

Using results from the WLTP, the highest power achieved was 1247.97kW

$$\frac{1247.97}{2257.5/Cell} = 0.553 \text{ cells.}$$

## 7 Chosen KERS System

This section introduces the tailored KERS for the Renault Trafic, although following a traditional, well used system seen in many modern-day hybrids, the difference being this system will be incorporating a supercapacitor for energy storage.

### 7.1 Chosen Braking System

Series braking in hybrid vehicles is a common option due to the ability to maximise energy recovery. However, parallel braking is preferred for this system, allowing for a recovery of kinetic energy during a wider range of driving conditions. Parallel braking also provides a balance between effective energy recuperation and a more traditional driver feel. As the system uses regenerative braking and friction brakes in unison (Burnham, Gajek and Oleksowicz 2012).

### 7.2 Electric Motor

An asynchronous motor has been selected due to the van's heavier weight and need for mid-range performance. These motors typically have efficiencies of between 75-80%, and are suited to handle variable speeds and loads, ideal for logistics. Despite the slight trade off in efficiency compared to a synchronous motor, which is around 90% efficient, the asynchronous motors durability and performance align better with the requirements of a commercial vehicle (Martin-Gambier, 2021).

### 7.3 Controller Unit

Once the energy is converted by the electric motor, it is then directed through a controller. This controls roll is multifaceted: it must regulate the energy flow, ensure that the energy harvesting is maximised during braking, and lastly, manage the discharge of energy when it's needed for acceleration (openecu.com, 2024).

The controller's efficiency impacts the overall effectiveness of the KERS system, as losses here can significantly reduce the systems benefits.

### 7.4 Using a Supercapacitor for Storage

The integration of Maxwell's BCAP0010 supercapacitors into the KERS system provides a significant enhancement in storage capacity against traditional battery options.

Supercapacitors known for their high efficiency, around 90% are adept at quickly storing and discharging energy. Each BCA cell has a capacity of 9.81kw/h (Maxwell, 2024). Based on calculations from the WLTP, while one cell might suffice, using two cells provides a buffer against unexpected energy losses and ensures system reliability.

This choice underscores the commitment to maximising efficiency and performance in an urban environment.

## 8 Plotting of Energy at the Wheel After Losses

Table 6 - Components List (Vine, 2024)

| Component                   | Assumed Losses |
|-----------------------------|----------------|
| Asynchronous Electric Motor | 25%            |
| Controller                  | 10%            |
| Supercapacitor              | 10%            |
| Gearbox                     | 5%             |

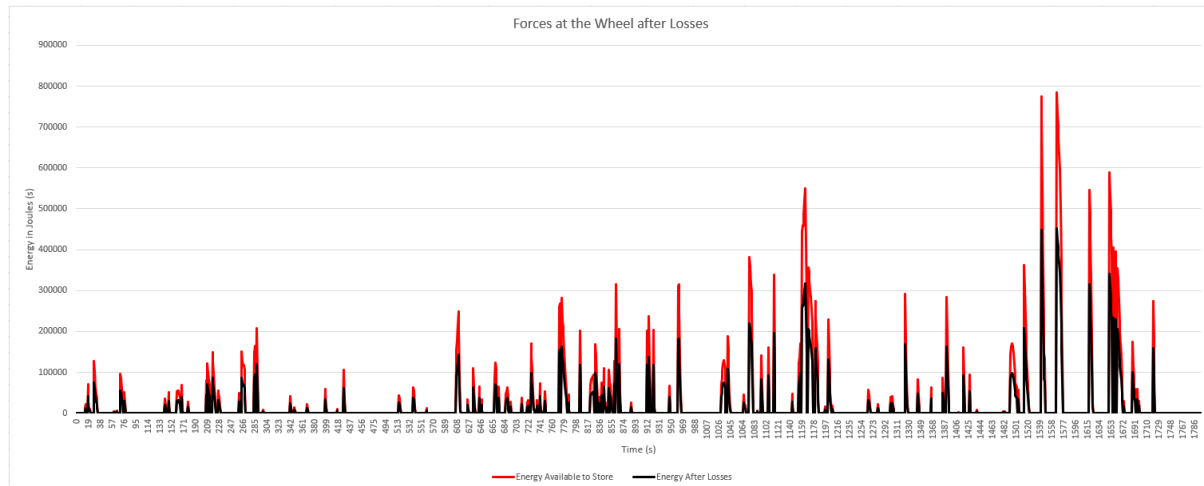


Figure 12 - Forces After Loses (Vine, 2024)

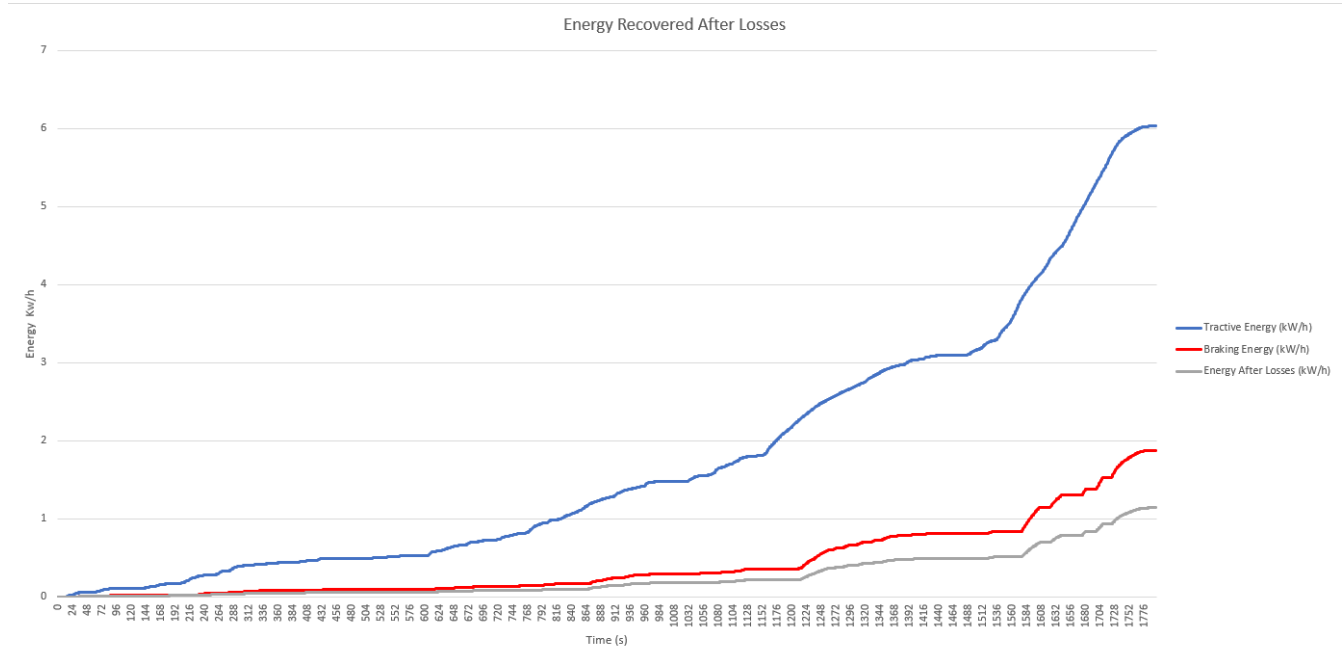


Figure 13 - Forces at the Wheel After Losses (Vine, 2024)

The above graphs demonstrate the significance of having efficient components. Even individual stages, which are considered efficient with a figure of around 90%, can make a significant impact on the outcome when combined with other stages.

## 9 Conclusion of KERS System

### 9.1 System Overview

- Conversion of Friction brake energy to electric power by use of a motor/generator unit.
- Power control unit which regulates energy flow between the motor and storage.
- Energy is stored in supercapacitors, offering rapid charge and discharge abilities.
- Integration into the vehicle's drivetrain, taking care of additional weight.
- Positioned in the rear of the van in a raised floor, making use of higher roof height, taking care to balance the weight.

### 9.2 Assumptions on Efficiencies

- Asynchronous Electric Motor: 75%
- Controller: 90%
- Supercapacitor: 90%
- Gearbox Losses: 5%

Energy Recovery Phase: 60.75%

Energy Delivery Phase: 57.71%

### 9.3 Driver Feel

The use of parallel braking and an efficient electric motor, the driver would feel slight regenerative braking when lifting off the throttle and be able to transition to friction brakes without noticing any real differences. This setup ensures energy recovery with minimal change to driving habits.

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<https://www.michelin.com.au/auto/advice/tyre-basics/rolling-resistance> (Accessed: 10 January 2024).

## 11 Appendices

Table 7 - Renault Trafic Body Styles (car.info, 2024)

| Body style           | Height         | Width          | Length         |
|----------------------|----------------|----------------|----------------|
| SWB Low roof         | 1,960mm        | 1,904mm        | 4,782mm        |
| SWB High roof        | 2,485mm        | 1,904mm        | 4,782mm        |
| LWB Low roof         | 1,960mm        | 1,904mm        | 5,182mm        |
| <b>LWB High roof</b> | <b>2,485mm</b> | <b>1,904mm</b> | <b>5,182mm</b> |
| SWB Crew Van         | 1,960mm        | 1,904mm        | 4,782mm        |
| LWB Crew Van         | 1,960mm        | 1,904mm        | 5,182mm        |

Table 8 - Renault Trafic Specs (car.info, 2024)

|                           |             |
|---------------------------|-------------|
| Trafic LL 29 2.0dCi 115   |             |
| Engine size (litres)      | 2           |
| HP                        | 116         |
| Overall length (mm)       | 5182        |
| Overall height (mm)       | 1953        |
| Overall width (mm)        | 1904        |
| Wheelbase (mm)            | 3498        |
| Loading Height (mm)       | 533         |
| Rear Door Width (mm)      | 1390        |
| Rear Door Height (mm)     | 1335        |
| Load Length (mm)          | 2800        |
| Load Width Max (mm)       | 1960        |
| Load Height (mm)          | 1387        |
| Load Volume (m3)          | 5.9         |
| Gross Payload (Kg)        | 1236        |
| Gross Vehicle Weight (Kg) | 2960        |
| <b>Kerb Weight (Kg)</b>   | <b>1724</b> |
| Towing Limit (Kg)         | 2000        |

|                  |             |
|------------------|-------------|
| <b>Test Mass</b> | <b>1824</b> |
|------------------|-------------|

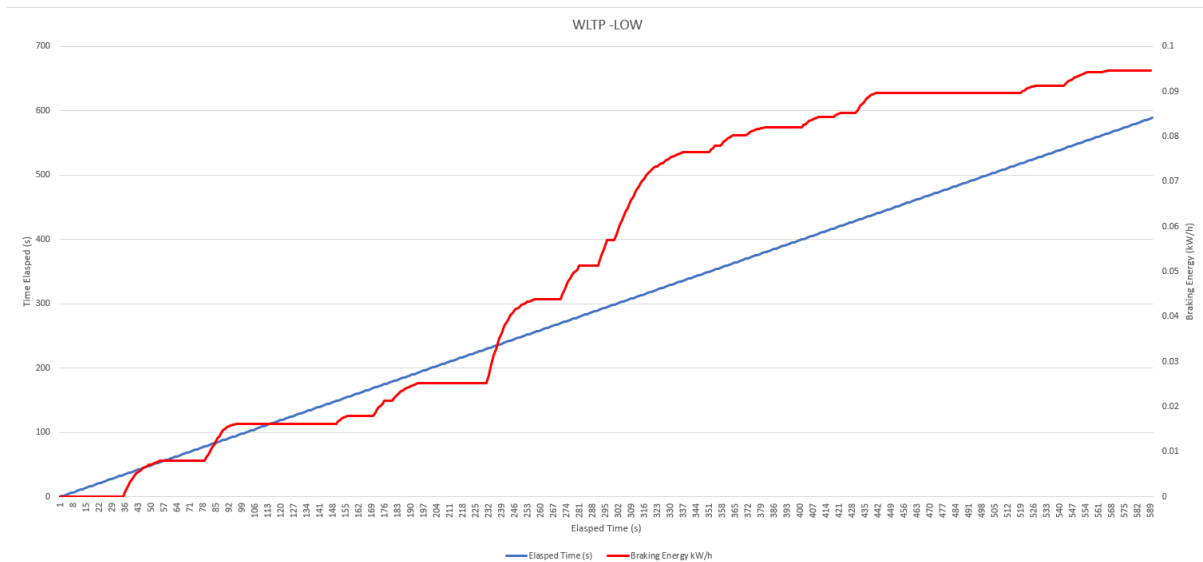


Figure 14 - WLTP LOW Braking Energy (Vine, 2024)

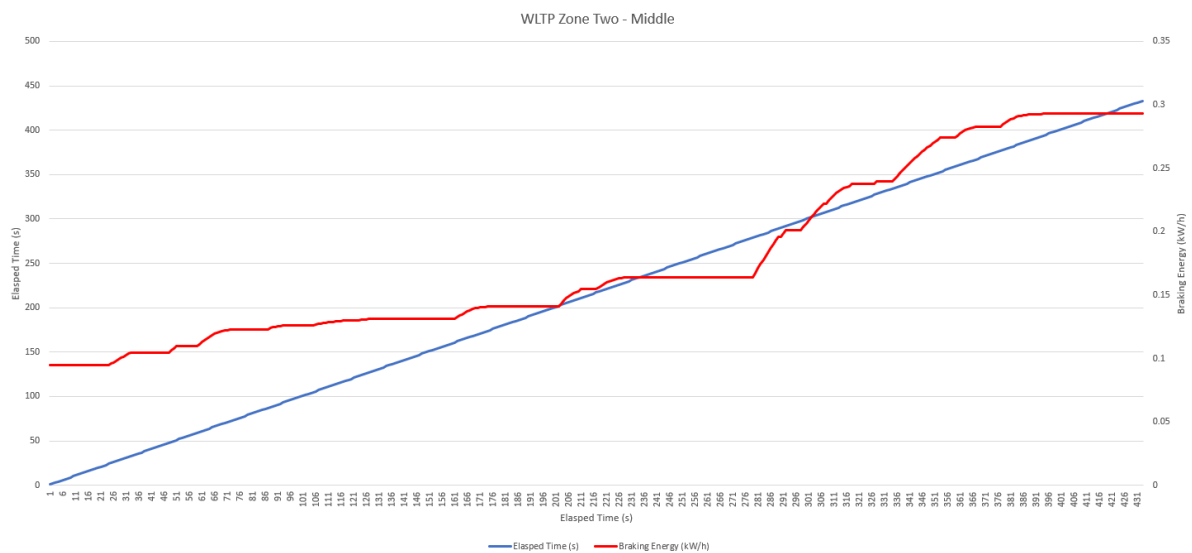


Figure 15 - WLTP Middle, Braking Energy (Vine, 2024)

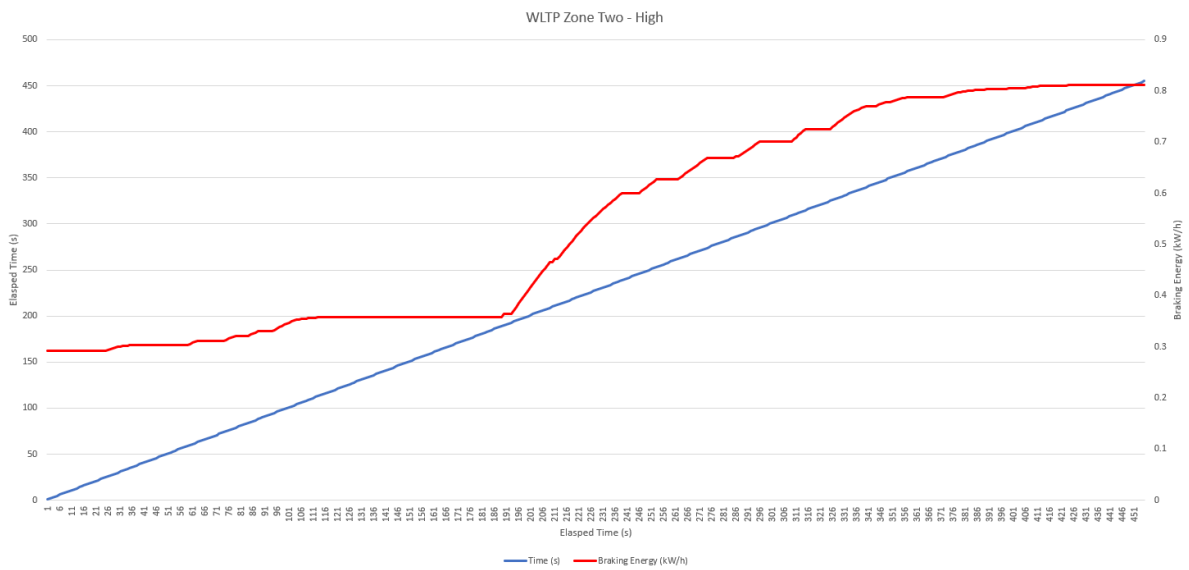


Figure 16 - WLTP High, Braking Energy (Vine,2024)

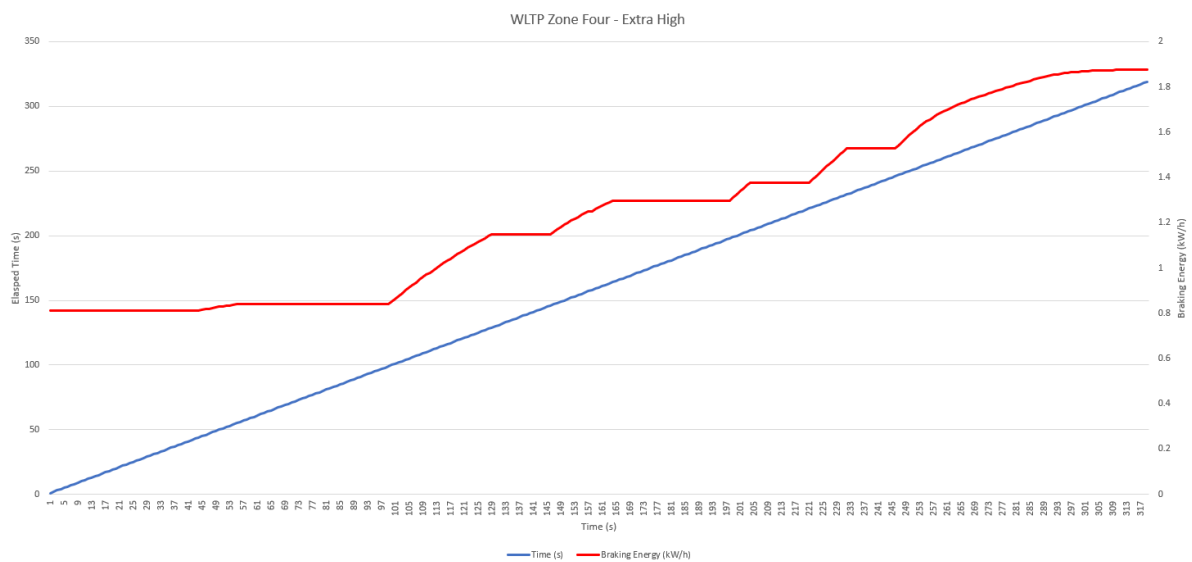


Figure 17 - WLTP Extra-High Braking Energy (Vine,2024)