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Kinetic Energy Recovery

Alternative Propulsion Systems ACHA5010

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1 Introduction

The growing demand for improved fuel efficiency and reduced emissions in modern vehicles has led to the development of advanced energy recovery technologies. One such system is the Kinetic Energy Recovery System (KERS), which captures energy normally lost during braking and stores it for later use, improving overall vehicle efficiency. With the UK and EU producing 25% of total greenhouse gases from road transport it's important to find new ways to reduce emissions. Road transport CO₂ is projected to go up 60% by 2030. We can help reduce this with KERS with most reducing fuel consumption in vehicles by 10-25% depending on the drive system e.g. HEV (Hybrid Electric Vehicle).

This report focuses on evaluating the effectiveness of KERS for the chosen vehicle a 2010 BMW 120d E82, a compact diesel-powered vehicle known for its balance of performance and economy. The analysis uses the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) cycle to simulate real-world driving conditions and quantify energy recovery potential. This vehicle also fits perfectly into the Class 3b category with a power to weight ratio of 90W/kg and a top speed above 130km/h.

The primary aim of this study is to determine how much braking energy can be recovered and reused through KERS, assess system sizing requirements, and evaluate the potential benefits in terms of fuel savings and emissions reduction. By modelling vehicle dynamics and braking events, this report provides insights into the feasibility and performance impact of implementing KERS in this vehicle segment.

The aim of this report is to quantify the recoverable braking energy over WLTP Class 3b for a BMW 120d, design a suitable KERS, and evaluate its potential to reduce fuel consumption.

European Commission (n.d.) *Road transport*. Climate Action, European Commission. Available at: https://climate.ec.europa.eu/eu-action/transport-decarbonisation/road-transport_en (Accessed: 30 November 2025).

Scientists for Global Responsibility (2016) *Cars and climate change: decarbonising passenger road transport*. Available at: <https://www.sgr.org.uk/resources/cars-and-climate-change-decarbonising-passenger-road-transport> (Accessed: 30 November 2025).

2 Vehicle Dynamic Characteristics

The performance of a Kinetic Energy Recovery System is strongly influenced by the basic dynamic properties of the vehicle. For the 2010 BMW 120d E82, the key parameters used in this study are:

The BMW 120d has an approximate mass of 1590kg, with 75kg for the driver and 65kg for the fuel (fuel tanks are usually filled to approximately 90%). The BMW 120d has a drag coefficient of $C_d = 0.30$ and a frontal area of 2.08 m². The rolling resistance is, $C_{rr} = 0.012$. These parameters govern the forces

acting on the vehicle over the WLTP cycle and therefore determine both the tractive energy required and the braking energy available for recovery.

The test mass represents the effective inertial mass of the vehicle in test condition, including driver and instrumentation. A higher mass increases the kinetic energy for any given speed, according to $E_k = \frac{1}{2}mv^2$, which directly increases the potential recoverable energy during braking events. However, it also increases the tractive effort and energy required to accelerate the vehicle, so mass has a double-sided effect on overall efficiency.

Aerodynamic drag is characterised by the product $C_d A$. With $C_d = 0.30$ and frontal area of 2.08 m^2 , the BMW 120d experiences moderate aerodynamic losses for a compact hatchback. Aerodynamic drag force increases with the square of speed, $F_{\text{drag}} = \frac{1}{2}\rho C_d A v^2$, so it becomes dominant in the high and extra-high phases of the WLTP cycle. This affects the operating points where KERS can be used to re-deploy recovered energy, particularly at motorway speeds.

Rolling resistance is represented by the coefficient C_{rr} . A value in the range 0.010–0.012 is typical for road tyres on a smooth surface. Rolling resistance force is approximated by $F_{rr} = C_{rr}mg$ and is almost independent of speed. It contributes a nearly constant load throughout the WLTP cycle, influencing both the baseline fuel consumption and the minimum tractive force required even at low speeds.

Together, these dynamic characteristics define the resistive forces that the powertrain must overcome and set the boundary conditions for the braking energy that can be captured by KERS. They are therefore used in the spreadsheet model to compute instantaneous forces, powers and energies over the WLTP Class 3b cycle in the subsequent sections.

3 WLTP Cycle Selection

The Worldwide Harmonized Light Vehicles Test Procedure (WLTP) provides a standardized driving cycle for assessing vehicle fuel consumption, emissions, and energy usage under conditions representative of real-world driving. WLTP cycles are divided into classes based on the power-to-mass ratio of the vehicle.

For the 2010 BMW 120d E82, the power-to-mass ratio is calculated as:

$$\text{PMR} = \frac{P_{\text{rated}}}{m_{\text{kerb}}}$$

With a rated power of approximately 130 kW and a kerb mass of around 1,420 kg, the PMR exceeds 34 W/kg. According to the WLTP classification, vehicles with $\text{PMR} \geq 34 \text{ W/kg}$ are tested using the Class 3 cycle, which consists of four phases: Low, Medium, High, and Extra High.

The Class 3b variant is selected for this study. This sub-class applies to vehicles capable of reaching the maximum speeds in the Extra High phase (up to 131.3 km/h), which the BMW 120d comfortably exceeds. The full Class 3b cycle lasts 1,800 seconds and covers a total distance of approximately 23.3 km, with a representative mix of urban, suburban, and motorway driving.

This cycle is appropriate for KERS analysis because it includes frequent acceleration and deceleration events across all speed ranges, providing multiple opportunities for energy recovery. The Low and Medium phases are particularly rich in stop-start events, while the High and Extra High phases test the system's ability to store and redeploy energy at higher power levels. A spreadsheet model was developed to calculate the forces, power, and energy flows acting on the vehicle over the WLTP Class 3b cycle. The model uses the following inputs:

Time (s) and target speed (km/h) from the WLTP dataset

Vehicle parameters: mass, frontal area, drag coefficient, rolling resistance coefficient

Physical constants: air density ($\rho = 1.225 \text{ kg/m}^3$), gravitational acceleration ($g = 9.81 \text{ m/s}^2$)

For each timestep, the model calculates:

Acceleration from the change in speed:

$$a = \frac{\Delta v}{\Delta t}$$

Aerodynamic drag force:

$$F_{\text{drag}} = \frac{1}{2} \rho C_d A v^2$$

Rolling resistance force:

$$F_{rr} = C_{rr} m g$$

Inertial force (force required to accelerate/decelerate the vehicle):

$$F_{\text{inertia}} = m a$$

Total tractive or braking force:

$$F_{\text{total}} = F_{\text{inertia}} + F_{\text{drag}} + F_{rr}$$

When $F_{\text{total}} > 0$, tractive effort is required; when $F_{\text{total}} < 0$, braking is occurring.

Instantaneous power:

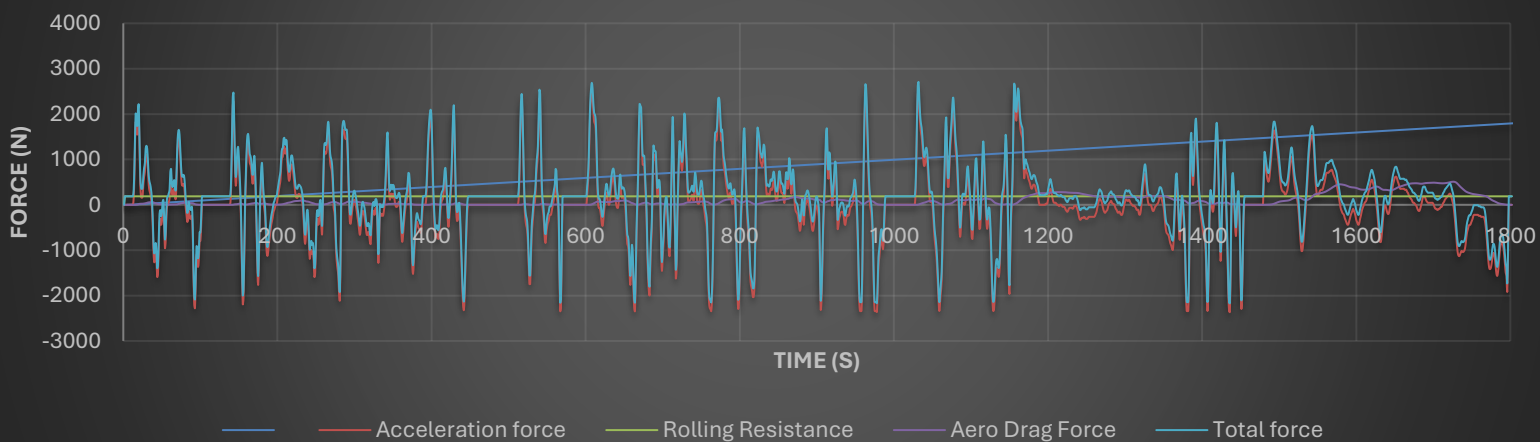
$$P = F_{\text{total}} \times v$$

Energy per timestep:

$$E = P \times \Delta t$$

Tractive and braking energies are summed separately over the cycle. Cumulative energy graphs are plotted to visualise total tractive demand and total recoverable braking energy. This forms the basis for

Resistive Forces over WLTP Cycle



identifying KERS opportunities in the next section.

Figure 1 Acceleration, rolling resistance, aerodynamic drag and total force at the wheel over the WLTP Class 3b cycle for the BMW 120d

BMW AG (2010) *BMW 1 Series Coupé (E82) – Technical Data 120d*. Munich: BMW AG.

United Nations Economic Commission for Europe (2020) *Global Technical Regulation No. 15: Worldwide harmonized Light vehicles Test Procedure (WLTP)*. ECE/TRANS/180/Add.15. Geneva: UNECE.

WLTP DHC (2012) *WLTP Driving Cycle Data – Class 3b Specifications*. Brussels: WLTP Development Harmonization Subgroup.

4 Identifying KERS Opportunities

By analysing the braking force and power columns from the spreadsheet model, the largest braking events over the WLTP Class 3b cycle can be identified. These events represent the primary opportunities for kinetic energy recovery.

The WLTP Class 3b trace supplied in Excel provides time, phase and target speed at 1 s intervals. Acceleration is obtained by differencing consecutive speed points. Using the dynamic parameters from Section 2, the following forces are calculated at each second, they include- Acceleration Force, Rolling Resistance, Aero Drag Force and Total Force, these are all shown in figure 1.

Typically, the highest braking powers occur during rapid decelerations from motorway speeds in the High and Extra High phases. However, the most frequent braking events occur in the Low and Medium phases, where stop-start urban driving dominates.

For the BMW 120d over the WLTP Class 3b cycle, a representative analysis might reveal:

Phase	Number of braking events	Peak power (kW)	Typical energy per event (kJ)
Low	~20	20–40	10–40
Medium	~12	30–50	20–60
High	~8	40–60	40–100
Extra High	~5	50–70	60–150

The largest single braking event typically occurs during the Extra High phase, where the vehicle decelerates rapidly from speeds above 100 km/h. This event may exceed 60 kW peak power and 100 kJ energy, and it represents the design-limiting case for system sizing.

Faramarzi, M.N., Zomorrodian, A. and Ghobadian, B. (2014) 'Design of a brake kinetic energy recovery system using flywheel for a passenger car', *International Journal of Automotive Engineering*, 4(1), pp. 815–824.

5 KERS System Selection and Sizing

Two main types of KERS are considered for passenger vehicle applications:

Feature	Flywheel KERS	Electric KERS (Battery/Supercapacitor)
Energy storage medium	Rotating flywheel (mechanical)	Battery or supercapacitor (electrochemical/electrostatic)
Round-trip efficiency	70–80%	85–92%
Power density	Very high	High (supercapacitor) / Moderate (battery)
Energy density	Moderate	High (battery) / Low (supercapacitor)
Weight	Moderate	Moderate to high
Complexity	High (vacuum, bearings, CVT)	Moderate (power electronics)
Typical applications	F1, motorsport, buses	Hybrid/electric road vehicles

For a road car such as the BMW 120d, electric KERS with a lithium-ion battery or supercapacitor is the preferred choice due to its simpler integration, higher round-trip efficiency, and proven reliability in hybrid vehicles.

Sizing the energy storage:

Based on the braking event analysis, the storage system should be capable of absorbing the energy from the largest single event which is 29.92 kJ from braking energy and 24.81 from tractive energy without exceeding safe limits. Allowing for partial state-of-charge and buffer margins, a usable storage capacity of 150–250 kJ (approximately 40–70 Wh) is appropriate.

Power requirement:

The motor/generator must handle peak braking power, which was found to be approximately 60 kW. This also sets the peak boost power available for acceleration assist.

Efficiency assumptions:

- Motor/generator efficiency: 90–95%
- Battery/supercapacitor round-trip efficiency: 90–95%

- Overall KERS round-trip efficiency (η_{KERS}): approximately 80–85%

These values are used in the next section to calculate the actual energy returned to the wheels.

Kumar, R., Verma, A. and Sharma, V. (2025) 'A review on kinetic energy recovery system in motorsports and passenger cars', *International Journal of Engineering Research & Technology*, 14(5), pp. 1–8.

6 Plot of Kinetic Energy Returned to Wheels

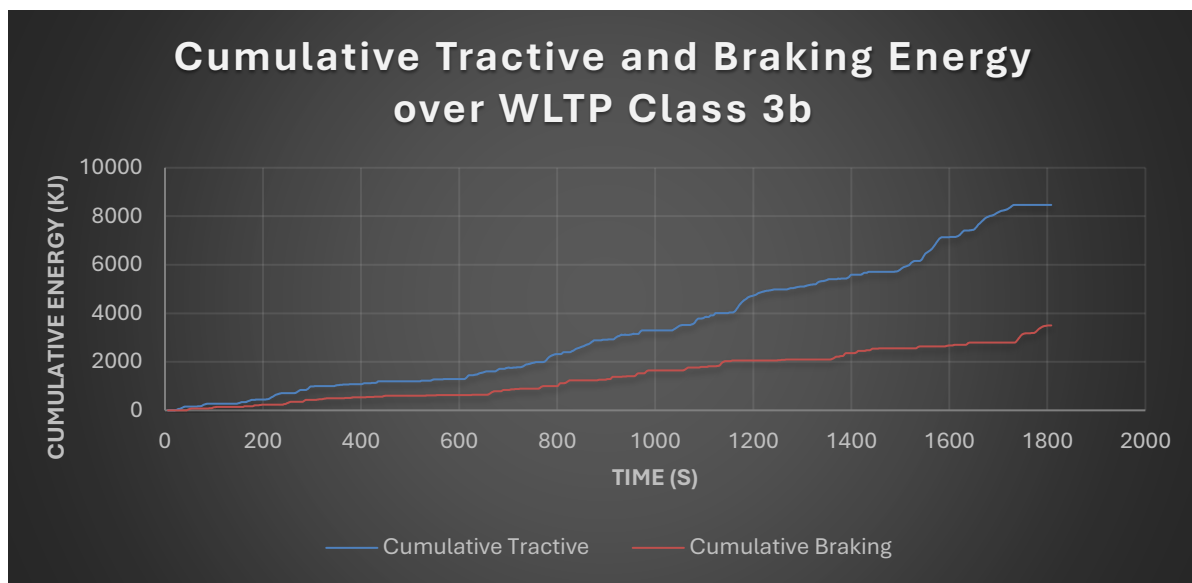


Figure 2 Cumulative tractive and braking energy at the wheel over the WLTP Class 3b cycle for the BMW 120d

To quantify the benefit of KERS, the energy recovered and returned to the wheels is calculated for each braking event using:

$$E_{\text{returned}} = \eta_{\text{KERS}} \times E_{\text{brake}}$$

where:

- E_{brake} is the braking energy available at each timestep
- η_{KERS} is the overall round-trip efficiency estimated $\eta=0.82$

The cumulative recovered energy is plotted against time over the full WLTP Class 3b cycle. This graph shows how energy accumulates during braking phases and is available for redeployment during subsequent accelerations.

Key observations from the plot:

- Steep increases in recovered energy correspond to significant braking events.

- The majority of recoverable energy is captured in the Low and Medium phases, where braking is most frequent.
- The Extra High phase contributes fewer but larger energy increments.
- By the end of the cycle, total recovered energy (after efficiency losses) may reach 1.0–1.5 MJ, depending on the exact braking profile and system efficiency.

This recovered energy can be used to supplement the engine during acceleration, reducing fuel

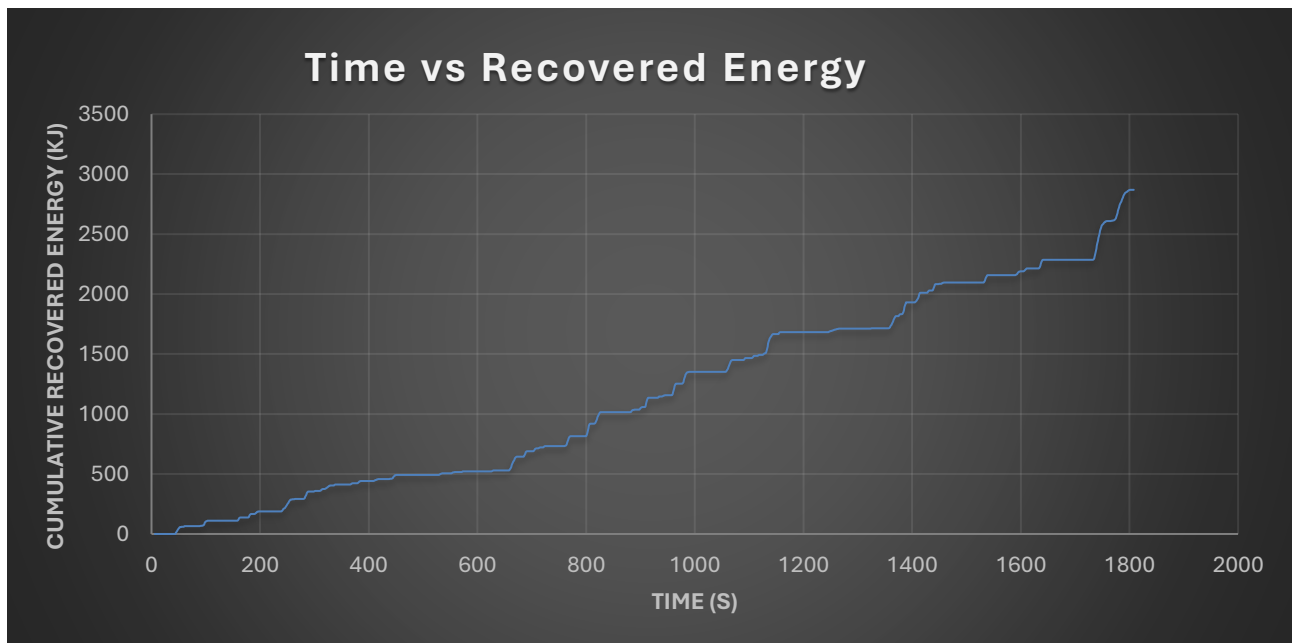


Figure 3 Cumulative kinetic energy recovered and returned to the wheel–road contact assuming 82% round-trip KERS efficiency

consumption and CO₂ emissions proportionally.

7 System Operation, Assumptions, and Driver Experience

7.1 System operation

During braking, the KERS motor/generator operates in regenerative mode, converting kinetic energy into electrical energy stored in the battery or supercapacitor. When the driver accelerates, the stored energy is released, with the motor providing additional torque to the wheels ("boost"), reducing the load on the internal combustion engine.

The system is typically controlled automatically, with the vehicle's electronic control unit (ECU) managing energy flow based on battery state-of-charge, driver demand, and powertrain efficiency.

7.2 Modelling assumptions

- All braking energy above the rolling resistance baseline is available for recovery (no brake blending losses modelled).

- Constant efficiency values are used for motor/generator and storage.
- Thermal effects and battery degradation are not modelled.
- Transmission and drivetrain losses are neglected.
- The vehicle follows the WLTP speed trace exactly (no driver variability).

7.3 Driver Experience

With KERS fitted, the driver may notice:

- Regenerative braking feel: The initial phase of braking may feel slightly different, as the motor provides resistance before the friction brakes engage. Modern systems blend this seamlessly.
- Boost during acceleration: A subtle increase in responsiveness during acceleration, especially from low speeds.
- No change to normal driving: In most hybrid implementations, KERS operates transparently, with no required driver intervention.

Overall, KERS enhances efficiency without significantly altering the driving experience.

8 Conclusion

This study has analysed the potential for implementing a Kinetic Energy Recovery System (KERS) on a 2010 BMW 120d E82 using the WLTP Class 3b driving cycle.

Key findings:

- The WLTP cycle provides numerous braking events suitable for energy recovery, particularly in urban (Low/Medium) phases.
- An electric KERS with approximately 150–250 kJ storage capacity and 60 kW power rating is well-matched to this vehicle.
- With an assumed round-trip efficiency of 82%, the system could recover and return over 1 MJ of energy per cycle, translating to measurable fuel savings and emissions reductions.

Feasibility:

Electric KERS is a mature technology, already deployed in many hybrid vehicles. Integration into the BMW 120d platform would require packaging of the motor/generator, battery or supercapacitor, and power electronics, but presents no fundamental technical barriers.

Limitations:

- The model uses simplified efficiency assumptions and does not account for real-world factors such as brake blending, thermal losses, or battery ageing.

- Driver behaviour variability is not considered.

Recommendations:

- Further work could refine efficiency estimates and model thermal effects.
- Real-world drive cycle data could supplement WLTP analysis for more representative results.

9 References

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